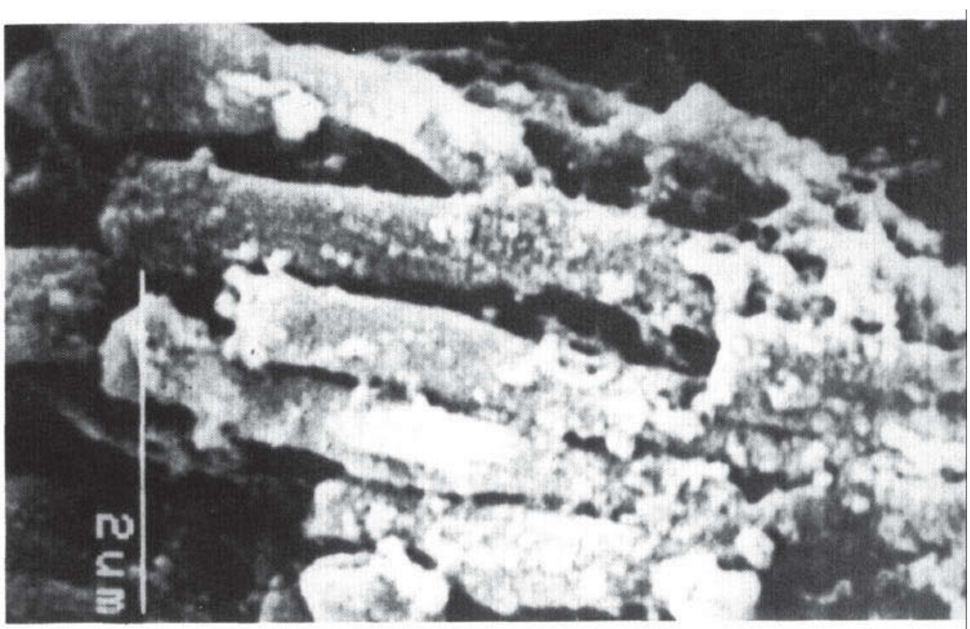
RESEARCH PRIORITIES IN ARCHAEOLOGY SCIENCE

edited by
Paul Mellars



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Research priorities in archaeological science

edited by
Paul Mellars

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1 Introduction

Paul Mellars

It is probably healthy for any discipline, once in a while, to take stock of its present position, its past achievements, and – most important – its future directions. The present document arose as part of a general policy formulated by the Research Board of the Council for British Archaeology to publish a series of papers attempting to define the essential research objectives and priorities in a range of archaeological areas *(Research objectives in British archaeology,* 1983, CBA). The Archaeological Science Committee was invited to contribute to this publication, but felt that the wide and diverse range of subjects involved in the various fields of 'archaeological science' would make it impossible to do justice to the essential research priorities within each of the relevant disciplines in the space of a few pages. The earlier document contained a brief but carefully worded statement prepared by Dr Susan Limbrey on behalf of the Archaeological Science Committee on the more general role of archaeological science within the overall structure and planning of archaeological field research in Britain.

The present document is designed to tackle these questions of research objectives and priorities at a much more specific level, dividing the general area of 'archaeological science' into a number of separate and, it is hoped, reasonably well-defined fields, and looking closely at the current needs and priorities within each of these. The document was conceived, and to a large extent written, before the publication of the important 'Hart Report' on the general structure and funding of scientific research in British archaeology *(Review of Science-based Archaeology,* 1986, SERC). It does, however, meet one of the primary requirements emphasized in the Hart Report (Section 5.3) – that of attempting to identify clear policies for the ways in which the available resources in archaeological science should be focused and employed over the course of the next 5–10 years.

The division of 'archaeological science' into the different subject areas adopted here is inevitably somewhat arbitrary, and could no doubt have been done in other ways. By the same token, there are certain very general fields of archaeological science which are not dealt with specifically within the present papers (most notably perhaps archaeological conservation and the application of various mathematical, statistical and computing techniques) and which in terms of the potential range and diversity of their applications could well form the subject of separate 'research priorities' documents in their own right. The range and scope of the papers presented here reflects to a large extent the practicalities of the ways in which current research is organized, and the varying scientific backgrounds from which specialists in the different branches of the subject have come.

It soon became clear that the range of expertise represented within the current membership of the CBA Archaeological Science Committee – wide-ranging as it is – was too limited to deal adequately with all of the relevant scientific fields. Accordingly, contributions were requested from a number of other people, selected because of their specialist interests and expertise in particular areas. The primary aim in compiling all the papers has of course been to achieve as wide-ranging consultation as possible within each of the subjects dealt with. While each paper has been drafted primarily by one or two individuals, all of the papers reflect much more extensive discussions with other specialists within the relevant fields in order to achieve, as far as possible, a general consensus within the views expressed. A number of specialist working groups, such as the Association for Environmental Archaeology and the CBA's own Implement Petrology Committee and recently formed Working Party on the Scientific Study of Human Remains, provided in several cases an ideal forum for this kind of widespread consultation and discussion. The overall responsibility for compiling and editing the papers has of course rested in the hands of the Archaeological Science Committee. It is probably unrealistic to claim that any document of this kind can reflect a total unanimity of views on the essential priorities for research within such a variety of scientific fields. Experience in compiling the different papers, however, suggested that there is in fact broad agreement on the most urgent priorities for future research within most subject areas, and the Committee has some confidence in presenting the views expressed here in these terms.

It should be emphasized that the major goal of these papers has been to define the needs for basic research – or specific research applications – within the different scientific disciplines which contribute to archaeology, rather than to comment on the more general questions of organization, funding, training, etc within archaeological science as a whole. The latter questions have already been dealt with more directly in the report of the Dimbleby Committee *(The scientific treatment of materials from rescue excavations,* 1978, DoE) and in the general statement contributed by the Archaeological Science Committee to the original CBA document, *Research objectives in British archaeology* (1983). Even so it is clear that in some cases the questions of basic research objectives are difficult to separate from those of the organizational or financial aspects of the research. The individual contributors were therefore invited to comment on these points when they felt that they were especially relevant to their own subject areas. In the event, certain points cropped up so frequently in the written comments, or in subsequent discussions in the Archaeological Science Committee, that they clearly deserve more general emphasis. Briefly, these may be summarized as follows:

1 Probably the most critical and frequently expressed need is for an adequate structure to ensure

the continuity of essential professional and scientific resources. This applies both to the provision of laboratory resources (including equipment, reference collections, databases, technical support, etc) and – above all – to the creation of a proper career structure which can attract and retain the most competent and highly trained people. Many archaeological scientists clearly feel that the situation both in government-funded laboratories and in many university and museum laboratories fails to inspire confidence in either of these goals at the present time. Without some reasonable continuity and security in these fields, much of the expertise and accumulated achievement built up over the past twenty years will inevitably be lost.

2 On the question of training and recruitment into archaeological science, it is encouraging to see that a number of specialized university courses in various scientific fields have been introduced within recent years – although it could be argued that the opportunities for training in some of the more specialized areas (eg the analysis of human remains, or the application of quantitative and computational techniques) remain inadequate. Since most of these courses depend on the recruitment of postgraduate students, it is clearly essential that adequate grants or studentships to support postgraduate students in these subjects should be provided, and that the courses should continue to attract first-rate students with initial degrees in pure or applied science subjects, in addition to well-qualified graduates in archaeology. At present, the Science and Engineering Research Council provides ten quota Research Studentships per year to support PhD research in archaeological science, but only four Advanced Course Studentships to support students on the more basic, pre-doctoral training programmes referred to above. Set against the numbers of students and numbers of universities applying for the awards, and, more generally, the potential for the development and application of scientific techniques in archaeology, both types of award are clearly inadequate, but the small number of studentships available for the more basic training courses is particularly disturbing. In this context it is salutary to recall that one major training programme in archaeological science (at the University of Southampton) has had to be suspended during the past year, not through any shortage of well-qualified applicants, but through the inability of the students to obtain financial support for the course.

3 There is a widespread feeling among members of the archaeological science community that while a substantial amount of funding has been made available to support the application of science in the context of rescue excavations (principally through the HBMC-sponsored laboratories and research contracts) there is a critical need for more support directed specifically at basic, innovative research. The funds provided through the SERC Science-Based Archaeology Committee have of course been extremely important in this context over the past ten years, but still cannot support all the research projects which the SERC Committee itself has classified as of first-rate scientific quality and deserving of support (see Annual Reports of the SERC Science-Based Archaeology Committee, 1981–5). It is equally important to stress that 'research' in archaeological science must involve not only the development or refinement of new techniques of scientific analysis in archaeological contexts, but also the application of both new and established techniques to the solution of new research problems. To define 'research' in archaeological science purely in terms of the development of new analytical techniques would not only be hopelessly limiting to the long-term development of the subject, but also contrary to the accepted practice in all other branches of science. This point may perhaps seem self-evident, but has not always been so clearly appreciated in the recent pattern of financial support for archaeological science provided by the SERC. Most disturbing of all, perhaps, is the fact that with the exception of the crucial support provided by the Science-Based Archaeology Committee of the SERC, extremely little support for original scientific research is available from any other archaeological funding bodies in Britain at the present time.

4 Publication in archaeological science is in many ways well catered for through the existence of specialist journals such as *Archaeometry,* the *Journal of Archaeological Science, Circaea,* and the *Journal of Field Archaeology.* Two aspects of publication, however, continue to cause serious concern to most archaeological scientists. Firstly, it is essential that where scientific contributions are included in major fieldwork reports or monographs, full provision for the detailed publication of the scientific work should be made, on an equal footing to that accorded to the strictly archaeological data. Relegation of important scientific analyses and critical data to appendices, microfiches, unpublished archives, and the like is generally unsatisfactory and – in the longer term – dangerous to the maintenance of proper scientific standards. If the archaeologists provide second-rate forms of publication for scientific data, there is an inevitable danger that they will receive second-rate scientific contributions in return. Secondly, and allied to the last point, is the need to maintain stringent standards to ensure the quality of research and publication in archaeological science. Probably the best safeguard in this context is the adoption of a specialist peer review system for all publications in archaeological science – including not only those in the specialist journals but also those in individual site/fieldwork monographs. This is accepted as a routine procedure in all areas of the natural sciences, and should be adopted as an equally routine procedure for publications in archaeological science.

5 At a more practical level, it is necessary to re-emphasize the importance of close consultation and communication between archaeologists and scientists at all stages in the planning and execution of archaeological field projects. This point has been made repeatedly in the past, but continues to be a recurrent bone

of contention between specialists in archaeological science and their archaeological collaborators. Where scientific work is carried out in association with field projects, it is essential that the scientists should be involved at all stages of the work, from the initial formulation of the research problems to the detailed plans for the publication of the results. Poor communication between archaeologists and scientists continues to be the major source of problems and potential ambiguities in the application of science in archaeological field projects.

6 Lastly, it is necessary to stress the more general problems of site conservation in certain aspects of archaeological science – particularly in the field of environmental and palaeoecological studies. Certain types of site clearly possess unique qualities for preserving crucial palaeoecological information, especially in the case of wetland deposits such as those of the Somerset Levels, the Cambridgeshire fenlands, and ancient lake deposits such as Seamer Carr and adjacent sites in North Yorkshire. Drainage, peat cutting, and other commercial activities are posing immediate threats to all of these deposits, destroying not only the archaeological content of the sites (ie organic remains in the form of wood, bone, textiles, etc), but also many aspects of the associated palaeoenvironmental data. Inevitably, new and more refined techniques of analysis will open up new prospects for securing important data from these deposits, of relevance not only to archaeology but also to wider studies of past environments in Britain. Rescue projects to secure environmental data in advance of destruction of the deposits themselves can be no more than a short-term solution. The only long-term solution is to ensure that at least certain parts of these unique deposits are preserved to allow for systematic reinvestigation and reinterpretation by improved scientific techniques in the future.

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2 Environmental studies

M Jones

1 Introduction

The use of soils, sediments, and biological evidence to elucidate past human environments is far more than the icing on the archaeological cake. Environmental studies have made major contributions to the very framework within which the human past is viewed, both in terms of its division into chronological units and of understanding communities whose economies centred around the manipulation of biological resources. A diligent treatment of the potential of environmental evidence therefore occupies a central rather than a peripheral place in the formulation of archaeological research priorities.

2 Basic research: new techniques and procedures

2.1 Diversifying the database

The range of material examined within environmental studies is constantly increasing, and this is one of the strengths of the subject. Reconstructions based on a range of biological and sedimentological categories rather than a single category are both more reliable and more detailed. As new categories of environmental evidence come to light, research into their analysis should be supported even prior to the establishment of their full archaeological potential. Waterlogged and midden deposits in particular contain a great deal of untapped potential in this respect.

2.2 Taphonomy

An understanding of the series of steps that link a living system to the deposition of environmental evidence in the archaeological record is crucial in the use of that evidence for the reconstruction of past environments and economies. There is a pressing need for research into taphonomy, through detailed analyses of the structure of the evidence, simulation studies, and observation of modern parallels.

2.3 Sampling

The importance of standardized sampling procedures is emphasized in section 6.2. Their design in turn entails research into minimum sample sizes for particular categories of materials studied for particular ends.

3 Basic research required: specific research problems

3.1 A reconstruction of the changing human environment and changing use of biological resources

This is a central priority in archaeological research. We should aim to understand the complete sequence of human interaction with the environment through time in its various regional manifestations, rather than concentrating all our resources on specific portions of that sequence. This entails resources being distributed within and between archaeological time periods.

Within individual time periods, resources should be spread such that the broadest possible range of types of site and environmental setting is examined. The latter should be perceived in terms of differences in geology and landform, a more cost-effective approach than attempting an even coverage in simple spatial terms.

Between time periods, resources should be distributed such that those periods for which little environmental evidence exists are favoured. For most categories of evidence this entails all of the pre-Iron Age period, as well as the Anglo-Saxon period.

4 Research applications

For the reasons outlined in section 1, environmental evidence is as much part of the national archaeological heritage as are monuments and artefacts. We therefore have certain obligations to apply the knowledge derived from environmental research. These obligations relate both to preservation and fieldwork.

4.1 Preservation

The most endangered bodies of environmental evidence are waterlogged deposits, be they from low-lying urban sites or hilltop peat bogs. A sample of such deposits should be selected for preservation in their own right, rather than incidentally as a result of preserving more 'conventional' sites.

We should also recognize that pieces of relict landscape, such as ancient woodlands and old meadows, are irreplaceable components of our national archaeological heritage.

4.2 The selection of sites for excavation

The potential for environmental archaeology must be taken into consideration if resources are to be profitably allocated. Two types of site should be favoured, those with good stratigraphy associated with environments of deposition, and sites in heterogeneous environments. The former includes sites that are associated with, for example, peat deposits, valley sediments, dune deposits. The latter includes sites that contain both acid and alkaline sediments, and both aerated and air-free deposits, thus yielding the broadest range of categories of environmental evidence.

4.3 Multidisciplinary approaches to excavation

While aiming at the spread of resources outlined in sections 3.2 and 3.3 it is vital that sufficient resources are allocated to individual projects to ensure that a multidisciplinary environmental approach is implemented producing adequate samples of each category of data. Such an approach is immeasurably more valuable than one producing disparate and inadequate samples from a large number of separate projects. The ability to structure such an approach depends on the kind of research outlined in section 2.3.

5 Organization and funding

5.1 Responsibility for funding

The interdisciplinary nature of environmental archaeology renders it particularly vulnerable to 'falling down the gap' between different funding bodies. Some of the vulnerable areas are outlined here.

Research with substantial contributions to development of the natural environment, or to human and animal nutrition and disease. It is vital that the considerable potential of this sort of interdisciplinary work is not stifled because the various funding bodies take too narrow a view of their remits.

Research of value at the local level. As with local archaeology in general, research into the environmental history of specific areas may have considerable appeal to the general public, but less appeal to bodies allocating funds for scientific research.

Research in relation to long-term excavations. While it is important for the environrnental specialist to be intimately involved with the excavation process, scientific research funds are often allocated for periods of three years or less, favouring research on the more ephemeral excavation projects.

To avoid valuable research being lost down gaps such as these, it is imperative that funds for excavation be granted *subject* to adequate financial provision being made for the environmental research that is generated, whether or not that provision is to be made by a separate body.

5.2 Institutional structure

Environmental archaeology is currently conducted within a series of laboratories established by the DoE in relation to government excavation, and an *ad hoc* collection of University Departments of Archaeology, Botany, Zoology, Anatomy, Environmental Sciences, and Geography, reflecting the particular interests of individual academics. This structure is inadequate to cope with the necessary environmental research generated by current archaeology fieldwork in Britain. In addition to requirements for more space and more staff, certain organizational improvements may be mentioned.

Secure job structures are required, not only to encourage high-quality archaeological scientists into the field, but also to ensure that long-term archaeological projects are catered for with sufficient continuity.

Reference collections of biological material are the most important tools of the trade. Most in current use are incomplete, and depend for their expansion on luck, informal contacts, and the spare time of individual researchers. A nationally coordinated effort to equip labs with full collections would greatly enhance the quality of research.

Database software needs to be compiled at a national level for each of the categories of data. Software that can transform primary data into camera-ready tables and figures will effect a substantial increase in efficiency.

Cooperation between institutes, so that resources and expertise can be utilized to the full, should be encouraged and facilitated at every level, from the support of meetings and newsletters and the sharing of equipment, to cooperative research ventures.

The channels for *publication* of environmental research are already inadequate, and should be expanded rather than curtailed. Regional journals should be discouraged from excluding environmental sections in archaeological reports.

6 Methodology and procedures

6.1 Sampling strategies

In order to achieve the separate aims of spreading resources within and between archaeological time periods (section 3.1) and implementing adequate multidisciplinary programmes within each project (section 4.4) it is vital to establish the most cost-effective ways of acquiring an adequate sample of environmental data. The minimum useful sample size for particular categories of material is often high, and often poorly established. The formulation of cost-effective sampling strategies that take the individual nature of particular categories of evidence and their taphonomy (section 2.3) into account are therefore a top priority.

6.2 Standardization

While a certain degree of flexibility is necessary to meet the individual requirements of individual projects, our methods are at present lacking the level of standardization necessary to permit objective comparison of results from separate projects. Agreement must be reached, not only on overall sampling strategy (section 6.1) but also on flotation and sieving procedures, and on the mesh apertures used in each process. The better-established environmental laboratories have a great deal of experience in these techniques and should lead the way towards this standardization of procedures.

3 Archaeological pollen analysis

N D Balaam & R G Scaife

1 Basic research: techniques and methods

1.1 Taphonomy

As with many other branches of archaeological evidence, the effects of the multitude of post-depositional processes on the pollen record are poorly understood. Over the years there has been considerable research put into pollen analysis designed to assist with the interpretation of processes of pollen production, dispersal, sedimentation, and preservation. There has, however, been a shortage of detailed testing and comparison of pollen data with other available sources of information – in particular, well-documented arable or pastoral episodes within firmly defined catchment areas.

In the past, there has been relatively uncritical acceptance of the results of pollen analysis by archaeologists. It is of the utmost importance that more detailed research is undertaken into the manner in which historical events are reflected in the pollen record of all manner of sites (lacustrine sediments, peats, and soil). Comparative studies are required in which other sources of vegetational evidence (particularly historical and/or ethnographical records) are tested against the palynology. Such work will clearly not guarantee a definitive interpretation of pollen analytical results – the biases inherent in any other form of record (documentary or otherwise) and the variability of pollen-bearing sediments will ensure that. It is, however, important that we try to develop further our interpretation of the available data to enable the fullest comparison with other archaeological information and a more complete understanding of the possible effects of post-depositional changes. This work would of necessity largely be concerned with post-medieval and modern records and as a consequence could not provide the ideal analogues for the interpretation of prehistoric data. Such studies could be of importance in *trying* to understand the pollen data pertinent to archaeological sites.

The taphonomic processes involved in the pollen record of soils are particularly complicated by the problem of movement of the pollen grains within the soil. In the early days of soil pollen analysis many assumptions were made about the nature of this movement. More recently some of these assumptions have been questioned and there is a clear need for detailed experiment on, and observation of, a wide variety of soil types and situations. The experimental earthworks established at Overton Down, Wiltshire and at Wareham Heath, Dorset were notable attempts to initiate this type of research (along with a number of other studies). There is, however, an urgent need for revitalization of interest in experimental work of this nature, particularly in relation to archaeologically related pollen analysis. These studies should also be expanded to encompass differing geographical regions, thus embracing a wide range of ecological conditions.

1.2 Relationship of archaeological sites and events to the pollen record

The advent of radiocarbon dating made possible the first good comparison between the pollen record from peat or lake sediments and nearby archaeological evidence. The inherent inaccuracies and imprecision in radiocarbon dating (sampling error, contamination of sediments, variability between sample materials, etc) ensure that the exact relationship between archaeological and palynological events may often be uncertain. On some sites, the availability of archaeologically datable soil profiles along with sedimentary pollen records should allow the precise location of the archaeological event with the pollen profile. There are, however, problems with the interpretation of soil pollen and its comparison with other sources of pollen data and they need detailed study to make possible the more widespread intercomparison of different sources of pollen evidence.

1.3 Analysis of pollen-poor sediments

The main emphasis in pollen analysis, both archaeological and mainstream, has been on deposits which are rich in fossil pollen. More recently a small amount of work has been directed at inorganic sediments which are comparatively poor in preserved pollen. To enable gaps in the geographical cover of pollen analysis to be filled it will be necessary to extend pollen analytical interests to areas which have in the past been neglected because of the absence of rich pollen-bearing deposits. The techniques for concentration of pollen from large samples of pollen-poor material are available and could be much more widely tested and used on material from this country. It would be a great advantage to be able to compare the analysis of such material with other sources of pollen data.

1.4 Analysis of calcareous soils

The extensive areas of calcareous soils in the archaeologically rich areas of southern and eastern Britain have resisted the application of soil pollen analysis. There have been a few notable exceptions to this pattern but the particular problems associated with the analysis of these soils have yet to be studied in detail. Again, there is need for experiment and observation of a wide range of such situations to enable assessment of the full potential for the analysis of these types of soil.

1.5 Pollen analysis in the urban environment

The analysis of urban deposits has been consistently avoided by palynologists owing to the immense interpretative problems of such deposits, including those imposed by the variety of pollen sources, sediment disturbance, and differential preservation. A number of workers feel that research into the significance of pollen in certain types of urban deposit may be justified. As with a number of the other subjects discussed above, the paramount need is for a programme of observation and experimentation before there can be any realistic attempt at the interpretation of any such analyses. Such modelling may be problematic in view of the absence of contemporary analogues of medieval environments in Britain but may be feasible from research in other areas of Europe.

1.6 The importance of spatial studies

The problem of the siting and spatial distribution of events observable in the pollen record is rarely considered. Early research using 'three-dimensional' pollen analysis was undertaken in the mid 1960s. There has been surprisingly little further application of these techniques although they are of potentially great significance to archaeologically orientated pollen analysis. Far too much palynological research has involved the interpretation of solitary profiles which provide little spatial information. There is much to be gained from the investigation of spatially and temporally related profiles (on a local rather than a national scale) which may well prove of great potential and usefulness to archaeological investigations.

2 Basic research: specific problems

A number of the specific problems associated with archaeologically orientated pollen analyses are concerned with the characterization of vegetational communities or successions. In many cases these problems may be eased by the application of techniques of detailed close sampling in association with plentiful radiocarbon dates. This technique provides much greater temporal resolution by the close sampling of peats or lacustrian sediments at intervals as close as 2mm or less. It has largely been applied to the enigmatic prehistoric 'elm decline' at *c* 5300 BP but could well be applied to any phase of archaeological activity represented in the stratigraphy.

2.1 Palaeolithic

Detailed palynological studies of the anthropogenic impact on the environment have been confined to the Flandrian period. No concerted attempt has been made to examine the possible effects, if any, of palaeolithic man upon his local environment. Prehistoric studies still assume his role to be subordinate to that of natural causes. Study of earlier interglacial sediments, often in association with archaeological/artefactual materials, has generally been viewed solely in terms of dating, climatic change, or broad sequential vegetative successions. Although sediments of this date are usually minerogenic and not ideally suited to the detailed study exemplified by close-spaced analyses of Flandrian peats, it may be possible with the correct choice of archaeological site to procure anthropogenic data on these earlier periods. Such anthropogeny has been alluded to in the Hoxnian type sequences. Other Acheulian sites having 'fresh' and therefore autochthonous flintwork should be viewed as sources of potential interest although sites of substantial interest such as Swanscombe are in poor pollen-preserving media which only allow pollen analysis through the concentration of the low pollen numbers present.

The palaeoecologist's understanding of the environmental conditions of earlier periods needs to be presented lucidly to the archaeologist. Time-lag in data diffusion between natural sciences and archaeology has been somewhat long. Problems confronting the archaeologist such as, for example, the apparent absence of Upper Palaeolithic archaeology referrable to the end of the Devensian (Zones I-III) might become clearer.

2.2 Characterization of Mesolithic clearances

Sporadic clearances recorded in pollen analysis of sediments of pre-Neolithic date have sometimes been attributed to deliberate human interference with the vegetation. There is a clear need for further detailed research on a wide variety of sites where the clearance episodes could be recorded using palynological techniques such as close sampling and 'three-dimensional' analyses in collaboration with detailed archaeological survey. The application of multidisciplinary analyses in elucidating what were possibly transient clearance phases in the forest would assist the palynological interpretation.

2.3 Neolithic farming practices and the development of secondary woodland

The imprecision inherent in pollen analysis has meant that details of the nature of early farming practices and secondary woodland development are little understood. Only with detailed, close-spaced, high resolution pollen diagrams of sediments/peats associated with known phases of agriculture will vindication of land-use models or agricultural practices be possible. There is therefore a requirement again for very detailed analyses, using closely-spaced pollen samples from sites in small, well-defined catchment areas. This research would be greatly assisted by the integration of a variety of different archaeoenvironmental and archaeological studies.

2.4 Coastal archaeological studies

The study of the cultural and environmental archaeology of the coastal areas of the British Isles (as indeed elsewhere in Europe) is hampered by the loss of considerable land areas to the encroachment of the sea. Since the early recognition of coastal submergence eustatic movements have been widely studied in terms of their implications for the plotting of former coastlines, isostatic readjustments, and the calibration of sea-level datum curves. At a number of points around the coast there are examples of the survival of peat deposits of early Flandrian (Flandrian I) to Atlantic (Flandrian II) date which contain Mesolithic sites and/or evidence of anthropogenic activity which have been submerged by marine transgression. In some circumstances archaeological evidence has been subjected to later (Flandrian III) submergence which has been recognized for many years. The potential of these assets is in many cases visibly wasting and it is important that attention is paid to them while they are still available for study. Occasionally they have received attention from researchers into sea-level change and/or vegetational history but there has been little concerted research from the archaeological viewpoint in recent years - partly perhaps because few have yet recognized the potential and importance of such an approach to these deposits.

2.5 The function of Bronze Age and later field systems and the relative importance of arable and pastoral farming practices

Recent research through field survey and aerial photography has greatly expanded the amount of data available on the form and extent of prehistoric and later field systems. There is, however, distressingly little known about the function of these monuments; suggestions as to their use are largely the result of supposition on the basis of field shape, size, etc. There is a clear need for detailed palynological investigations of these systems, linked with pedological and archaeological survey, so that a more objective statement as to their function and duration can be made. The requirements of such research are clearly-defined catchment areas and a sufficient variety of sampling sites to allow attempts at three-dimensional studies to be made. The relative importance of the arable and pastoral components of the farming system always presents a problem. It seems likely that this problem will only be solved for any particular site by the adoption of a multidisciplinary approach in which a variety of environmental data can be assessed.

2.6 Expanding the pollen map

Although large parts of the British Isles have received some form of 'cover' from pollen analysts, there are still a number of areas which have received little attention (eg the south-east and midlands of England). Frequently these may be adjacent to palynologically well-documented areas but differences in geology and geomorphology mean that no inferences about the vegetation and land-use of these areas can be drawn from the existing pollen data. One such example is that of Devon where, although considerable palynological work has been undertaken on the granite upland of Dartmoor, the nature of the prehistoric environment of the surrounding lowlands is virtually unknown. A similar example is that of south-central England where contrasting lithological and therefore edaphic variations may have resulted in markedly contrasting ecotypes during the Flandrian. It is important that in this and similar areas research is done to locate sites suitable for pollen analysis which can help to illustrate their environmental history. It should be recognized that often it is necessary to examine sites and sediments which appear less than ideal to traditional palynologists and which may not have a direct link with an archaeological site in the first instance.

3 Research applications

3.1 Understanding site function

It is apparent from the categories listed above that pollen analysis has a considerable amount to contribute to a fuller understanding of the function of a site or landscape. Archaeological studies which depend solely on the evidence of the forms of the monuments can only present a very limited view of their function. The complex issues concerning a site's function can only be properly approached by the integration of various lines of research. The most useful results will often only be achieved by the examination of material from beyond the confines of the site itself - for example the pollen analytical investigation of peat mires adjacent to well-excavated/documented archaeological sites (in addition to any on-site soil pollen data). Here, 'on-site', soil-based palynological studies and context-oriented sampling may be placed within the broader framework of longer temporal change. It is important therefore that the field archaeologist should recognize the value of locally contemporaneously-deposited peat and sediment sequences.

3.2 Prospection

Pollen analysis has on occasion been responsible for the discovery of hitherto unknown archaeological sites. There is potential for the location of further archaeological evidence from the detailed study of existing palynological data and its integration with various forms of archaeological survey. In general there has been little cross-referencing of archaeological and palynological data unless the palynology has been specifically commissioned as part of an archaeological project. It is important that archaeologists should examine pollen data from regions of impoverished archaeological evidence. Such assessment can and should result in the identification of anthropogenic factors which, although recognized by the palynologist, may not be fully appreciated for their archaeological significance. In future pollen analysis could usefully play a role as a tool of survey in areas where the archaeology is little understood.

3.3 Nautical archaeology

The substantial publicity surrounding the investigation of the flagship *Mary Rose* hints at the potential of such sealed, well-preserved contexts. While botanical remains of macroscopic nature may perhaps provide a clearer insight than pollen into plant utilization, it is likely that the study of the pollen from selected contexts/artefacts (ie those not contaminated by later sediments) from within the sunken structure will provide corroborative or additional data. Pollen and seed remains recovered from the same archaeological contexts need not necessarily yield similar information and interpretations. Further submarine environmental archaeological investigations are likely to occur in the near future as an increasingly large number of well-preserved shipwrecks in sediment environments are discovered and investigated. It is therefore desirable to appraise fully the potential of pollen analysis in such situations.

4 Plant macrofossils

M Jones

1 Introduction

The two principal categories of evidence are carbonized and waterlogged remains. The former are more or less ubiquitous in archaeological deposits, and are normally dominated by fragments of wood and of the fruiting parts of cereals and weeds. Waterlogged remains are more varied and diverse and, when conditions are suitable, they occur in considerable concentrations. Two less familiar categories are mineralized remains, found in deposits rich in calcium salts, such as latrines and lime-based constructional materials, and dessicated remains, which in Britain are more or less confined to material sealed within upstanding buildings. While carbonized and waterlogged items are likely to remain the two principal categories, mineralized remains may prove to have a greater potential than is currently recognized.

2 Basic research: new techniques and procedures

2.1 Taphonomy

Considerable advances, through analysis of site formation processes, have been made in our understanding of how plant resources were used in the past. The three elements in this have been:

a) detailed analysis of plant assemblages in relation to the morphology of living populations of those species

b) the use of ethnographic parallels

c) experimentation at centres such as the Butser Hill Ancient Farm Project

The work so far has been most detailed on cereals in the carbonized state. It would be useful to extend this work to economic plants other than cereals, for example pulse and fibrecrops and the whole range of non-domesticates, and to explore taphonomic processes leading to well-preserved waterlogged remains. In other words the approach adopted at the North German site of Feddersen Wierde could be usefully developed, for example on crannog sites.

It would be valuable to explore the application of sophisticated chemical and physical techniques to taphonomic problems, for example the use of electron spin resonance to elucidate the thermal history of carbonized remains.

2.2 Genetics and taxonomy

A broad outline of the microevolution of a number of domesticated plants has been derived from archaeological evidence. Beyond this outline, such evidence has generally been superseded by hybridization experiments and detailed chromosome studies. However, the potential of archaeological evidence has recently been considerably expanded by more detailed examination of archaeological remains on the microscale. There is enormous potential for development in this field.

Some long-chain organic molecules may remain intact even in carbonized material, opening the way for the application of a wide range of spectrographic and radiometric techniques with a view to chemotaxonomy. The application of such techniques as nuclear magnetic resonance and pyrolysis mass spectrometry would be useful.

2.3 Ecology

British palaeoecological research has tended to involve the use of 'indicator species' to argue back from their modern ecology to environmental conditions in the past. The emphasis of future research could usefully be shifted towards communities of species rather than individual species, with an awareness of potential changes in ecological behaviour. The latter may only be achieved through multidisciplinary studies in which the full range of plant macros is viewed in the context of the full range of biological and sedimentological evidence.

Comparative studies of modern ecosystems that reflect a wide range of human involvement are vital to an undersanding of changing ecological relationships through time. Such studies may- be conducted in old meadows and ancient woodlands, as well as in experimental habitats simulating past conditions of agriculture and human interference.

2.4 Improvements in standard procedure

The three 'problem areas' are sampling, extraction, and identification, which are dealt with here in turn.

Consensus over *sampling* method is still lacking despite some useful publications in this field. The sites that pose the greatest problem are those with a substantial element of vertical stratigraphy, in particular middens and urban sites. The sampling of such sites for plant macros requires attention.

Methods of *extraction,* involving flotation and wet-sieving, are less controversial, and the main advance would be the standardization of procedural details such as sieve mesh apertures.

Identification is hindered by the absence of a British atlas/key of seeds and fruits, the incomplete nature of extant reference collections, and the absence of any aids to the identification of macroscopic remains other than wood, bud scales, seeds, and fruits. The construction of comprehensive reference collections, together with atlases and keys, would be an enormous undertaking, but a few economic steps in that direction might be noted:

a) A British supplement/commentary on Greta Berggren's excellent series of Swedish seed and fruit atlases would be a most worthwhile investment of effort.

b) The kind of coordination of seed supply and exchange that exists between botanic gardens could be usefully developed within the archaeological community for reference material of all kinds.

c) The new approaches to taxonomy outlined in section 2.1 could be the way forward to detecting economic plants other than cereals and seed crops in the archaeological record.

3 Basic research: specific research problems

3.1 Plant economy

The extant database for Britain is at its most extensive for cereal crops in the Iron Age and Roman periods. Apart from this we have a patchy record of cereal and legume crops from the Neolithic period onwards, and some evidence of garden and orchard crops and specialist plant resources in the Roman period and from the late Saxon period onwards. Our knowledge of plant economy prior to the Neolithic period and of woodland management in most periods is minimal. The various gaps point to the following priority areas for future research:

The economic use of plants other than cereals. This entails giving priority to settlement sites of all periods, particularly pre-Iron Age, which are in such locations that waterlogged deposits are likely to occur. It also entails an improved understanding of taphonomic factors (see section 2.1) so that plants can be recognized as having been utilized.

The articulation of plant products within early exchange networks. This entails, first, a study of how crop production in general is linked within local exchange networks, and second, a study of the appearance of luxury and specialist crops that may involve long-distance transport and market exchange. The first may be achieved principally by framing consistent sampling strategies for landscapes containing numbers of contemporary sites, rather than framing them on a site-by-site basis. Such strategies should be framed with a clear view to perceiving taphonomic variation.

The second study would entail the extension of the kind of research that has been conducted within Roman, late Saxon, and medieval towns to late Iron Age *oppida,* and to well deposits from Roman and post-Roman rural sites.

Changing man-plant relationships. A number of the developments outlined in section 2 have considerable implications for the study of changing man-plant relationships, such as the problem of transition to agriculture. It is felt that priority should be given to those multidisciplinary projects with the best chance of providing the detailed taphonomic and genetic information outlined in sections 2.1 and 2.2 in the most clearly understood archaeological contexts. In other words, the favoured approach should be processual rather than 'origin-seeking'.

Early woodland management. Changes in management have apparently occurred between the Neolithic and late medieval periods, and though their implications for land utilization are important, their chronology is at present unknown.

Despite the widespread occurrence of waterlogged wood in British archaeology, studies of woodland management such as were conducted within the Somerset Levels Project are rare. The approach adopted in that instance could be usefully developed for waterlogged wood-bearing deposits of all dates.

3.2 The human environment

The main use of plant macros in environmental inference has been as a complement to pollen analysis, which provides the 'backbone' of knowledge of environmental change. Plant macros have allowed more precise identifications, have aided the distinction between regional and local components of the plant record at particular sites, and have produced detailed information on the environment of human settlement. It is suggested that priorities for future research involve the latter area.

The human environment is so intrinsically linked with the plant and animal economy that there are many areas of overlap between the following priorities and those cited in section 3.1.

The agrarian landscape prior to prehistoric enclosure. Little is known of agriculture prior to the appearance in the second millennium bc of enclosed landscapes, or what such enclosure entails from an agricultural point of view. An ecological examination of carbonized and, where possible, waterlogged assemblages of this date may provide the relevant information.

The development of segetal and ruderal communities of plants. The categories of vegetation associated with human disturbance may not have remained constant, and indeed the segetal/ruderal division may not have always been so pronounced. Such changes reflect changes in the activity of humans and their relationship with the environment. As such, they form an important area of study, on the basis of weedy species from both carbonized and waterlogged assemblages. Such research has ramifications in both the rural and urban contexts and, especially in the latter, will be most profitably pursued in close conjunction with insect studies.

4 Applications

4.1 Procedures

It has only recently been recognized that plant remains in various forms are as ubiquitous in the archaeological record as the more familiar materials such as pottery and animal bones. In the same way that we have routine procedures for collecting these more familiar categories, we should ensure that this is true for plant remains. A standardized procedure for collecting carbonized material through flotation should be applied within excavation as a matter of course, and a carefully constructed strategy for the analysis of waterlogged deposits should be a prerequisite for the excavation of sites yielding such materials.

4.2 Organization and funding

Routine bulk flotation for carbonized material and, where necessary, wet-sieving for waterlogged material should be seen as integral to good excavation procedure, and excavations should be organized and funded accordingly.

Most of the new research proposals outlined above would normally be conducted within a university framework. However, those outlined in section 2.4 may be more efficiently pursued within professional units, and it would be unfortunate if they were excluded from developing new techniques. In general terms, every step should be taken to integrate the activities of units and universities in this respect.

5 Soils and sediments

R I Macphail, N D Balaam & S Limbrey

1 Data sources for archaeological soil studies

Data of value to palaeopedological studies may be broadly divided into primary and secondary. Primary sources essentially consist of soils which remain in *situ* while secondary sources consist of material which has been eroded and redeposited.

1.1 Primary sources

Buried soils. These may have been buried by a natural agency, eg by colluviation, or by human works such as construction debris or an earthwork. In some cases, the date of the soil's burial may be determined (with varying degrees of precision) by a study of the artefacts within the soil or by the application of radiocarbon dating to the organic components.

Unburied soils. Present surface soils may preserve relict features of their earlier history. They will also be of particular value for comparison with any adjacent buried soils.

1.2 Secondary sources

Colluvium and alluvial deposits are also important data sources. In addition to their role in burying the soils or features on which they are laid down they may have material and features within them which relate to the land-use of the area from which the material was originally eroded.

2 Basic research: techniques

2.1 Poorly-preserved soils

Most soils examined in the course of archaeological research are in less than ideal condition for pedological study. Many have been truncated to some extent and most have also been modified since burial by subsoil pedogenesis; if the soils are unburied they have obviously been subject to continuing pedogenic and agricultural processes. It is important that techniques for the study of these poorly-preserved and unburied soils be developed as they represent a large proportion of the material available for archaeological pedology.

Consideration should be given to the establishment of a national database of archaeological/pedological analytical data to aid the interpretation of such poorly-preserved soils. The analytical results from any particular site may not be of any immediate significance to that site. If, however, these results were to be incorporated in and compared with a large body of comparable data they could well contribute to a fuller understanding of soils from other sites. A 'core' set of analytical techniques would obviously be essential to such a project. The standard analytical methods used should cover loss on ignition, organic carbon, pH, nitrogen and phosphorus content, other cations, cation exchange capacity, and grain size. The interpretation of such data would require specialist expertise in both soil science and pedology.

2.2 Micromorphology

Despite the potential of micromorphological study of archaeological soils and the early investigations that utilized the technique, there has been little development of the subject within archaeology until comparatively recently. Micromorphological studies are the most reliable way of characterizing archaeological soils. They are also the best way of differentiating pedological processes, eg natural pedogenesis, anthropogenic factors, and post-burial changes. Even in unburied soils polycyclic features can be interpreted and may be related to the archaeology.

Experimental work is at present under way in both Britain and Europe on the identification of micromorphological characters which can be attributed to particular environmental conditions or land-use. There is, however, a need for these characters to be tested against well-understood archaeological examples in addition to their comparison with modern soils. There is a manifest need for more resources to be committed to all aspects of the micromorphological study of archaeological soils and especially to this basic experimental work.

2.3 Soil magnetism

Palaeomagnetic dating techniques have been used on 'natural' fine-grained sediments for several years; more recently they have been applied to sediments such as colluvium. The reliability of these applications needs to be established by extensive comparative studies with material dated by other techniques, such as radioarbon and artefact analyses.

Magnetic susceptibility of soils is enhanced by burning and biological activity, and thus material from soil 'A' horizons will, in general, tend to have higher susceptibility than subsoils. The use of measurements of susceptibility as an aid to the interpretation of archaeological horizons has already received a certain amount of attention. It is, however, necessary to experiment with the technique more widely and to apply it to a wider range of archaeological deposits.

In view of the complications which may arise in the interpretation of magnetic susceptibility measurements in podzolic and gleyed soils and where short-lived 'A' horizons may have formed during deposition of colluvium, it is important that research into such methods of analysis be closely linked to and compared with other methods of pedological and environmental study. In particular, micromorphological studies should be used to help identify the causes of magnetic enhancement of the soil, together with chemical and mineralogical analyses of the magnetic minerals.

2.4 Phosphate survey

Techniques of soil phosphate analysis have been used in connection with archaeology for many years. For the most part these have been solely concerned with the location of sites and/or occupation areas within sites. Recent work has focused on the application of phosphate studies to a more detailed characterization of sites and, more particularly, land-use. There is a need for further investigation of the value of such detailed analytical techniques to archaeological studies. The usefulness of these techniques in areas of lowland high base status soils should be fully investigated since much of the research into phosphate analysis has so far concentrated on acid soils in areas of 'marginal' land-use.

3 Basic research: specific problems

3.1 The history and extent of loess deposits

Some work has already been done on the contribution of loess to a number of soil types in Britain but there is a need for further investigation into the distribution of loess deposits, the effect of these on early holocene soil formation, and the history of erosion of these soils.

The contribution of loess to soil development and its effect upon prehistoric settlement patterns (in particular, the possible effect of loess cover, and its subsequent loss, in areas which are now heathland) needs further study. The erosion of loess from unstable slopes in south-east England during the late Boreal/ early Atlantic has been suggested; much of the evidence for this erosion and for the factors which would have contributed to instability of the material will be preserved in secondary deposits and in the very earliest buried soils of the area. Investigation of these deposits requires an interdisciplinary approach involving pollen analysis, molluscan studies, and micromorphological and other pedological and geomorphological studies.

3.2 Post-depositional soil changes

Even the most securely buried of archaeological soils will have been subject to post-depositional pedogenesis. Many soils have quite obviously been grossly affected by processes which obscure or destroy characteristics of use in interpretation. Some of these processes, such as the mineralization of soil organic matter and the movement of material within the soil profile, can be studied through experiment and controlled observation (eg through experimental earthworks such as those at Overton Down, Wiltshire, and Morden Bog, Dorset. The time-scale of experiments of this nature, however, limits their immediate applicability. More use could be made of the study of comparatively recently buried soils of known land-use history. Micromorphological analysis of their structure might be particularly valuable; it is often possible to detect post-depositional change in buried soils through micromorphology (for example the deposition of calcium carbonate crystals within an originally decalcified buried soil can be detected by this means).

3.3 Erosion and the formation of colluvial and alluvial deposits

The extent to which the landscape and the distribution of archaeological sites has been changed by various erosion processes and deposition of alluvium and colluvium is increasingly understood. Recent investigations of the colluvial deposits in chalkland dry valleys have emphasized the potential of these deposits but there has been little analysis of colluvial deposits outside the southern English chalk. In general, areas which have been under arable agriculture since Neolithic times have been little studied by archaeological pedologists because of the scarcity of buried soils, but much relevant information could be gained through the detailed study of the colluvium and alluvium in these areas. The techniques of analysis would obviously have to be adapted to suit the variety of lithologies encountered.

3.4 Pedogenesis and soil 'degradation'

Archaeological soils can contribute a great deal to the understanding of pedogenic trends and the history of soil development. Soil formation reflects both 'natural' pedogenesis and the effect of human utilization of the land. Present studies indicate that human impact has been decisive in the way soils have developed in the UK. There is little evidence of early Flandrian pedogenesis preserved within archaeological soils. Clearance and tillage in the Neolithic dramatically altered the character of these soils and in some areas erosion was initiated which severely truncated the soil profiles. Wherever they become available Neolithic period buried soils should be studied in detail; an understanding of the development of pre-Neolithic soil is essential to the accurate interpretation of the evidence for the development of and use of the soils of later periods.

The processes of acidification and hydromorphism which result in the development of podzols and gley soils has received relatively frequent study from archaeologists and pedologists. This is largely the result of the concentration of (and interest in) well-preserved archaeological monuments in areas of upland and/or base-poor parent materials. Often, the pattern of podzolization and hydromorphism has been described as being c Bronze Age/Iron Age in origin and has been directly attributed to human influence. Studies are beginning to show how locally restricted human impact may have been within these areas at any particular time and how in some areas relatively base-rich or finer parent materials resisted these pedogenic trends until historic times.

The archaeological history of lowland soils in the British Isles in early periods is little understood. In contrast to the upland areas, lowland soils have rarely been the subject of intensive archaeological pedology. Many of these soils today suffer from drainage imperfections (resulting in gleying) and their early development and land-use history should be a focus of study.

Other lowland soils are, of course, fertile and of great economic importance. The land-use and pedogenic history of these areas is comparatively little known and this is a major omission as it is these same areas which will often have made a major contribution to ancient economies. Their extensive use through history has unfortunately destroyed many of the more obvious archaeological remains and removed upstanding monuments such as earthworks which are traditionally the repository of pedological data. The study of such areas is dependent upon the application of techniques which examine secondary data sources and remanent features within the modern soils.

3.5 Urban deposits

Buried soils which are undisturbed by later activity (human and other biological) are rare in urban contexts. They are, however, extremely important as a source of information on the early urban and pre-urban environment and land-use. Wherever located they should be studied and recorded in detail.

The phenomenon of the 'dark earth' found in many urban excavations is known in some cases to derive from medieval pit and ditch digging. It is often more difficult to interpret Roman and Saxon 'dark earth' deposits because of later contamination and cultivation of the material. In some cases the 'dark earth' may have been formed under cultivation, but there is little direct evidence for this. The possibility that it may also be derived from the collapse of insubstantial mud-walled buildings is under careful consideration. There is a continuing need for urban deposits of this nature to receive detailed pedological study.

3.6 Man-made soils and prehistoric soil management

Aspects of the deliberate maintenance of soil fertility in antiquity have generally been studied in a piecemeal fashion in this country. However, there is a significant amount of evidence for prehistoric manuring and soil improvement (largely in areas which utilize coastal resources). It is time that the investigation of these practices and of soil management generally became the subject of concerted study.

4 Research applications

4.1 Evidence from archaeology as an aid to conservation and exploitation of modern soils

An understanding of past soil types and distributions is an essential part of the management of modern soils. It is necessary to understand the effect of human activity on the soils and to distinguish these effects from those of climatic change.

Pedogenesis. Archaeological studies can contribute a great deal to the understanding of pedogenic trends and the history of soil development. It has been demonstrated that human land-use has a very significant impact on the development of soil profiles, especially through cultivation.

Erosion. Modern soil erosion is causing increasing concern to agronomists. Archaeological soil studies can do much for our understanding of rates of erosion and may in some cases suggest mechanisms by which soil wastage can be averted or diminished.

4.2 Interpretation of archaeological survey

Archaeological survey of settlements and field systems has too frequently been conducted in isolation from a consideration of the evidence provided by a study of the distribution of both modern and (particularly) buried soils. The archaeological pedologist has much to contribute towards the interpretation of such surveys both through an assessment of the potential of the soils of an area and through planned sampling and analysis of palaeosols located during the survey.

6 Vertebrate archaeozoology

Geoff Bailey & Caroline Grigson

This report is written on the assumption that the major objective of archaeozoological work is to contribute to an understanding of past human behaviour, biology, and society. This is not to overlook the strictly zoological, environmental, or chronological information supplied by faunal remains, but rather to emphasize the fact that the majority of such material is deposited either by human agency or in the context of human activity, and is recovered from archaeological sites excavated with primarily archaeological objectives in mind. Animal bones are often among the most numerous materials found in excavation, and need to be treated in every way as 'artefacts' of the same (if not greater) potential and importance as other classes of archaeological data. The retrieval of faunal remains should play an integral role in excavation strategy, and their interpretation an integral role in the reconstruction of past economy, settlement, and society. The report is divided into four main sections. Sections 1 and 2 deal with fundamental research; section 3 discusses the different stages in the analysis of faunal material from archaeological sites; section 4 deals with funding.

1 Basic research: new procedures and techniques

The importance of the collection and recording of basic descriptive data, such as the identification to species and anatomical part, metrical and non-metrical attributes, and the quantification of animal remains is beginning to be understood and acted upon. Nevertheless major research effort is still needed to fill the wide gap between the collection of data on the one hand and their interpretation in ways which are scientifically valid on the other. Some examples of the more pressing problems are given below, but the list is by no means conclusive.

1.1 Taphonomy

One of the most important problems in archaeozoological analysis, and at present the single most insurmountable barrier to effective interpretation of faunal remains, is the nature of the biases introduced by taphonomic and retrieval processes - that is by the various processes of destruction and deposition that modify bones during the period between the death of an animal and the arrival of its bones on the archaeozoologist's bench.

These biases involve both cultural and non-cultural factors and can operate at four levels:

a) Through patterns of carcase butchery and rubbish disposal.

b) Through physical and chemical attrition by trampling, destruction by carnivores and other animals, and weathering before burial.

c) Through physical and chemical attrition after burial, depending on such factors as soil pH and movement or disturbance of sediments.

d) Through poor recovery, damage caused by excavation, and inadequate conservation or curation.

Moreover, these processes will have differential effects on the remains of different animal groups (mammalian, avian and fish bones, and invertebrate exoskeletons), and on faunal remains of different species, age, sex, size, and structure, as well as causing large absolute losses of bone material. These potential biases affect almost every aspect of faunal analysis and interpretation. However, relatively little is known about the precise way in which they operate, or how they should be taken into account in the interpretation of archaeological material.

New experimental and ethnoarchaeological research, involving both field and laboratory procedures, should be devoted to identifying the effects of these processes. This might include detailed measurements of the density of bones of different species, of different anatomical elements and parts of elements, and of different ages and states of health; analysis of the effect of physical and chemical attrition on the condition and fragmentation of bone under controlled field or laboratory conditions; feeding experiments with dogs and other carnivores; and analysis of humanly-imposed patterns of butchery, bone modification, and rubbish disposal.

1.2 Ageing and sexing bones and teeth and the establishment of kill-off patterns

Several methods of estimating the age and sex of bones and teeth are available. Their use in indicating changed mortality related to changed patterns of animal exploitation and husbandry is well known. These methods also have a potentially key role in seasonality studies. Methods of ageing include the analysis of eruption sequences, wear patterns, crown height measurements and cementum layers in teeth, suture closure in skulls, epiphyseal fusion and fine structure in post-cranial bones, and growth increments in fish otoliths. Sexing is usually based on morphological or metrical distinctions on sexually dimorphic bones, but there are few criteria for the recognition of castrates. There is still considerable uncertainty about the accuracy, efficacy, or applicability of these various techniques.

The main need for new research here is in the testing and comparison of existing methods and in their refinement, for example by the application of techniques such as scanning electron microscopy, thin sectioning, or X-rays, and by their extension to a wider range of species. A major handicap is the scarcity of modern control data in the form of information on bones and teeth from animals of known age, sex, plane of nutrition, and life history. More work is needed with live animal populations and could be encouraged by closer links with institutions such as the ARC, the MRC, and the Rare Breeds Survival Trust. The importance of modern control data cannot be overemphasized, and their collection represents a high priority.

At the level of interpretation there is a need for more information from contemporary and historical contexts about the differing relationships of hunting, fishing, and husbandry practices to kill-off patterns and the resulting fauna1 remains, and the effects of such variables as birth rate, natural mortality, and food supply on population structure.

1.3 Osteological modification and pathology

The effects that husbandry practices, such as traction, confinement, and variation in diet, have on the structure, ageing, and pathology of bones are poorly understood. Research is needed into the recognition of osteological indicators of differing husbandry practices. The pathology of bone needs more study, the production of a detailed guide to the recognition of pathological symptoms is badly needed, and so is research on the anthropological implications of animal disease. As in section 1.2 there is a need for good control data from modern animals with known life histories.

1.4 Quantification of food remains

Attempts to quantify the relative amounts of various foods (plant as well as animal) in the diet are invariably hampered by large uncertainties: by differential taphonomic processes acting on different classes of material, and by lack of information about appropriate conversion factors for translating the material remains into units of food. Apart from taphonomic factors, further research is needed to compare different methods of quantifying fauna1 data, such as the assessment of numbers of individuals, and to develop appropriate statistics. More data are also needed about food yields, for example the relationship between bone size and meat weight and between meat weight and nutritional parameters such as calorific value and protein content, and about their degree of variation.

1.5 Intra-site spatial variation

Within-site patterning of fauna1 remains may suggest ways in which different parts of the site were used, for example for food preparation or rubbish disposal. On large and complex sites, like hillforts and towns, such variations may indicate differences in social class and in practical and symbolic attitudes to rubbish disposal. Research here is needed on sampling and methods of *in situ* recording and measurement, on multivariate techniques of spatial analysis, and on the integration of fauna1 data with other classes of excavated information. Although there are some ethnographic and archaeological observations on the definition of categories like ‘meat-bearing’ and ‘waste’ bones and their association with differing archaeological contexts, there is a need for the development of suitably designed excavation programmes with large and well-collected fauna1 assemblages and good horizontal and contextual control. Improved techniques for detecting intra-site patterning may in their turn clarify patterns of skewed bone distributions as evidence for the importation or removal of animals or parts of animals, and hence as evidence for the role of the site within a wider settlement context, as a centre for trade or redistribution, or as a place with a specialized economic, social, or ritual function within a wider system of settlement and economy.

2 Basic research: general problems

Although every archaeological site with fauna1 remains may raise specific research problems of its own (which are not always predictable in advance), we describe below a few of the many problems that are of more general interest; they need to be resolved on the basis of an overview of material from new as well as past excavations, and with modern comparative and ethnographic material when necessary. In many cases they involve some of the new techniques and procedures already mentioned.

2.1 Artificial and natural bone accumulations

The problem of distinguishing natural bone accumulations from those collected by people is a classic issue with sites such as caves or rockshelters which could have been used as dens by carnivores, and has a major bearing on the interpretation of Palaeolithic material. However, it is equally a problem with archaeological sites of other types and periods, which may include bone collections accumulated or modified by water movement or by non-human as well as human predators. The extent of natural interference in fauna1 collections supposedly accumulated by human agency needs to be examined by the use of taphonomic studies in a variety of archaeological contexts, and could include the analysis of the frequency and spatial distributions of anatomical elements and parts of elements, and the nature and extent of bone fragmentation and surface modification.

2.2 Early animal husbandry and domestication

The question of the origins and development of animal domestication remains an archaeozoological minefield of differing concepts and techniques. This is in need of clarification by the collection and comparison of faunal assemblages from a variety of well-controlled archaeological contexts, for example from sites of differing character, function, and archaeological period (particularly Mesolithic and Neolithic), and by the application of a wide range of comparative studies, including taphonomy, kill-off patterns, behaviour patterns, anatomical element distributions, and morphological, metrical, and, perhaps, chemical analyses.

2.3 Later developments in animal husbandry - secondary products

The question of whether or not there was a 'secondary products revolution' after the initial development of husbandry techniques is being investigated with the aid of faunal data from sites of the appropriate time period, in particular through the use of demographic parameters. These investigations could be broadened to a more general study of variations in the use of domestic animals for particular end products, especially those with wide implications for patterns of agrarian change, such as the use of animals as sources of mechanical energy, and the development of wool production.

2.4 The organization of food supplies and animal utilization in towns

Urban sites provide the opportunity to examine the organization of food supplies in a way which can be used to supplement documentary sources of information, or provide a substitute for them. Animal remains, particularly those of fish, birds, and mammals of known breed, can suggest where and at what season animals were obtained, and whether they were brought into the town dead or alive, complete or butchered. Detailed spatial analysis can show up working areas in which horn, bone, antler, skins, and feathers were prepared, and may also suggest patterns of refuse disposal, reflecting hierarchical, social, and religious differences in consumption in different parts of the town. Urban studies can pinpoint the importation of exotic pets, and more importantly exotic pests such as the black rat. Such introductions, and certain pathological conditions in animal and human bones, may have important epidemiological implications.

2.5 Hunting, birding, and fishing strategies

Fish, birds, and, to a lesser extent, mammals have very distinct behavioural traits such as migration, restriction to particular environments, seasonal aggregation patterns, reaction to predation, and so on. In order to be successful as hunters people have to adapt their predatory behaviour to the behaviour of their prey. Hence analysis of the remains of prey species in terms of their known behaviour can be a very relevant source of information about human behaviour. This is of particular significance in societies that obtained their sustenance solely by hunting and gathering, but may also be relevant in any later sites from which hunting took place. It is particularly important in the study of subsistence and commercial fisheries.

2.6 Stratigraphic interpretation

The condition and fragmentation of bone and the degree of modification by pre-depositional attritional agents such as weathering or carnivore gnawing may provide clues about the nature and rate of sedimentation, which may be of use in resolving stratigraphic problems. Such data may also aid in the interpretation of site function, by indicating discontinuities in human use or occupation. The species composition of faunal assemblages can also aid in the resolution of chronological problems, particularly in the Pleistocene.

3 The analysis of faunal material from individual sites

3.1 Personnel and planning

Faunal analysis is a highly specialized discipline and faunal analysts require specialist training with an adequate background in both the archaeological and zoological aspects of the subject. There is a general need for improvement in training schemes, comparative collections, and coordination between various institutions.

The integration of faunal analysis with that of other archaeological materials is essential at all stages, including planning, excavation, sampling, and retrieval during excavation, and post-excavational interpretation. If the full archaeological potential of faunal data is to be realized, there should be frequent communication and feedback between the faunal analyst(s), the excavation director (assuming that he or she is not also the faunal analyst), and other specialists. Ideally this communication should begin at the earliest possible stage, so that the excavation strategy may benefit and be modified as required as the work proceeds. Much of the patterning in the faunal data may give rise to hypotheses which can profitably be examined against other classes of information or perhaps stimulate new ways of looking at them and vice versa. It is, of course, essential that integrated analysis of this type be moderated by a scrupulous regard for the dangers of circular argument. However, these dangers are more likely to be avoided by communication between specialists than by work in isolation.

3.2 Sampling and retrieval

The usefulness of faunal data for all but the crudest questions is fundamentally weakened by inadequate sampling and retrieval methods. This is especially so with the small material: small bones and fragments of the large animals and bones of small animals such as birds, fish, and rodents. It is demonstrably the case that dry-sieving, and preferably wet-sieving, in many cases dramatically increases both quantity and quality of the excavated sample. Sieving is admittedly labour-intensive and time-consuming. But the worst effects of this can be mitigated by adequate advance planning, and by a careful programme of on-site sampling which can be adjusted to suit the nature and richness of the material in different archaeological contexts. However, it is vital that the fauna1 specialist be involved on-site in such a sampling programme, and that excavation be planned as far as possible to meet the needs of sieving.

Handling and treatment of material in the trench and the sieve is another area where on-the-spot specialist advice is desirable and sometimes crucial. The regrettably all too common occurrences of multiple fresh breaks, abrasion of diagnostic surfaces, and the numerous examples of isolated teeth which clearly belonged together in a complete mandible until they were broken apart by carelessness or ignorance in digging, are cases in point. The involvement of the fauna1 specialist on-site in the excavation and *in situ* consolidation would avoid such loss of information.

A simple but easily overlooked aspect of retrieval is adequate packing. Bones should not be jammed together in large numbers in large bags. Fragile bones, especially jaws, should be bagged separately. Bags should then be immobilized in not-too-large boxes of standard size.

3.3 Post-excavation planning

The Cunliffe Report has recommended that when excavation ends a post-excavation research design should be agreed upon. Such discussions will almost invariably result in the saving of time; for example it may be agreed at this stage that finds from a particular context are too mixed to warrant detailed analysis, or that resources should be concentrated on particular areas of a site, or on particular types of information. At this stage the questions that the research will aim to answer may be formulated, and the form that publication is to take agreed upon.

3.4 Recording

It is highly advantageous if the excavator, in consultation with the specialist personnel, works out a system of recording stratigraphic provenance which combines clarity, simplicity, and consistency with minimal ambiguity or redundancy. This is especially important in fauna1 studies, where it is often desirable to separate individual specimens from the 'bag' in which they have been grouped by the excavator or sieve operator, so that they can be regrouped with specimens of similar type. This means that large numbers of specimens, amounting to many thousands or tens of thousands, have to be individually marked with a code which indicates their full provenance. Badly designed recording systems can easily double or treble the labour involved.

Small amounts of fauna1 data can conveniently be recorded on record sheets or edge-punched cards, but, with large quantities, computerization is often regarded as desirable, and certainly some careful thought should be given to the use of microcomputers and to the design of data sheets and systems of coding information which will facilitate the transfer of fauna1 data to computerized form if required. Computerization has very considerable advantages: it speeds up basic sorting, tabulation, and analytical procedures, and it stores information in a permanent, systematic, accessible, and easily reproducible manner. In designing computer systems, it is essential that software is provided which will allow the sorting, selection, and analysis (metrical, distributional, and spatial) of the relevant data. The desirability of computerization in standardized form should be tempered by the needs and problems posed by each particular fauna1 analysis. Otherwise there may be a tendency to lose sight of the purposes of the fauna1 analysis, and the problems it is intended to solve, in the interests of systematization. Several different systems of computer coding have already been devised and put to use. While there might be some merit in combining the best of these different approaches, it is questionable whether the imposition of a single standardized system is desirable, since this could lead to loss of flexibility, to the collection of large quantities of irrelevant observations, and to the neglect of other types of information. If standardized systems of computerization are advocated, they should be made widely available and be backed up by the necessary software. The use of computer tapes and discs to store data in archival form should allow for the reproduction of back-up copies to guard against accidental loss.

3.5 Publication

Each fauna1 report should contain all the information - anatomical, zoological, economic, environmental, spatial, and social - that the fauna1 remains can be made to furnish, with full details of the methods employed. This requires the reproduction of a body of fairly standardized data as the essential basis for all interpretative work on that site and for any inter-site comparisons. Ideally all these data should be included in the final publication. But in cases where there are so many that the publication becomes impossibly expensive and unwieldy, they can instead be published as appendices in microfiche form, or kept in well-organized archives from which information can be quickly and cheaply retrieved. If this is done the final publication should contain summaries of the fauna1 data.

Interpretation is equally essential and involves the detailed statistical analysis of the fauna1 data within the context of the site as a whole, of its other contents, and of its surroundings. It should be seen in relation to previously published work and current research interests.

Cooperation with other specialists and the excavation director is essential at all stages, and all involved should be aware that demarcation disputes can arise over who publishes what if general guidelines are not discussed and agreed in advance. Other points that need discussion and agreement are the general time limits on final publication of the site report and the degree of freedom that the faunal specialist should have to publish independently. Publication of major analyses has sometimes been held up for many years, for example by a lack of information on stratigraphy and phasing, or by delay in the production of other information, to the professional detriment of the specialist. These problems should be recognized in advance by all concerned, and are easier to overcome if there is communication and cooperation from the earliest stages of an excavation.

3.6 Curation and storage

Faunal material needs to be labelled, packaged, and stored in such a way that it will be easily available to other researchers in both the immediate and the more distant future. The final resting place of the material, and the responsibility for the final packing, labelling, and transport, should be determined in advance. Decisions about the way in which it is to be sorted (eg in contextual units or by species) prior to storage will need to be made in consultation with the specialist after the primary research has been concluded. It is desirable that the faunal specialist involved in excavation should have exclusive access to the material whilst work is in progress. However, it is essential that the time which this takes is kept to a minimum, and that the collections be made available as soon as possible in a readily accessible form for other interested researchers. The actual length of time should be agreed by all the specialists involved, but should not be extended by such factors as delays in publication.

4 Funding

The funding of archaeozoological research falls into two distinct categories of equal importance: financial support for basic research of the types outlined in sections 1 and 2; and financial support that makes possible adequate analysis of faunal material from archaeological sites as described in section 3.

4.1 Funding basic research

At present most basic archaeozoological research in this country is carried out within the academic framework of universities, financed either by the universities themselves or by government or other outside institutions, such as the Science and Engineering Research Council. This support is much appreciated and its continuation is vital.

It seems to us, however, that various bodies might with advantage consider widening their terms of reference to include historical aspects of their fields of interest. For example, the Natural Environment Research Council could legitimately involve itself in the study of the history and the prehistory of environmental change and of human influence on the environment, the Agricultural Research Council could involve itself in the history and development of animal husbandry in Britain, while the British Academy could recognize the importance of faunal remains as artefacts of early human behaviour, as it did when it supported the British Academy Early History of Agriculture Project.

Some basic archaeozoological research involves working with modern material and these aspects of research might be financed by organizations with relevant interests. Pathological studies, for example, fall within the scope of veterinary research, demographic studies of animal populations within the scope of research supported by the Natural Environment Research Council, and studies of calcified tissue and the interrelationships of animal and human pathology within the scope of medical research.

The Royal Society is pre-eminent in providing fellowships for scientific research and could well support archaeozoological research under this heading.

4.2 Funding archaeozoological reports

The simple fact that this aspect of archaeology costs money has been largely disregarded, except in those units which employ archaeozoologists. Excavation directors who call in faunal specialists at the post-excavation stage are often ignorant of the time and money required for a worthwhile study, and are consequently appalled by either the size of the final bill, or the delay in producing results, or both.

The following items need to be budgetted for (in terms of time and money):

1) The presence of a specialist on-site to supervise the excavation of bones and on-the-spot conservation, coding, and packaging, plus the cost of assistance for routine operations such as cleaning and labelling.

2) The sampling and collection of other faunal remains, for example modern comparative material if needed to resolve particular problems raised by the archaeological material.

3) Further conservation and curation of material and transport to the laboratory.

4) Study of the material in the laboratory. The basic requirement here is adequate space. The equipment is usually simple and cheap, except where microscopy is involved.

5) Recording all data either manually on record sheets or cards, or by typing into a computer. The latter is usually more efficiently done by microcomputer or a terminal, and may be aided by paying for expert assistance. The use of computers may be expensive unless the fauna1 specialist has access to institutional facilities.

6) Sorting the data into categories that are useful for analysis. This can be done manually, by the use of edge-punched cards, or by the computer, depending on the recording system employed.

7) Analysis of the various classes of data and comparison of the results with those from other relevant sites, using statistical testing methods whenever appropriate. This stage will probably involve library work as well.

8) Writing up the final report for publication. Additional expenses will be incurred in typing, drawing illustrations, photography, and the preparation of the data in archival form.

9) Curation, packing, and transport of material for final storage.

The responsibility for funding this aspect of archaeological work is clearly part and parcel of all the other excavation and post-excavation processes. It is clear that permission to excavate should be withheld and archaeological budgets should not be approved unless allowance has been made for the expenses of the archaeozoological work, whether the work is carried out under the auspices of national bodies, universities, local societies, or private individuals. A very major problem, although one which is common to most other classes of archaeological finds, is that the amount of fauna1 material is very difficult to predict in advance of excavation, so that the amount of financial support may have to be reassessed as the excavation proceeds. In general it is to be expected that all such finance ‘comes from the same source as the funding of the rest of the site work. However, in specific cases where large amounts of material are involved, some or all of this may be suitable for PhD dissertations, in which case money could alternatively be sought from bodies that finance academic research.

One aspect of archaeological work that we have stressed is the importance of the curation and accessible storage of fauna1 material from excavations. This too requires finance. When the sponsoring body is a large institution, the actual objects retrieved from excavation may simply enter its collections, but even here it is essential that curation and adequate storage are attended to. If the finds are to go elsewhere, for example into local or national museums, decisions have to be made at an early stage about who will take actual and financial responsibility for their curation and storage.

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7 Invertebrate zooarchaeology

K D Thomas

1 Basic research: new techniques and procedures

1.1 Diversifying the database

To date, most studies in invertebrate zooarchaeology have been on remains of molluscs, insects, and parasites, although other groups of animals are being recovered from archaeological contexts and archaeologically significant deposits. These include the remains of protozoa, coelenterates, bryozoa, crustacea (especially branchiopods, ostracods, isopods, and decapods), chilopods, diplopods, acarines, spiders, and echinoderms. All these can give valuable ecological, economic, or stratigraphic information. When they are studied at all this is usually done by museum- or university-based zoologists who have the relevant taxonomic expertise.

1.2 Taphonomy

Studies on the origin and differential preservation of assemblages of invertebrate animals are of fundamental importance to their interpretation. Even well-studied groups like the land snails and the insects present formidable problems. For land snails, there is a major problem in sorting out the degrees of mixing which have occurred in various assemblages and how such assemblages can be interpreted on various spatial and temporal scales. There is an urgent need for close collaboration between mollusc specialists and soil scientists to investigate the processes by which shells are incorporated into soils. The insects, too, present great problems of interpetation, especially assemblages from urban contexts. Preliminary work on these difficulties has shown the potential value of collecting and analysing assemblages in various modern catchments.

1.3 Sampling

The standardization of sampling techniques will only be possible when the fundamental problems of taphonomy have been sorted out. There is a great need for flexible sampling programmes to be designed at the outset of an excavation to allow for off-site as well as on-site sampling and to ensure that sampling strategies for the various specialist studies are as integrated as possible.

1.4 Identification

Correct identification of specimens is fundamental to all bioarchaeological investigations. This requires access to comprehensive collections of reliably-identified reference materials (preferably located where the work is based) and, in the case of small specimens (most invertebrates fall into this category), good quality microscopes. Ideally, all environmental laboratories should have access to a scanning electron microscope.

1.5 Quantitative studies

There is a need for a more rigorous approach to the quantification of assemblages and to the application of statistical techniques. Access to computer software is essential. Metrical analyses of size and growth patterns, especially in land and marine molluscs, are in their infancy, yet are showing their potential value both in palaeoecology and in palaeoeconomy.

1.6 Physical and chemical analyses

Advances in radiocarbon dating of small samples will mean that small snail shells and even insect cuticles will be datable. Oxygen-isotope studies on marine shells from middens may cast light on past temperatures as well as seasons of shellfish exploitation. Microprobe analysis of elements in shells might yield data on past environments (seawater conditions, soil type, plant foods available, etc).

1.7 Intra-site variation

There is a need to increase the diversity of samples from most sites to determine the spatial variations over the site. This is especially true of insect and parasite studies in urban sites. This will inevitably lead to the generation of more samples for analysis, with associated delays in production of results and increased costs.

2 Basic research: specific problems

2.1 Recognition of palaeobiocoenoses

Samples of soil or sediment contain numerous specimens of invertebrate animals not all of which are necessarily contemporary with one another or derived from the same once-living communities (ie biocoenoses). Taphonomic studies, involving experimental and other approaches (eg study of modern catchments) will give clues to how the muddle can be sorted out. Detailed analyses of the weathering and alteration of specimens might also help (eg use of SEM to examine weathering of shell surfaces; analysis of crystalline replacement in shells; measurements on remanent proteins; or radiocarbon determinations on single specimens).

2.2 Scales of interpretation

A major problem in palaeoenvironmental reconstruction using bioarchaeological remains is deciding what spatial scales are appropriate. Again, taphonomic studies should give us some clues. The integration of various lines of evidence, derived from both stenotopic organisms and those which are readily dispersed, as well as from the local context and soil/sediment data, should also prove fruitful. This will only be achieved if there is an adequate flow of data between specialists at all stages prior to the completion of final reports.

2.3 Ecological data

Ecological zoologists are not systematically collecting the modern autoecological and synecological data which are required by invertebrate zooarchaeologists in their interpretation of various groups. It is essential that zooarchaeologists be allowed time and facilities to collect such data.

2.4 Exploitation of invertebrates by man

Analysis of shell middens has been transformed in recent years by new techniques and approaches. There is still a need to move from simplistic questions, such as 'What was the importance of shellfish in the annual diet?' to those based on a more realistic analysis of subsistence systems, past exploitation strategies, disposal behaviour, use of ethnographic models of shellfish exploitation, determination of seasonal components of behaviour, etc.

2.5 Exploitation of man by invertebrates

This is a neglected area of human palaeoecology, even though we are aware of the huge impact that various groups have on man at the present time. More attention needs to be paid to the recovery of remains (parasites of man, his domesticated animals and his crop plants, disease vectors, pests of stored foods and structures, etc) and their integration into models of subsistence.

3 Research applications

3.1 Palaeoecology

Reconstruction of past environments should not be limited to the local and regional setting of sites but should include assessments of biotic resources, possible reasons for site location, likely environmental constraints, etc. This requires a full integration of evidence from invertebrate studies with all other sources of palaeoenvironmental data.

3.2 Palaeoeconomy

Aspects of this cannot be divorced from the ecological setting of the site(s). On-site data from invertebrates might indicate their use as food, the range of habitats exploited by past human groups - and particular ecological zones within broad habitats (eg particular inter-tidal zones of the seashore), seasonality of exploitation, problems such as parasites, disease, or pests, etc. Context-related analyses can yield information on spatial organization of sites. Higher levels of economic organization, such as trade, might be deduced from exotic species of invertebrates.

3.3 Stratigraphic interpretation

Some specimens of insects or molluscs might indicate disturbed deposits and possible mixing. Some species are known to have been introduced into Britain at certain times; their occurrence might be used to 'date' a deposit or to indicate later intrusions.

3.4 Dating

Recent work on land snails in southern England has shown the existence of a regular sequence of colonization during the Flandrian; these mollusc biozones might form the basis for a generalized local scheme for dating. As mentioned above (1.6), advances in radiocarbon dating may enable individual shells or insect exoskeletons to be dated.

3.5 Contribution to other disciplines

Invertebrate zooarchaeology is also making distinctive contributions to other areas of scholarship, *inter alia* historical ecology, animal ecology, zoogeography, Pleistocene and Holocene biology, population genetics, evolution.

4 Organization and funding

4.1 Personnel

There are only two entomologists employed on a full-time basis in public sector archaeology as well as one specialist who combines a good knowledge of insects with specialisms in land snails and waterlogged seeds. There are no public sector environmentalists who devote their whole time to the analysis of molluscs from archaeological sites. There is one public sector worker who devotes part of his time to the analysis of parasites from archaeological sites. There is a need for more workers and a better career structure for those already employed. Training facilities are available in a few university departments of environmental archaeology. There is a great need for such training: few departments of zoology or biology are producing graduates with a good knowledge of animal systematics, while no departments of archaeology can turn out graduates equipped with the necessary biological skills.

4.2 Sampling and retrieval

4.3 Recording and computerization

4.4 Curation and storage

The general comments made in sections 4.2–4.4 in the preceding chapter on vertebrate remains apply with equal force to the analysis of invertebrate material.

4.5 Reference material

There are various problems here:

a) The need for at least adequate reference collections with reliably-identified specimens and preferably ranges of specimens for each species.

b) The provision of space, storage facilities, curation, and maintenance for such collections.

c) The conservation of existing species in our fauna. The status of most species of invertebrate animals is poorly known compared with the vertebrates and indiscriminate collecting to create reference collection could do great harm.

d) Certainly for the rarer species and for the 'minor' groups (see section 1.l), few environmental laboratories can justify the 'convenience' of holding reference collections. For these groups, visits to museums or collections in university departments will have to be made.

Collaboration over, or exploitation of, existing museum collections should be encouraged; it will keep the environmental specialist in contact with other workers on invertebrate groups, and help keep the correct usage of zoological nomenclature up-to-date.

4.6 Publication

Invertebrate zooarchaeological reports are unfortunately usually relegated to appendices of the 'main' archaeological report and the results are rarely integrated with other reports. Standardization of data collection and presentation is desirable up to a point; we must beware of forcing the specialist into an intellectual straight-jacket which suppresses originality of analysis and interpretation.

4.7 Funding

There is a fundamental need to create more posts in public archaeology for specialists in invertebrate zooarchaeology. Existing workers are overburdened with a backlog of material. The use of specialists in the universities is to be encouraged, although there are problems of integration when a geologist or systematic zoologist is contracted to do work without having any idea of the aims and methods of archaeology. Funding should include proper provision for on-site and post-excavation work, for the analysis, storage, and curation of material, and for data processing, drawing, photography, and typing of interim and final reports.

8 Human remains

S W Hillson

Human remains are a valuable archaeological resource. They represent the closest approach that can be made to people living in the past - a record of the biological effects of society and environment as they impinged on man. Extensive research continues on the anthropology, pathology, forensic science, anatomy, biochemistry, and physiology of modern human populations. This opens new avenues for research in ancient material.

1 Basic research

The investigation of human material involves many disciplines, but a number of areas of particular interest can be defined. Most apply to hard skeletal tissues. Finds with good preservation of soft tissues are rare, and must be treated as special cases.

1.1 Preservation and sampling

Processes of preservation must be understood if archaeological collections of human material are to be interpreted biologically and comparisons made between sites and with living populations. The early stages are quite well understood from modern forensic studies. Little is known, however, about preservation of hard and soft tissues over a longer period. The role of soil processes, the form of skeletal material and other elements present, the type of burial, all need investigation. Post-mortem changes have been noted in the histology of archaeological tissues, but have been little studied. The mineralogy of archaeological bones, dentine, enamel, and cementurn, and the preservation of their organic components, are still little known. Chemical and physical analysis could be very usefully applied. The archaeological and biological interpretation of collections of human material as samples of once living populations requires further consideration. Where statistical approaches are being applied, the effects of bias in burial and differential preservation and recovery must be taken into account.

1.2 Biochemisty

Some organic residues do survive in skeletal tissues from archaeological sites. Analysis of this material may yield information on biological variation and physiology. Amino acid residues, for example, may yield data on variation. Collagen, the most resistent protein, is also the least variable. But other proteins may leave behind amino acid residues that are more useful. Enamel protein, for example, seems to persist in archaeological material and is a potential source of such information. It also seems possible to investigate immunochemical factors such as blood groups in archaeological bone. Modern forensic techniques might uncover a variety of such factors. These are used extensively in studies of biological variation in living populations. In addition, a variety of trace elements occurs in bone. Analysis of elements such as strontium may yield information on diet. Much further work needs doing on the physiological basis of trace elements and their persistence in buried bone.

1.3 Determination of age and sex

Reliable determination of age at death and sex is a basic requirement. A relatively large number of techniques is available for human skeletal material, but there is still scope for further development. A variety of methods based on the histology of hard tissues needs investigating. Growth of tissues such as enamel and dentine may provide accurate methods for ageing young individuals, or at least a calibration for dental eruption as an ageing technique. Tissue turnover may give rise to other methods, such as the development of osteones in bone. Age-related dental tissue deposition may yield other histological methods for adult individuals - layered deposition of cementurn, secondary dentine apposition, progressive translucency of root dentine. These methods have been demonstrated in modern material, but have yet to be applied widely in archaeology. Dental attrition is a long-recognized ageing method, but much further work is needed on methods for calibrating it. Age determination in adults is one of the most difficult areas. Sex determination is by contrast more difficult in juveniles. Dental measurements appear to have considerable potential for helping with this problem.

I.4 Growth and development

There is a wealth of information on the biology of growth in living human populations. Growth is often used as an index of diet and hygiene. It may be of great value in assessing the way of life of ancient populations. Relatively accurate ageing methods for juveniles allow the dimensions of the bony skeleton to be plotted against age, in a 'cross-sectional' study of growth. It should be possible to compare growth in archaeological collections with radiographic data from living populations. The histology of bone could provide detailed information on tissue turnover, growth, and remodelling. The histology of dental tissues yields information on growth, and disturbances in growth, throughout childhood and into adolescence. Dental eruption is also part of growth and is well studied in living man. The histological techniques might be used to compare eruption rate and sequence in archaeological material.

1.5 Size and shape

The morphology of the adult skeleton has been studied for many years in archaeology. Cranial morphology, in particular, seems to offer possibilities for assessing biological variation and relationships. A standard set of measurements has long been available and statistical methods for comparing individuals and collections are also well established. Further work is, however, needed on methods for describing the complexities of skeletal form mathematically. Particular problems arise with fragmentary archaeological material. Measurements and statistics must cope with elements missing from individual skulls. Some features of the skeleton are not measureable, but manifest themselves only as present or absent. The possibilities of such non-metrical variation in the dentition and in the skeleton have still to be fully investigated. For all these studies, further research is needed on the interpretation of such skeletal variation in terms of the biological relationships of once living populations.

1.6 Palaeopathology

Recent studies of pathology in man have emphasized disease as a biological process. A wide variety of conditions has long been recognized in archaeological skeletal material, but now it is possible to interpret some of them in terms of population biology. Much research still needs to be done, in the absence of soft tissues, on the diagnosis of bony pathologies. One particular skeletal manifestation may have any number of possible causes. For many diseases, evidence appears so rarely in the archaeological record that a study of past epidemiology is not really feasible. Other diseases are so common that they provide a good basis for palaeoepidemiological study. A number of such studies has been done already, but there is still much room for research. Joint disease may yield information on the impact of society and environment. Dental diseases, particularly those related to the plaque deposits which form on teeth during life, can provide some information on the composition of ancient diets. The pattern of injuries to the skeleton yields information on environmental hazards. In addition, there are several common but unexplained anomalies of the skeleton which require investigation.

2 Research applications

Basic identification of age and sex, measurement of skeletal form, and description of pathological conditions are now routinely carried out for human skeletons from archaeological sites. Research into techniques is likely to improve the quality of this information. Archaeologists will benefit from research into the ageing of fragmentary material, determination of sex in younger individuals, high precision ageing of juveniles, more reliable ageing of older individuals, and more accurate diagnosis of disease.

Archaeology should, however, be asking for more than this. Human material can provide answers about communities and populations - biology, demography, family relationships, genetic similarities and differences that might help trace the movements of peoples, diet, hygiene, and health. For statistical validity in these types of study, it is important to examine large collections of skeletons. There are large groups of material preserved in museums and universities. Many of them have not been studied in detail for many years. Excavations still produce considerable quantities of human material. Such collections are not only of great interest in themselves, but they can also be used to build up a large body of comparative data. This would be of importance in interpreting new finds and would allow the rather sparse collections typical of many excavations to provide more than just basic identifications and descriptions.

3 Organization and funding

Studies of newly-excavated human skeletons are subject to a problem not usually encountered in research on other mammals: human skeletons must be reburied after study. This means that, like excavation, examination of human bone collections tends to be a once-and-for-all affair. When a large collection of skeletons is recovered then a considerable research team must be assembled to study it adequately. This places demands on funding and organization.

If such demands and the constant demands of smaller collections are to be met, then it is essential that the background work has been done. Development of techniques and recording systems, planning for future needs, the assembling of comparative material, and thestandardization of procedures for examination and recording are all urgently required. Studies of human material involve many disciplines. Work ranges from research in specialist (not necessarily archaeological) areas to routine compilation of reports for excavators. It would be better if all this research effort were coordinated. A standing committee could maintain contact between different areas of research, and with other areas of archaeology. It could liaise with other organizations and could act as a recognized channel for contact and advice on human material. Additional roles for such a committee could be the definition of standards for reports and the holding of an archive of reference information. It might also help to coordinate the rapid research effort needed when large new collections are excavated.

Funding for reports on newly-excavated material has come from the Department of the Environment and now from HBMC, but much work is done on a voluntary, unpaid basis. This often causes reports to be written in isolation and does not make best use of resources, either in working material or researchers' time. Funding for a number of related specialist projects has come from the Science and Engineering Research Council. The Science-Based Archaeology Committee of the SERC lists biology of human populations as one of the 'main themes of research' in its notes of guidance for applicants. Occasional funding for projects involving archaeological human material has come from the Medical Research Council.

Funding is needed for training of new personnel, and for basic research into techniques. There are many exciting projects which could be carried out on existing museum collections. It is important to fund work aimed at establishing reference material and standardizing procedures. Consideration also needs to be given to the coordination of funding for routine reports and to the urgent demands of newly-excavated large collections.

4 Methodology

It is difficult to define standards in a developing subject, but some would prove useful, particularly in the preparation of reports on individual sites. Research on techniques could lead to standards in a number of areas.

4.1 Recovery procedure

Standard requirements for the recovery of skeletons during excavation would make studies and reports more comparable. These procedures could include the recording of data on soil chemistry, and the collection of samples to aid studies of preservation.

4.2 Age and sex determination

Basic standards in techniques and presentation of results would allow direct comparisons and could make the degree of precision clearer.

4.3 Palaeopathology recording

Different studies have used a wide variety of methods for recording the presence and severity of pathological conditions. A standard could be designed to allow comparison with epidemiological data from living populations.

4.4 Size and shape

Standards of measurement have long been available, but in practice only a few are used in any one study. A reduced group of measurements could be defined as a minimum requirement. It might also be possible to define a minimum list of non-metrical variants.

Standards like these would allow a centralized archive to be maintained. Routine reports would become more generally useful and easier to interpret.

9 Archaeometallurgy

E Slater

The routine examination of archaeological metalwork and metalworking debris is so well established that it might appear that the development of new research priorities is not of vital importance. However, the long history of archaeological interest in metallurgy has ultimately been to the detriment of current archaeometallurgical research. There has been a perpetuation of certain lines of approach and little opportunity to refocus objectives, or even to consider the purpose of some of the work. The guidelines were originally established at a time when the use of metals was thought to follow a logical sequence involving the discovery and dissemination of new materials and techniques, with each innovation marking a major technical advance. Thus two strands of research emerged - the analysis of early copper-based material to chart chronological developments in alloying and the experimental work on smelting and casting. Additionally, change was seen as a more important element than the consolidation of established techniques or materials. Thus there are thousands of analyses relating to Bronze Age artefacts but few non-ferrous objects of the Iron Age and later periods have been analysed. Also the excavation of Iron Age furnaces and experimental work on bloomery iron production have been seen as priorities, but there has only been a limited examination of Dark Age material. The picture of prehistoric and early historic metallurgy that has emerged is very fragmented, with intensive work in some areas but neglect in others. Thus several new avenues for research remain, but full potential will only be realized if there is a corresponding reappraisal of the philosophy underlying archaeometallurgical research. The assumption made here is that the scientific examination of metalwork and metalworking debris is directed towards the investigation of the raw materials used, the manufacturing techniques employed, the location of metalworking centres, and the patterns of distribution and discard of the products; but this is only the primary stage. It may be sufficient to answer specific site-oriented questions, but there are many other archaeological problems such as the way the material world was perceived and exploited, the general level of technology pertaining at any particular period, the standardization and conservation of techniques, and the mechanisms involved in the origination and transference of ideas and concepts. One of the major limitations in archaeometallurgical work is that the primary collection of data has often been seen as an end in itself, with the description of an object given priority over its interpretation. Therefore, whilst the research priorities listed below are concerned with scientific problems, their implementation should not be divorced from the archaeological framework.

1 Basic research

There is some overlap between sections 1 and 2 but the topics in this section relate to the collection of fundamental data that could form a background for several research projects.

1.1 Raw materials

No ore extraction sites in the United Kingdom have yet been dated unequivocally to the pre-Roman period, and most of the Roman workings are concerned with the extraction of gold, lead, and iron. There is one tin smelting furnace tentatively dated to the 2nd century BC, but no Bronze Age smelting furnaces. The situation is little better for the later periods and, in general, there is a paucity of direct information about the sources of raw material used for the production of copper, tin, lead, silver, gold, brass, and pewter. There is far more documentation available for iron smelting sites of the Iron Age and later periods, and many of them are located in areas which would allow the use of local ores, but the problem remains of linking artefacts to these production centres and those that remain undiscovered. Most hypotheses on the use of specific ore sources and the scale and organization of the metalworking industries are based on distribution patterns of artefacts. Two other sources of information are available - the composition of the metal and the distribution of moulds -but these are mainly restricted to the copper-based metals. One vital piece of comparative data is missing - the location and composition of possible ore sources. The distribution of ore bodies in Britain is documented in the Geological Survey reports, but the assessment of their importance and economic potential is based solely on modern criteria. Therefore, the main requirements are:

a) Detailed fieldwork to record major ore outcrops and to eliminate very mixed, low yield, or inaccessible deposits.

b) The collection of ore samples for mineralogical, chemical, and isotropic analysis.

c) A survey of historical records which refer to the control, lease, and exploitation of ore deposits.

Gold and tin were probably extracted from placer deposits, and it would seem inevitable that most tin came from south-west England, but there are sufficient analyses of goldwork available to suggest that a similar survey of gold placer deposits in Scotland, Wales, and Cornwall could prove fruitful.

Although all ore deposits are very inhomogeneous, ore analyses are essential to determine the minerals present and the potential yield of the ores. They might also provide information on the presence of particular diagnostic elements that could be useful in a comparison with artefact analyses, although further work on the partitioning of elements during smelting might also be needed. However, the single most important development would be lead isotope analysis applied to suitable ores (section 2.1).

1.2 Non-ferrous smelting

Since there is so little direct evidence for the methods used to smelt non-ferrous ores, the techniques described in the literature have been based mainly on a knowledge of the conditions required for smelting, the information provided by the medieval treatises, and an assumption that the furnaces would have been similar to those used for iron smelting or based on the same design as those excavated abroad. Thus, it is suggested that bowl or shaft furnaces were used and the LBA bun ingots, for instance, have been interpreted as the blocks of metal that collected at the base of the bowl furnace. However, before these hypotheses can be accepted and the lack of smelting sites dismissed as a product of excavation strategy, there needs to be far more experimental work on small-scale extraction processes such as crucible smelting, and the investigation of the ceramic debris that this would produce.

1.3 Characteristics of iron

Since it has been assumed that there is little possibility that the chemical composition of iron objects could be a reflection of the type of ore used, few iron objects of any period have been analysed. One suggestion now being made is that the slag inclusions in iron could prove diagnostic. Therefore, the experimental work on the partitioning of elements in iron smelting and smithing slags needs to be extended to investigate the character of slag inclusions in iron and the effects of working on their composition and distribution.

1.4 The effects of working on non-ferrous metals

An appreciation of the degree of segregation shown by the different elements in non-ferrous metals is important in the interpretation of chemical analyses (section 4.1). The experimental work on coins, involving the investigation of the effects of production and burial on the surface composition of a coin, is a prime example of the work that needs to be done on all types of metal alloys. There is some information already available on the segregation of specific elements, so the main requirement is an integrated experimental programme to examine the effect of the variables involved in casting, working, use, etc on the distribution of those elements whose concentration is measured during routine chemical analysis. This would involve metallographic analysis and therefore provide a collection of representative microstructures, and the experiments in cold and hot working would indicate the degree of stress that a particular alloy can withstand. Much of the information on the physical properties of metal alloys comes from measurements relating to modern industrial practice where the conditions and composition of the metal may not be strictly comparable to historical examples.

2 Research applications

2.1 Lead isotope analysis

The single most significant recent development in the analysis of archaeological metalwork has been the application of lead isotope analysis. This is used to source lead via a comparison of the isotopic composition of an object and potential ore sources. The isotopic ratio in an ore is influenced by its geological age and, whilst many lead ores in Britain are of a similar age, there is sufficient evidence to suggest that there may be differences in isotopic ratios between the major source regions. This technique is not restricted to metallic lead because copper, tin, and zinc ores often contain small quantities of lead that can be carried over into the final metal. If lead isotope analysis could be shown to be discriminatory for the British material this would open up a large number of research projects, including the sourcing of lead in

a) copper-based metalwork where lead is a minor component or a deliberate alloying ingredient

b) pewter

c) silver objects or bullion produced through the cupellation of lead ores

d) lead-tin solders

e) lead objects and ingots of all periods

One obvious limitation is the possibility of admixtures of lead from different sources, and lead isotope analysis might be less effective in addressing problems such as the reuse of Roman silver.

2.2 Cupellation

Most silver used in the past is likely to have been produced through the cupellation of lead. There are examples of cupellation furnaces in Britain from the Roman period onwards, but there is no clear indication of the yield that might be expected. One of the problems is the variation of silver content through an ore deposit but a combination of isotopic analysis, the analysis of ore bodies, and experimental cupellation might give a far better indication of the potential scale of silver production than the estimates currently available.

2.3 Heat treatment of iron artefacts

The microstructure shown by iron objects is very sensitive to change in chemical composition and methods of manufacture, and the use of techniques such as quenching, carburization, pattern welding, hammer welding, etc is clearly reflected in a metallographic section. Unfortunately, few British objects of any period have been subject to metallographic analysis and a routine programme of examination is needed. The importance of this lies not just in identifying the manufacturing techniques used but in indicating the degree of control and knowledge involved, for instance by showing whether a particular technique was restricted to specific types of object or whether the composition of the metal was deliberately modified to produce a particular effect.

2.4 Analysis of post-Bronze Age non-ferrous material

There is controversy on the advisability of continuing analytical programmes involving copper-based material. The crucial question is the purpose of the work. In some cases where the ultimate aim is to identify the source of the metal, there has not been sufficient preliminary research into the size of the database needed, the selection of objects for analysis, the elements that might prove diagnostic, or the statistical treatment to be applied to the results. Other programmes have been more successful, particularly those with the more limited aim of charting any major chronological or geographical variations in the composition of a particular alloy. Such programmes could usefully be extended to cover the analysis of bronze, brass, gold, silver, and pewter objects of the post-Bronze Age periods - but only if there is a specific historical problem involved such as the origin of Viking Age silver or the decline in Continental imports of brass.

The problems involved in the collection and interpretation of minor and trace element contents in non-ferrous metalwork are well known and much discussed and they should at least be considered, in concert with the purpose of the work, before any detailed analytical programme is devised.

3 Organization and funding

The whole question of using historical records, from the ecclesiastical and civil rolls through to the medieval scientific treatises, forms part of a far greater requirement - the recognition that much archaeometallurgical research should be a collaborative enterprise involving archaeologists, historians, economists, anthropologists, geologists, metallurgists, ceramicists, and other scientists. This is an oft repeated cry, and one that appears to attract general support, but the methods of funding do little to promote it. Most research funding is directed towards two main areas - the post-excavation examination of material from a single site and the development of new scientific techniques. The application of those techniques in integrated research programmes is less well favoured.

However, attitude can be an even greater obstacle than lack of finance. There are still excavation reports where the structural ceramics, slags, moulds, crucibles, metal artefacts, and debris are all described independently without any recognition that they all represent facets of metallurgy, let alone that this is only one of a series of interrelated pyrotechnological processes; the firing temperature of the pottery or the use of a haematite slip can be as informative about the metallurgical processes represented on the site as the metallurgical debris itself. Few areas of technological research will reach their full potential unless this interdependence is recognized.

4 Methodology and procedures

4.1 Analysis

A very wide variety of analysis techniques has been used for the chemical analysis of metalwork, including optical emission spectroscopy, neutron activation analysis, X-ray fluorescence, atomic absorption spectrophotometry, and microprobe analysis: new methods such as PIXE and PIGME will doubtless soon be added. It is unlikely that there will ever be standardization on one particular technique, and this would not necessarily be advantageous, but the use of older methods like OES should be discouraged. One of the major problems involved in the analysis of metals is their inhomogeneity. This means that there are difficulties in assessing the comparability of analyses produced using different methods - no block of material of completely uniform composition has yet been produced to act as a standard equivalent to the US Geological Survey standard rocks - and in determining how representative the sample being analysed is of the bulk material. This will become an increasing problem as analytical techniques are developed to operate on smaller and smaller samples. The current variations in sampling strategy hinge on the interpretation of analytical data. The composition of a metal is a product of so many factors that many would argue that the significance of a whole string of trace element contents cannot currently be appreciated. Therefore, they would consider it sufficient to remove samples by drilling because the aggregate analysis of the powdered drillings would give a reasonable estimate of the composition of the major elements. However, all the structural evidence would be lost and another sample would have to be taken to investigate surface segregation, the distribution of trace elements, etc if they were eventually seen to be important.

One possible change would be the requirement that all analysis samples should be removed as complete sections where practicable. They could then be examined metallographically and by microprobe analysis before the analysis of a portion of the sample, and the rest could be retained for future work or replaced in the object. Where such sampling would cause too much damage, routine screening could be conducted using surface analysis techniques or the whole object analysed by neutron activation analysis. This is only one suggestion and it is unlikely that there will be universal agreement on one particular strategy. However, it is vital that a forum is established to promote discussion of the whole question of metal analysis, including standardization on the range of elements whose concentrations should be measured and the development of a programme to assess the comparability of analyses using different methods.

4.2 Databank

There are many thousands of analyses relating to British material scattered throughout a whole range of literature. These need to be brought together into a single computerized databank in a form that would allow them to be sorted into fields such as period, type of material, elements analysed, analysis methods, date of analysis, standards used, bibliographic source, etc. It is recognized that this would involve considerable expenditure of time and money, plus a commitment to continual updating, but it would be an enormous benefit for a whole range of research projects and would identify those areas which require further research effort.

10 Ceramic analysis

Ian Freestone

1 Introduction

Many techniques are now available which allow the detailed physical and chemical characterization of ceramic artefacts. Given a suitable archaeological sample it is now possible to determine many aspects of technology, provenance, and, in some cases, use. For many purposes the nature of the sample is perhaps the most important constraint, particularly if it is recognized that the sample required often includes comparative ceramics and ceramic raw materials.

In this report attention is focused on those areas of research that it is thought will improve the quality and/or quantity of information extractable from a ceramic assemblage and those that will make this information easier to obtain. The paramount criterion against which a *priority* is determined is a continuing need felt by those working in the field for the results of such a piece of research.

The need is also recognized for strategic research in certain areas which will build up a foundation of information and understanding upon which later investigations may draw. No major breakthroughs in instrumentation or theory are anticipated. Finally, no attempt is made to delineate cultural, chronological, or geographical affinities of material which should be studied.

2 Ceramic technology

2.1 Forming techniques

Dispersed evidence in the literature indicates that thin-section, X-radiographic, and xeroradiographic techniques are useful in determining construction methods. There is a need for a comprehensive and systematic comparative study of these approaches on a range of materials for a range of construction methods. A major aim of the study should be the production of high-quality standard photomicrographs and radiographs that could be used as a starting point by other workers.

2.2 Physical properties

In order to understand the reasons behind the potter's choice of clay, type and quantity of temper, firing temperature and time, etc, it is desirable to understand the effects of these parameters on the working and firing properties of the clays and the physical properties of the resulting ceramics. These investigations are likely to involve comprehensive and systematic programmes of laboratory replication as well as testing of ethnographic material. The integration of the experience and the empirical and tacit knowledge of modern potters producing traditional pottery will be particularly valuable.

3 Provenance

3.1 Elemental analysis

There is a need for a well-characterized universal analytical standard or set of standards for early ceramics, which in particular contains the full range of trace elements in the quantities likely to be present in the unknowns. There have been suggestions of this kind for some years but a problem has been the production of the standard(s) for distribution. It would facilitate matters if agreement could be reached to use some pre-existing standard material. For example, the National Bureau of Standards (USA) produces homogenized standard clays, as do the British Chemical Standards (UK). At present there is confusion: some laboratories use standard clays or rocks, and some do not (thereby isolating their database to being 'in-house' only), but there is no agreement about standards and individual laboratories make informal contacts and exchange of standards to meet specific needs. The adoption of a universal standard would make interlaboratory comparison of elemental provenance data considerably easier than it is at present and would encourage laboratories undertaking analytical work to produce data of a quality to be interchangeable with others. The result would be to facilitate and encourage studies of ceramic exchange over long distances, particularly on an international scale where it may be difficult, or expensive, to obtain samples for comparative purposes.

3.2 Petrographical analysis

At present, petrographical descriptions of ceramic thin-sections concentrate on the nature of the aplastic silicate mineral inclusions. In fact, a large amount of the information contained within the thin-section is ignored. This information includes the nature of the ceramic matrix and of the coarser clay and iron oxide-rich particles that it contains. This situation has arisen because ceramic petrography, which has evolved from the study of rocks, has no formal terminology to describe the observable characteristics of the matrix. The development of such a terminology, analogous to that which has been developed in soil microscopy, will greatly improve the discriminatory power of thin-section analysis. Furthermore it will improve the quality of petrographical descriptions, rendering the information therein more accessible to other workers.

A related problem is the origin of the inclusions in ceramics. At present the criteria to determine if inclusions are intrinsic to a clay, were deliberately mixed with the clay, represent crushed rock or weather disaggregated material are *ad hoc*. Similarly the boundaries between crushed fired sherd (grog), mudstone, and unfired clay particles are often poorly defined. These problems again reflect the derivative nature of thin-section analysis and a failure to develop a truly ceramic petrography. Well-structured experimental studies are required to solve these and other related problems.

3.3 Scanning electron microscopy

The scanning electron microscope has proved an invaluable tool in the study of ceramic technology. Recent developments suggest that it also has a potentially useful role in provenance investigations. Recent work on mudrocks by sedimentary petrologists has shown that back-scattered electron images in the SEM yeild considerable information on the mineralogy and petrology of fine-grained sediments. The usefulness of this approach in characterizing and discrimating between groups of ceramics, particularly those which have a low degree of vitrification, should be investigated. It may be possible to relate the clay mineralogies of the sherds to those of the major stratigraphic clay types. The methods may prove particularly useful in areas where inclusions are not source-diagnostic (ie quartz, flint, shell, etc).

A particularly useful aspect of the SEM may prove to be the automated image analysis facilities which are now becoming widely available. These will allow quantification of relative proportions and size and shape of phases and particles in an SEM image. Quantitative characterization of both the inclusions and the ceramic matrix is potentially attainable, and should greatly extend the application and the power of so-called 'textural analysis' of ceramics. In principle, similar automatic image analysis techniques could be applied to the polarized light microscopy of thin-sections. However, there are technical difficulties to be overcome (variable thickness of sections, distinguishing quartz and pores) before success can be expected.

3.4 Thin-section database

A substantial body of ceramic thin-sections (probably in the region of 10-20,000) relevant to archaeological work is held by various institutions and individuals in the UK. Given the relatively destructive nature of thin-section analysis, universal concern has been expressed about the accessibility of the sections to future investigations. Parallels are drawn with the situation of stone axe thin-sections, where it appears that some important thin-sections can no longer be obtained for study. Suggestions to avoid such a situation developing in the ceramics field often involve the establishment of some form of centralized storage location, probably on a regional basis. It is significant, however, that the advocates of such a system are often associated with a potentially strong candidate for the location of such a regional storage centre. The requirements of institutions (museums) to hold thin-sections of their own material, and of individuals to hold their own reference collections while they are studying a particular group, suggests that such a scheme may be unworkable. A step in the right direction, however, would be the establishment of a centralized computer register of thin-sections and their locations. Given the numbers currently involved, such a scheme is attainable at the present time, but would require funding in the first instance to set up a system and to enter the backlog.

3.5 Raw material database

There is a need to build up a database on the regional chemical, mineralogical, and petrographical characteristics of clays pertinent to early ceramics. Given current economic restrictions, it is probably impracticable to fund projects for this purpose only. However, groups applying for funds for ceramic studies could be encouraged to include an element of such work, related to their area of interest, in their programmes. The long-term prospects for provenance studies would be greatly improved by full publication of data of this type. The incorporation of the results of simple workability, drying, and firing tests on the clays would extend the utility of the database to studies of technology and production and would be very desirable.

4 Environmental stability

Most areas of research into early ceramics, including provenance work, TL dating, and firing temperature determination, are dependent on the assumption that the chemical and phase compositions of the ceramics have not been subject to significant post-burial alteration. Few studies have been devised specifically to test this assumption. Moreover, the limited information available is contradictory and open to conflicting interpretations. While the evidence to date suggests that major sources of error from weathering are unlikely to be common, it may well affect the 'fine structure' of analytical data and it may be important in specific instances. Projects aimed specifically at investigating weathering phenomenon in ceramics are required to resolve these problems.

5 Computer and statistics-based approaches

5.1 Quantification of pottery assemblages

A problem specific to archaeological ceramics is that of defining and estimating the quantity of material present when much of it has been broken. Developments in methods for estimating vessel numbers or vessel weights from fragments are potentially of great practical benefit. In particular it would be useful to compare assemblages of fragmentary meterial. In this context the development is needed of the necessary statistical theory to enable confidence limits to be put on percentage breakdowns of an assemblage and to enable significance tests on inter-assemblage comparisons to be carried out.

5.2 Typological analysis

An area of research which spans not only data treatment but also data capture, storage, and retrieval is the analysis *of shape* by computer. Techniques for the quantitative comparison of the outline shapes of artefacts by prior reduction of the shape to a series of measurements of length, curvature, angle, and so on have been in use in archaeology for many years. Only with the advent of relatively cheap computers and peripherals for recording and reproducing outline drawings is attention beginning to be given to the possibilities of storing, manipulating, and reproducing *complete* artefact outlines. Although methods of some sophistication for handling such data have been developed in the fields of computer-aided engineering design and automatic pattern recognition, archaeological artefacts in general, and pottery in particular, present unique problems which will require the development of new methods. A number of related research topics can be suggested. One with considerable implications for the faster and more cost-effective publishing of excavation reports would relate to the generation by computer of two-dimensional and pseudo-three-dimensional pottery profiles in a form suitable for publication, and the fast on-line retrieval of such profiles from large databanks of pottery held on computer media. In the context of post-excavation finds processing, the reconstruction of complete or partial vessels using outline shape information from the (potentially huge) number of potsherds that may be recovered is an area that should be examined. An ambitious but potentially very rewarding area for research would involve an investigation of methods for translating an archaeologist's subjective assessment of shape similarity into a computerized system, in other words a 'learning' system. This could provide considerable insight into the aspects of shape which an archaeologist uses to discriminate between given classes of vessel - information he often finds it difficult to provide himself.

The long-term outcome of the trends mentioned above may be the collaboration of scientists with ceramic specialists to provide *expert systems* for non-specialist archaeologists. Expert systems are computer programs which have access to both data and expert knowledge and opinion culled from published work or entered directly into the 'knowledge-base' by a human expert. While they are in their infancy in the archaeological field, developments in other subject areas, such as medicine, are encouraging and at least one example has been successfully set up for ceramic research.

6 Concluding remarks

On the whole, the proposals made here relate to the refinement and consolidation of existing approaches to ceramic analysis. The intention is to improve our ability to answer the questions that a particular ceramic assemblage might pose. A number of productive, or potentially productive, investigative methods have not been mentioned because the basic groundwork for their application to archaeological materials has been carried out and more experience is needed in their application before appropriate areas for further development work, if any, can be identified. Heavy mineral analysis and textural analysis probably fall into this category. The examination of organic residues to determine the use of a vessel is an approach which is under-utilized at present but which can be expected to grow in importance.

The need to integrate fully the range of information now accessible with the main body of archaeological evidence is a continuing challenge. The close mutual understanding and cooperation between archaeologist and analyst, needed to select and execute a project which is both useful and has a high chance of a successful outcome, requires dogged persistence and the accumulation of considerable experience. Such difficulties could be circumvented if analyst and archaeologist were the same person. However, the present climate is such that it is in the individual's interest, in general, to remain either archaeologist or analyst, with only limited experience and expertise in the collaborative discipline. A major aim therefore must surely be to produce an infrastructure where such hybrids may develop and flourish. Funding is clearly a limitation to such developments in the late 1980s.

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Any report on research priorities will inevitably be a mixture of pious hope, ill-founded intuition, plagiarism, and personal prejudice. This paper is no exception. While retaining my responsibility for its contents, I would like to acknowledge my gratitude to those colleagues who constrained my wilder flights of fancy and in some cases made substantial contributions themselves: M Hughes, M Leese, P Main, A Middleton, M Tite, S Warren, L Biek, A Woods, J Evans, I Whitbread, P Nicholson, P Day, C Orton.

11 Lithic analysis

Patricia Phillips

Introduction

The main areas in which archaeological science has aided in the study of stone raw materials and artefacts are 1) dating, 2) provenance studies, 3) microwear studies, and 4) thermal effect studies.

1 Dating

Dating, particularly by thermoluminescence, of burnt stone tools and structural elements lies beyond the scope of this paper. However, such studies should be further developed and more widely applied, particularly where the sites involved are older than the current range of radiocarbon dating (c 40,000 BP).

2 Provenance studies

Studies incorporating information about the source of raw materials have been at the forefront of archaeological research and interpretation for the past twenty years. In the next decade, provenance studies can be expected both to follow on with proven methods, such as petrological thin-sectioning, X-ray fluorescence, X-ray diffraction, and neutron activation analysis, and to make increasing use of such techniques as scanning electron microscopy, electron microprobe analysis, and inductively coupled plasma spectroscopy.

2.1 Petrological analysis

Petrological thin-sectioning of fine to coarse-grained rocks (not flint) has been used for decades by the CBA Implement Petrology Survey to identify the sources of British polished and ground stone implements, principally axes and perforated tools. In the last decade this work has been intensified, especially in northern England and Scotland.

Thin-sectioning of flints and cherts has not been developed in Britain, but is being used at present in France to characterize the petrography and identify the palaeontological inclusions of flint and cortex, and to identify possible sources. If possible this technique, combined with scanning electron microscopy, should be further tested in Britain, since it avoids many of the costs and processes involved in physico-chemical analysis.

2.2 Elemental analysis

X-ray fluorescence and X-ray diffraction are standard and efficient techniques. The energy dispersive XRF system commonly used in archaeological science only identifies about seven trace elements, but this has proved sufficient in separating out such widely differing materials as west Mediterranean obsidian and British tuffs. Wavelength dispersive systems can analyse a much wider range of elements. Many of the Scottish greywackes and sub-greywackes should also be separable using XRF or XRD, which have been applied routinely in other parts of the world to this type of geological problem.

Atomic absorption spectroscopy has been used extensively in the past to separate out British, French, Belgian, and Dutch flint mine products from each other, but has still failed to discriminate between the South Downs mines. This technique involves dissolving the sample, a process which produces a solution containing the trace elements to be measured, as well as a sludge which may retain a small amount of those trace elements. Neutron activation analysis has been applied to the same types of flint, and has supported most of the findings, and analysed for some extra trace elements. NAA remains a valuable technique for obsidian analysis, especially in difficult areas such as the Near East. However, scientific opinion now favours the technique of inductively coupled plasma spectroscopy as the weapon of the future for flint analysis. ICPS is still relatively new in archaeological science, and has previously been applied to pottery and glass. There are still problems with its application (such as the dissolution process), and the resolution of these is a high priority. However, it has the advantage of analysing for a large number of elements, and it has recently been successful in separating out two of the South Downs mine products which previously defied separate identification. All elemental analyses of lithics require relatively large samples (larger than ceramics, for example) to overcome problems of sample inhomogeneity, especially as it affects flint.

3 Microwear

Microwear analysis of flint and other chipped stone is a highly important field of development for the future, with its potential for identifying human subsistence and craft activity in the past. Current subjects of study include explaining and measuring the phenomenon of microwear polish, and identifying polishes on different non-flint raw materials, such as obsidian and quartz. Until now, assemblages have been sampled to identify, for instance, the uses to which particular tool types had been put, or to find out the use-materials of stone tools associated with a particular structure like a hearth. A more holistic approach is developing, and more sophisticated questions should be addressed in the next decade.

3.1 Methodology

The presence of microwear polishes depends on a variety of conditions, both in their formation and preservation. There may be difficulties in recognizing the polish from a use-material under the microscope, owing to insufficient polish development and/or post-depositional surface modifications. Therefore, even in favourable circumstances of polish preservation, analysts also utilize other features, such as residues and microscopic striations, to identify the raw materials worked and the action of the tool user.

3.2 Scanning electron microscopy

The scanning electron microsope has been used to investigate wear formation processes; its high magnifications and greath depth of field can be used to advantage, in particular on small experimental pieces. Its microprobe attachment can be utilized to analyze residues. SEM work, already in wide use, can be expected to expand in the future.

The identification of plant and animal residues trapped in the moment of friction between tool and raw material is a growing and potentially invaluable area, with the possibility of identifying plants and trees down to at least family level. However, much work inevitably depends on the recognition of microscopic parts of plants, and since botanists have not completely researched this area, much of the initial experimentation and recognition will devolve on microwear analysts themselves.

3.3 Polish measurement

The measurement of polishes by some objective means is a priority, although the mechanisms of polish formation will probably continue to make some derminations difficult both for the human analyst and the machine. Various methods have been tested to measure the amount of light given off by polished edges, of which the most successful appears to be that of Norwegian researchers who have measured changes in luminous intensity on the edge of experimental tools. Work in Britain on image processing may also eventually provide some objective 'measures' by which microwear polishes can be assigned to a given use-material.

4 Thermal effect studies

4.1 Magnetic properties

Various techniques such as magnetic susceptibility and thermoremanent magnetism can be applied in the laboratory and the field respectively in order to discover whether stones were heated in the past. These techniques have mainly been used on stone elements of hearths, or suspected hearths. When the natural magnetic properties of each stone type are taken into account, magnetic susceptibility, in particular, can provide clear evidence of previous heating. It can also indicate the approximate temperature to which stones were heated.

4.2 Heat treatment

More precise identification of burning or deliberate thermal treatment of stone artefacts or structural elements can be obtained by thermoluminescence, although the main aim with this technique is to date the heating event. Recently electron spin resonance has been used to find out if the duration and temperature of past heating of chert could be determined. Heating or annealing of flint and chert is of considerable interest as an early pyrotechnology. Several of the radicals in flint turned out to be potential temperature markers, and ESR therefore appears to be an important tool of the future in thermal effect studies.

5 Organization and funding

Archaeological science has a battery of techniques suitable for solving fundamental archaeological problems with stone raw materials and artefacts. Greater financial support in the future would enable more of these problems to be resolved. The next decade should also see a response to more complex archaeological problems, so that, on the lithics side, for instance, interrelationships between raw material procurement, possible thermal treatment, and artefact manufacture and use can be resolved by an integration of several different archaeological science techniques.

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12 Site prospecting

A J Clark

Introduction

Scientific techniques for archaeological prospecting and site survey have been developed largely over the past 40 years: first with the introduction of resistivity prospecting, then magnetic, both of which have remained the mainstays of the subject. More recently, electromagnetic instruments were introduced. The older technique of phosphate prospecting remains of value, and other chemical methods are possible.

Future needs can be divided into two: the development of new techniques, and the speeding up and improvement of those that already exist.

Magnetic prospecting

Magnetic prospecting was first developed by the Research Laboratory for Archaeology, Oxford, using the proton magnetometer and gradiometer. Largely for reasons of speed and preferential sensitivity to many archaeological features, this rapidly became the dominant technique of prospecting, its sophistication being increased by the Rheinisches Landesmuseum, Bonn, where computerized data collection and processing of survey results were developed.

The speed and spatial sensitivity of magnetic prospecting were further increased by the introduction of the use of a fluxgate gradiometer, which has the great advantage of continuous output, exploited by the Ancient Monuments Laboratory for trace recording on an XY plotter. This rapid method of building up magnetic maps has stood the test of time for 14 years. Now the addition of computerized data collection is adding considerably to its flexibility while reducing the time spent in report production. A prototype system making use of a microcomputer was developed some time ago at Manchester University, but the new generation of miniature portable computers is much more suitable. In order to avoid losing the advantages of the fluxgate gradiometer, further development of this approach will need to focus on the fully automatic logging of data at closely spaced sample points while the instrument is in continuous motion, and the rapid presentation of the data acquired for field inspection. The first of these has been achieved, notably by Philpot Electronics, but further research and development are necessary to improve reliability.

One of the criticisms of the fluxgate gradiometer is that its signal to noise ratio, and its tendency to direction sensitivity, limits its usefulness compared with proton instruments on some marginally magnetic sites. Further improvements in instruments are therefore needed. These should not exclude the possibility of the speeding up of proton instruments, or of attempting to produce cheaper optical pumping instruments such as the caesium magnetometer. These share with fluxgate instruments the advantage of continuous output, combined with greater sensitivity, but their cost is prohibitive.

A successful application of the fluxgate gradiometer has been for free scanning without recording, the operator recognizing archaeological anomalies visually from the behaviour of the instrument meter. The method is used, for example, for the rapid assessment of the archaeological content of landscapes traversed by potential road lines, and the extent of occupation of Iron Age hillforts. An instrument able to display an electronic (say liquid crystal) trace of a length of such a traverse would be highly desirable. Taking this rather further, a 'free-ranging' system, able to record the instrument signal and movement of a randomly walking operator, would be useful for working in heavily vegetated conditions and for obtaining a rapid assessment of the archaeological content of an area (such a system, based on radio, was partly developed for the AM Laboratory by the Plessey Company some years ago).

Resistivity

Resistivity, although relatively slow, has the advantages of being especially effective for defining building foundations and stone structures generally. It can also be more accessible to low-budget organizations.

Automatic computerized data logging is now available for resistivity instruments from Geoscan, and the remaining cause of their slowness is the need to insert probes. This has been mitigated by the Twin Electrode configuration developed at Bradford University, but further improvement is tending to follow two divergent lines. Continuous contact systems, which are pulled along to produce an uninterrupted stream of data, have been designed successfully by CNRS in France. A contrasting approach proposed in Britain is to set out rows of probes linked by multicore cable to an instrument and computer so that they can be rapidly scanned in any desired combination and multiples of the standard spacing - while another line of probes is being set out. This multiprobe approach is relatively convenient and inexpensive, and has the potential advantage of providing information in depth, which will be of great value in interpretation. There is also room for the improvement of instrument circuitry to achieve greater contact resistance tolerance and rapidity of response.

Further research on probe configurations could be worthwhile, for instance on 'focused arrays'. Some work has been done on the variations of resistivity response with climatic changes through the year. These can be quite dramatic, and crucially important to the effectiveness of surveys. Lithologies so far covered are sandstone and chalk, with some initial work on clay; but such studies need to be extended, initially to gravel and limestone bedrocks, and then to more localized regional types and conditions. Optimization of electrode spacings for various feature types and depths also requires continued attention.

Electromagnetic instruments

These are attractive because they offer the possibility of contactless resistivity (strictly conductivity) measurement, which can be combined with magnetic susceptibility measurement and metal detection in one instrument, depending on the signal frequency employed.

Magnetic susceptibility of most soils is readily enhanced by burning and possibly by other activities associated with human occupation. This enhancement in a uniform topsoil layer is readily detected by instruments of this sort, but not by magnetometers. A limitation of susceptibility instruments - poor depth penetration - has been used to advantage in topsoil prospecting, for instance the Bartington MS2. Instruments of the transmitter and receiver type have recently been developed to 'focus' at some depth. These need to be further developed, with particular attention to the high spatial resolution required in archaeology, and their response in conductivity mode rigorously compared with that of conventional resistivity meters.

The potential of the magnetic susceptibility phenomenon itself needs to be studied on a wide variety of sites and lithologies. This should be accompanied by expansion of the studies of the survival of the integrity of individual features in ploughed topsoil, initiated by the Butser Ancient Farm Research Project.

Knowledge of the variations with depth of soil magnetic susceptibility is a valuable precursor to magnetometer survey. A corpus of such information broadly distributed over Britain has been initiated by the Ancient Monuments Laboratory, and should lead to an increasing ability to predict the 'surveyability' of sites in different areas.

Radar

Ground penetrating radar is much favoured in the United States for archaeological prospecting, but has received less attention in Britain, with the notable exception of the Scott Polar Research Institute at Cambridge. This refined system has had much field testing as part of the Sutton Hoo project; it requires funding for further development, which should include speeding up its operation. More conventional systems of the type normally used commercially produce complex responses to often simple subsurface features, and would benefit from more extensive testing and, if possible, optimizing and improvement for archaeological work.

Other instrumental methods

Sonic and seismic methods seem to show less potential at the archaeological scale of operation, although the latter has found a striking application in the location of submerged terrain suitable for past human occupation on a drowned coastline off the United States. Miniaturized seismic reflection might also be suitable at least for such major features as prehistoric flint mines.

There could be scope for reviving the old technique of bosing by using electronic sensing and a visual output. This could increase sensitivity and reduce ambiguity of response, and might lead to the discovery of characteristic responses from different types of feature.

Thermal detection by airborne infra-red scanning has received attention, especially in France. The results achieved so far do occasionally seem superior to those achieved by normal photography, but further work would be desirable. Ground-based thermal detection by the implantation of sensors has been proposed, but, if it proves effective, a limitation on its usefulness is likely to be set by slowness of operation.

Chemical prospecting

Phosphate prospecting not only predates the instrumental methods of archaeological detection, but continues to be of value. Modern chemistry is enabling new information to be gained about the subtleties of phosphate preservation in relation to human activities, and the development of improved methods of analysis. Research is underway, notably at the Dorset Institute of Higher Education. It has been observed that phosphate and magnetic susceptibility can provide quite subtle information on site usage by distinguishing areas magnetically enhanced by burning, and hence probably human occupation, from such areas as stock enclosures in which phosphate is enhanced by manure. However, these areas are sometimes so clearly distinct that interference between the two phenomena is suspected, and research on this is required.

The definition and study of sites using other chemical species is also worthy of research, and has received some attention at the University of Nebraska. A promising example is residual calcium from the mortar of buildings. A disadvantage of chemical methods, whatever their subtlety, is their slowness. Therefore they must be used on a coarse grid for large area surveys, and for detailed examination are restricted to quite small areas.

13 Radiocarbon dating

Roy Switsur

Radiocarbon dating has been an established part of archaeological science for almost forty years. Despite a tendency in some quarters for it to be taken for granted, the measurements are among some of the most delicate in physics. There are in fact many areas of radiocarbon dating where further research both into the method itself and its applications to archaeological problems is urgently required. The aim of this paper is to highlight these areas for further research, with an eye primarily - though not exclusively - on the current situation in British archaeology.

1 Radiocarbon dating in Britain

Radiocarbon dating research in Britain has a very good record. Most of the initial research in the subject was carried out at two laboratories - those at the University of Cambridge and the British Museum - and many significant technical developments were made during this period. These include the design of some highly efficient, low-background, proportional gas counters capable of handling a range of sample sizes between 0.1 and 5 g of carbon; the introduction of the principle of multiple independent counters within a single anti-coincidence shield; the use of an efficient scintillation material as the active shield in place of a ring of Geiger counters, and the introduction of high-stability, solid-state electronic equipment. Antiquated chemical techniques which relied on trains of solutions of reagents for scrubbing the counting gases were replaced with purification techniques capable of working under high vacuum conditions. For the combustion of the specimens a semi-automated, high-pressure oxidation vessel was developed. At the British Museum techniques for liquid scintillation were perfected which included the chemical synthesis of benzene through a route using lithium carbide, and an efficient acetylene trimerization catalyst was introduced. Thus many of the techniques now used in radiocarbon laboratories around the world underwent active development in Britain.

As the need arose for an increasing number of age determinations in numerous research programmes, more scientists set up radiocarbon laboratories to augment those at Cambridge and the British Museum. We therefore now have conventional beta-counting facilities at the universities of Belfast, Birmingham, Cardiff and Glasgow, together with the NERC financed laboratory at the SRRC at East Kilbridge and the commercial laboratory at AERE, Harwell. In addition to these conventional laboratories there is a SERC financed Accelerator Mass Spectrometer facility at Oxford.

The conventional university radiocarbon laboratories were set up in various departments by individual scientists having interests in research projects requiring time-scales. In this sense they are dedicated laboratories and their function is different from laboratories in metallurgical or materials science departments, for example where the equipment has other basic departmental priorities but may be used for archaeological research if appropriate. The scientists directing these university dating laboratories collaborate with archaeologists in investigations where age determinations form a vital part of the study. These laboratories should therefore be regarded as national dating research facilities, although they are not directly supported financially by any research council for this purpose.

On the other hand the East Kilbride laboratory (which does not measure archaeological specimens) and the Oxford laboratory are directly financed by research councils for both staff and equipment. The British Museum, which primarily measures samples concerned with its own studies, is financed through its own treasury system, while the Harwell laboratory, which has contracts for Rescye Archaeology etc, operates by charging commercially economic prices for age determinations.

2 Research

Research into radiocarbon dating may conveniently be divided into sections that deal with (1) research into the fundamental principles of the method; (2) research into the techniques used in implementing the method; (3) research applications of the method in investigations or projects that frequently require collaboration with other methods of study. These will be considered briefly below.

The fundamental principles of radiocarbon dating annunciated during the early studies of Libby and his colleagues were shown to form a reasonable basis for age determination. However, as the scientific techniques have gradually improved and more precise measurements been made, it has been shown that certain corrections are required in order to obtain more precise ages. Thus the assumption that atmospheric radiocarbon concentration has been constant throughout many millennia has been shown to be erroneous. Research in 1959 by Willis, Munnich and Tauber at Cambridge, Copenhagen and Heidelberg, using samples of *Sequoia Giguntea* of known date, demonstrated that during the past 2000 years the radiocarbon concentration had varied by a few per cent. Subsequent work of this type on long-lived trees such as the bristlecone pine has confirmed this effect and shown the need for a calibration curve so that radiometrically determined *ages* could be converted to *dates* on the historical calendar. Much effort was expended, particularly in America, on this calibration during the two decades from the early 1960s. The precision of the work was about 5 per mil. The majority of this new work has been done by Stuiver *et al* in Seattle and Pearson *et al* in Belfast, enabling them to publish a double-checked calibration extending over the period AD 1950 to 2500 BC. Pearson *et al* have also made high-precision measurements on Irish oaks back to 5210 BC, but these need to be double-checked before being recognized as a calibration. One of the reasons that it has taken nearly 30 years to achieve a precise calibration even for this short time period has been the inadequate funding of the radiocarbon scientists who have long been aware of the need for fundamental research to improve the precision and reliability of their measurement techniques. Naturally archaeologists require calibrated dates extending further into the past than 2500 BC. Clearly it is important that this work should be continued and the calibration extended as far back in time as it is possible to obtain suitable samples of known date. This may be to the region of about 9,000 or 10,000 years ago and will allow precise calendar dates to be obtained for suitable archaeological samples throughout this period. Equipment necessary for this work already exists at Belfast, and it is sensible that the research should be supported there until completed. Duplicate measurements will be made by other workers in Europe and the USA. There is, however, a problem in extending the calibration beyond the limit of the growth rings provided by trees, and it is possible that this might be achieved by using annual sedimentary deposits such as the organic varves found in some anoxic deposits in lakes in East Anglia or possibly carbon contained in the polar ice caps. These deposits contain little carbon and so would require techniqes capable of using small samples with adequate precision.

Another important topic concerned with the principles of the radiocarbon method that requires further research is the fate of the naturally produced radiocarbon and its distribution among the various reservoirs of the carbon cycle. This has an important bearing on dating archaeological materials - as for example those of marine origin which occur at many important Palaeolithic and Neolithic coastal sites around the UK. The radiocarbon concentration in the sea-water reservoir varies, not only with time (as in the case of the atmosphere) but also with location, because of the incomplete mixing patterns in the various coastal regimes. Research into these factors will therefore require complex research projects, involving samples from a wide range of geographical and chronological contexts.

3 Parameters

Any dating method may be characterized by several parameters, which must include (a) the range, (b) the *resolution* and (c) the *materials* used in the determinations, and (d) *sample size.* The values of (a), (b) and (d) may depend on the individual technique used in the application of the method. For the radiocarbon method the techniques in use at the present time include gas spectrometry, liquid scintillation spectrometry andaccelerator mass spectrometry.

3.1 Range

When the project to set up a Tandem Accelerator facility at Oxford was mooted some fifteen years ago it was confidently expected that the range would comfortably exceed that of the conventional radiocarbon systems, and a range of 80,000 to 100,000 years would be achieved. However, despite the expenditure of much effort on the system, the range so far achieved in practice (30–35,000 years) falls far short of good conventional installations. Most conventional systems have a range of in excess of 40,000 years, some in the UK have a range of about 50–55,000 years, and there are certain laboratories that are able to reach 60,000 years without resorting to isotopic enrichment techniques, which could be used to increase this by about three half-lives. The range of the AMS instrument seems to be limited by its having a relatively large and unstable background, the cause of which is not well understood. The lenses of the ion-optics system suffer from spherical aberration and probably astigmatism, and so need to be operated with small apertures to reduce the defects. This limits the beam current through the instrument, which may be counteracted by a high source brightness. It is possible that part of the instability may be caused by some effect of intermittent charging of the apertures. Space-charge effects at the numerous cross-overs in the optical system could spread the beam and reduce its homogeneity. It is most important that research should continue into this elegant technique so as to fulfil its initial promise of long-range dating.

3.2 Resolution

The resolution of a dating method concerns its ability to distinguish between events or objects that occur close together in time. Radiocarbon dating has potentially the best resolution of all radiometric methods, and this is surpassed only by some dendrochronological work. The various measurement techniques are likely to have different temporal resolutions. The resolution depends upon the precision of the radioactivity measurements and the precision of the calibration. Some recent archaeological research is requiring the highest resolution of which the method is capable, but British laboratories, with one exception, do not have the equipment to meet this need. In order to obtain the precision of activity necessary it is essential to have a system of strict quality control. This implies highly stable apparatus for both measurements and for monitoring, stable laboratory conditions, rejection of outside interference, and the meticulous application of corrections to the measurements. Only in this way will precision of the order of 2 to 3 per mil be realistic. It is pointless merely to increase the counting time in the belief that this can enhance the precision sufficiently. Funds should be provided to enable the radiocarbon scientists to set up the appropriate equipment to establish and maintain the high standards that are required. So many research projects in archaeology now depend on tight chronologies that this research should be given a high priority.

3.3 *Materials*

The materials most frequently used by archaeologists in dating are wood and charcoal. While these are usually easily obtainable, their significance in dating associated objects and site phases is often overstated. For example, burnt roof beams do not normally give a date for the destruction phase but only some part of the growth of the tree from which they fashioned. Charcoal from a scatter around a hearth does not date the last fire, and could be a century or two too early depending on the size of timber combusted. Dating laboratories are becoming cautious about dating these materials without their being supported with better credentials.

There are other potentially useful materials that could be dated if efforts were made to secure them and record provenance more accurately. Such are bones, whether human or animal, which if well preserved can contain useful quantities of collagen. However, the chemical techniques currently employed for extracting this material and removing possible contaminants need further improvement; possibly the hydrolysis to amino-acids and preparatory chromatography would yield sufficiently pure material for dating. The bones, being relatively short-lived material, would give better chronological control than charcoal.

In appropriate situations iron artefacts, which can contain about 1% carbon, offer a source of dating material which has only rarely been exploited by archaeologists. Yet the carbon contained probably came from young saplings, a source contemporary with the time that the iron was obtained from the ore. Being protected by the iron, it is far less likely to be contaminated by other carbonaceous materials than is charcoal, and may therefore yield a more reliable age. However, the techniques for dealing with this material are still cumbersome and would benefit from a research effort to improve them.

Mortar, too, is material that contains carbon from the contemporary atmosphere, taken in when the slaked lime is converted to carbonate as the mortar sets. This material could give dates for the construction of buildings and of any repairs made. Research. is needed to discover the best way of using the material and of finding whether the original lime-burning was complete; if not a mixed age would be the result.

Marine shells also are potentially a good material for dating coastal sites and can yield ages from either the inorganic aragonite or calcite fraction or the organic conchiolin fraction. The latter constitutes some l–2% of modern shell material but becomes degraded with the passage of time. It is, however, more resistant than collagen in bones. Good techniques for extracting this need researching. It must be remembered that this material originates in a marine environment, so the effect of the reservoirs mentioned previously must be taken into account in assigning a radiocarbon age or historical date.

The above examples are but a few of many different sample types that could and should be exploited by archaeologists. There are other materials that are found in archaeological sites in small quantities that might be suitable for measurement by small sample techniques discussed below, including dentine from teeth or ivory, insect remains or other macrofossils, seeds, parchment, leather and food residues. Further research is necessary into techniques for processing these substances to obtain uncontaminated samples for dating.

3.4 *Sample size*

The majority of conventional radiocarbon laboratories tend to make measurements on samples within the range of about l-5 g of *carbon,* whether for gas counting or liquid scintillation. An exception to this rule is in calibration work where the starting point at Belfast is about 200 g wood. The great majority of archaeological sites are able to yield ample material for dating. There is, even so, an increasing number of projects in which it would be far more convenient to be able to deal with smaller size samples - of the order of fractions of a gram of carbon. The AMS techniques are, of course, suited to this smaller specimen size. However, research has progressed with conventional proportional gas counting techniques so that milligram-sized samples may be as easily measured as the more normal size. Miniature counters have been constructed at radiocarbon laboratories around the world and have been successful. Applications for research in this field to the British research councils have not so far been funded despite the obvious importance of the technique. Nevertheless the technique has been developed independently during the past decade or so at the Harwell laboratory where a successful dating system is now in regular use. The university dating laboratories urgently have need of equipment of this kind to deal with requests for collaboration in research projects. These small counters have excellent characteristics and can be produced to be equal in performance to the larger gas counters. Although the counting time for an individual sample is rather long., this is not a problem with modern solid-state, electronic data-acquisition systems. The technique is to employ a batch of several small counters simultaneously within a single active shield so as to obtain the required number of measurements in a given period. The costing is very favourable compared with other systems since the sample preparation time and reagents used are correspondingly less for the smaller sample size compared with the normal size.

3.5 *Techniques in sample processing*

Besides the research into sample preparation and new materials, there is a need for research into the techniques used in processing the purified specimens in the laboratories. All the conventional dating laboratories in the UK now use the high-pressure bomb oxidation technique mentioned earlier for the specimen combustion, since this is very effective and time-saving. The next series of laboratory processes is one of gas purification followed (depending on the individual laboratory technique) either by counting the activity of the purified carbon dioxide or the synthesis of either methane or benzene prior to counting the radioactivity. These processes involve cryotgenic distillation, vacuum manipulation, measurements of gas volumes and others. At present these are all carried out manually, so there is immense scope for automation and system control by microcomputer. If effective automation systems could be developed, the processes could be optimized for greater efficiency, allowing a greater throughput of samples. Such automation, because of inadequate funding, is long overdue in our radiocarbon laboratories.

A further innovation that could have important applications in large excavations or sites with complicated stratigraphy is the construction of a mobile radiocarbon laboratory. This would be used at the excavation site for the rapid evaluation of the age of test samples to guide the excavations during initial surveys. The dating apparatus would be mounted in a 'camper' type vehicle equipped as a laboratory and capable of complete processing of samples including the radioactivity assay in a manually operated counter. The vehicle would be self-contained with supplies of reagents and refrigerants. The ages produced by an overnight measurement, though not of high precision, would be sufficient to be used as a field guide in the site survey and subsequent work. Since this laboratory would be on the site and closely involved in the excavation this would provide more than a basic chronology. The immediacy of the results would help to guide the field work and could thus save much time and effort. Where required, duplicates of important samples could be obtained and dated more precisely in a conventional laboratory.

3.6 *Statistics*

While the rules for the calibration of a radiocarbon age to produce a calendar date have been generally well explained in the recent literature and the ways of comparing two dates are generally known, the methods of working with groups of dates are not nearly so clear, and many contradictions of interpretation appear in the literature. There is an important need for research into specific techniques for the statistical treatment of groups of dates so that the information contained in the range or uncertainty of the dates is not lost. The rules should be explained for the interpretation of the results of such treatment so as to avoid ambiguities.

4 Standards

The International Standard of radioactivity for radiocarbon dating was a batch of oxalic acid distributed by the National Bureau of Standards in Washingtron. The current standard is the second batch of this acid, the first having been exhausted, and its activity has been agreed by measurements made at several laboratories around the world. However, in several ways this is not an ideal material for a standard and some laboratories have encountered technical difficulties in its use. It is a scarce material and so not fully suitable for setting up and monitoring experiments nor establishing quality controls. However, a very useful set of samples for this purpose has been made available by the Harwell radiocarbon laboratory, consisting of benzene of known radioactivity, simulating ages of up to 20,000 years. These substandards have the considerable merit of avoiding problems of specimen preparation and oxidation and purification inherent in other materials of known date, such as samples of dated timber, which do not extend over a sufficiently long range to be practical. The use of these substandards should be encouraged to aid comparability among the dating laboratories. For those not using scintillation spectrometry, the benzene may easily be oxidized to give suitable counting gases.

Another problem surrounds the standards available from commercial sources for assessing the quench correction (or better, the counting efficiency) of liquid scintillation systems. This correction directly affects the activity of the sample being dated and so must be known at least to the measurement precision that is required. the activity of these standards is certified only to a precision of 2 or 3% and so needs to be calibrated by the dating laboratory for use in work with natural radiocarbon. Their uncritical use could result in errors of around 200 years. While they may be acceptable for clinical and biochemical radioactivity studies, there is a need for more precise standards for dating work, which is far more exacting.

5 Radiocarbon ages database

There is a need to compile a database of radiocarbon ages and calibrated dates of archaeological interest. This is now becoming a matter of some importance because of the rate at which the relevant age determinations are being made. If the establishment of the database is long delayed, its usefulness will be seriously diminished. In order that it should have credibility, however, it is important that the database is established and maintained at a recognized dating laboratory with access to comprehensive computing and networking facilities so as to ensure its proper support and continuity. Free access to the system by research groups would be through the academic network JANET. This operation should be financed as a national archive and the full expenses of the contributing laboratories must be covered. Preparation of entries would be a continuing task for which there would be no incentive. It would be necessary to establish a suitable format for the entries to cover all likely eventualities and include techniques for searching for various parameters. If used properly, this could be a very important archaeological research tool. Such a database would not be intended to replace, but rather be an addition to, the definitive publication of abstracts of research projects in the journal *Radiocarbon,* where full details of the specimens and the all-important provenance would continue to be published. A reference to this definitive publication would need to be included in the database which, if to be of a reasonable size, could hold only minimal information concerning each entry. There are plans for amalgamating such a national database as part of an internatonal scheme in which the UK could play a leading role.

6 Collaboration

It is crucially important for the future of science in archaeology that the archaeologists and scientists should work in close collaboration in all stages of research. Each has a definite part to play in any combined project, and each has expertise obtained by years of study and experience to contribute which the other cannot possess. The collaboration should thus be of mutual benefit. In any proposed project all the collaborators should be brought into the discussions at an early stage in planning the research so that the various requirements and possibilities can be explored. In university research, at least, the distinction between 'producers' and 'consumers of radiocarbon dates (as is sometimes employed in the commercial world) is untenable. In procuring the specimens for measurement the scientist should be closely involved in taking the samples, just as in the collection of samples for thermoluminescence and potassium-argon dating. In all these contexts the information concerning the sample provenance is vital in the interpretation of the results. The chemical and physical properties of the environment are not usually recorded by the archaeologist, who is normally concerned primarily with the stratigraphic context and archaeological associations of the material on the site, and may be only vaguely aware of the possibilities of contamination of the radiocarbon samples. The necessity of this intercollaboration is increasingly being recognized, and a number of conferences have been organized recently at the University of Groningen to bring together archaeologists and scientists to promote this awareness.

7 Funding

The funding of research projects in archaeological science at the present time is directed -primarily towards the innovation and development of scientific techniques. Once techniques have been developed and validated there is generally very little funding for their application in archaeology - the purpose for which they were developed. Needless to say, unless the results of archaeological science are applied to archaeology in a systematic and wide-ranging way, the subject as a whole will receive little benefit. It is vitally important that the equipment in radiocarbon dating laboratories should be the best available, so that the very delicate measurements can be made to the highest levels of precision and reliability. Equipment is now available commercially (designed with the help of radiocarbon scientists) with excellent specifications and performance, and we should now accept as a high priority that all the university conventional dating laboratories should be re-equipped with these reliable instruments to replace their old apparatus. The cost of this would be in the region of a million pounds - far less than the amounts which could be spent on other projects without so great a return. This investment would be of benefit to the whole archaeological community, providing a consistent flow of precise dates of high reliability.

Finally, scientific research in archaeology can advance only with a holistic approach in which funds are provided for multi-discipline investigations involving the close collaboration of radiocarbon scientists, not only with archaeologists, but with a range of other environmental scientists, geographers and geologists. It is essential that research projects in archaeology should be regarded as a professional team or group effort, as in modern physical and chemical sciences. The day of the lone excavator has gone. The full potential of archaeology will be achieved only if this interdependence is recognized. As emphasized in the Introduction to this document, any archaeological site report which relegates the contributions of the scientific collaborators to a series of specialist appendices must be seen as an anachronism in current archaeological research.

Acknowledgements

During the course of the preparation of this paper the majority of the British radiocarbon scientists and their publications were consulted so that their views could be properly represented. One or two people, unfortunately, were not available. A larger number of archaeologists were also asked for their suggestions and these, as might be expected, were less homogeneous. However, the general opinion was for greater collaboration with the scientists as set out above. While the final views and assessment of the current situation must be my own, I wish to express my appreciation to the numerous people who have helped me to assemble this contribution.

14 Radiocarbon accelerator dating

John A J Gowlett

1 Introduction

Radiocarbon dating by Accelerator Mass Spectrometry (AMS) is now a major vehicle in the production of radiocarbon dates worldwide. Many archaeologists probably still lag in their perceptions of this method, since it has arrived in practice very suddenly. Less than a dozen dates were reported at the Seattle Radiocarbon Conference in 1982, but hundreds were cited at the Trondheim Conference of 1985 when no less than 33 papers were presented on one form or another of accelerator dating. The Oxford accelerator unit also has already (1986) published more than 500 archaeological dates.

Although Oxford has the only radiocarbon accelerator facility in Britain, its dates are widely available through the SERC national facility service, and dates from accelerators abroad may also become available to British archaeologists. By 1984/5 several radiocarbon accelerators were producing dates for archaeology somewhat routinely - those at the University of Arizona (Tucson), Zurich, Toronto, Simon Fraser University (Vancouver) and Oxford. It was estimated at a Smithsonian Institution workshop early in 1985 that 3,000 accelerator dates had been produced, as against 9,000 conventional radiocarbon dates in the previous year. This is likely to have been an overestimate, but the figure of 25% or all dates is almost certainly valid for 1985/6 in Britain and worldwide.

Consequently, any appraisal of research priorities must get away from the notion that accelerator dating is something weird, wonderful and untested, on the edge of everyday experience. Profound changes in dating practice are on the way worldwide, regardless of any purely national decisions, and it is important that British archaeology should take the full benefit of this.

2 The scope and objectives of accelerator dating

The prime benefits of accelerator dating stem from the tiny sample size necessary, even for very old samples. They can be summarized as:

1) the ability to date directly organic remains of interest, eg seeds or identified animal bones;

2) the ability to select the sample that is best suited to dating a particular context, eg charred plant remains sealed in baked clay, for dating an oven;

3) the ability to use chemical processing to maximum advantage, eg by isolating amino acids from bone collagen;

4) the ability to carry out repeat dating, and thus to resolve many issues where doubt would otherwise have persisted.

Combinations of these advantages make the method so broad and flexible that it has applications in almost every period and area. As supplies of dates are limited, and the dates are relatively expensive, it makes sense to concentrate research priorities on the most important outstanding problems, and to avoid areas where conventional dating can operate perfectly well. The following themes are likely to become, or remain, particularly important (see J A J Gowlett & R E M Hedges (eds), 1986, *Archaeological results from accelerator dating,* for more detailed discussions):

1) Origins of agriculture, and domestication of plants and animals. The relevant plant and animal remains are often scarce and precious, making the method of great value. So far most emphasis has been placed on the Middle East, where much remains to be done, but northern Africa, south-east Europe and the Far East all merit high priority in future dating programmes.

2) Origins and spread of anatomically modern man. Accelerator dating can match the chronological range of conventional dating (c 40,000 BP), while maintaining major advantages. Progress in controlling chemical backgrounds should allow dating to at least 50,000 BP, hence a start on re-evaluating the disappearance of the Neanderthals, and the appearance of anatomically modern man. Poor preservation may restrict opportunities in Africa and the Middle East, hence the focus is likely to be on Europe.

3) Dating of Palaeolithic sites and art objects. Programmes are already well advanced on dating the earlier and later stages of the Upper Palaeolithic in western Europe. They include the direct dating of carved bone and antler tools, such as weapon heads and decorated batons. The geographic scope of these projects ought to widen across Europe, and emphasis should be placed on dating particular species of fauna. Research projects will probably be concerned with, for example, rates of change in associated lithic industries, and the impact of climatic changes on settlement.

4) Dating of the earliest Neolithic in Britain. Direct dating of human skeletons with minimal damage is an approach which could involve several hundred dates. A blanket approach might not, however, give the best returns. Accelerator dating might be employed to advantage on selected problems, such as exploring the chronology of the interface between the Mesolithic and Neolithic, both in Britain and elsewhere in western Europe.

5) Dating of early civilizations. Many more dates are needed for the formative phases preceding civilizations in such areas as the Nile valley and Mesopotamia. These will need to be samples with excellent contexts,

and repeated measurements may be needed to give high precision.

6) Dating of Brinze Age metalwork. The quantities of wooden hafts or sheaths found with numbers of metal artefacts are quite adequate for dating. Precision of c ±60 years necessary for Bronze Age dating has now been reached. Fifty good samples could be found in Britain for this kind of dating, but thereafter re-evaluation of research directions would probably be needed.

7) Solving of 'test case' problems. Truly crucial dating opportunities are relatively restricted from the Iron Age onwards, except in the cases of museum objects, parchments, etc, which are however numerous, and could be the basis for many good projects. In the area of archaeological site dating the most rewarding approach might be to focus on certain 'test case' projects, comparing results of multiple dating on known-age and unknown-age sites. Examples of sites meriting further work are Pompeii and the Mary Rose as known-age sites, and Akrotiri and Cadbury Castle as 'unknowns'. These last are quite well dated but within rather broad limits and with a number of 'rogue' dates. Such evaluations would help archaeologists to assess how much weight to place on radiocarbon results in varying circumstances.

3 Technical developments

In the initial stages of AMS dating 'working solutions' were found to several major problems that hindered the introduction of accelerator dating. Subsequent research has been aimed at finding more satisfactory long-term solutions. The emphasis has been on the chemistry of sample preparation the form of target (prepared sample) to be introduced into the accelerator, and the design of ion source.

The principal technical limitations to operation so far have been:

1) that sample processing introduces contamination, limiting the range of dating to c 35–45,000 years (comparable with most conventional dating);

2) the use of solid graphite targets restricts precision, since they are not entirely homogeneous.

To some extent these problems are linked, and they are common to all accelerator installations. Future developments in the techniques of sample preparation and dating are likely to focus on three major goals:

1) Extension of range. In principle an extension of the radiocarbon time range should be possible by means of AMS techniques, since the problem of background radiation encountered in conventional dating does not arise. In practice this cannot be achieved until 'chemistry background' (contamination by modern carbon introduced during processing) has been further reduced. The chemistry operations fall into two parts: (a) purifying the sample; (b) converting it into a form suitable for introduction into the ion source for dating. The more complicated the latter operations, the higher the risk is of introducing contamination from reagents or apparatus. An iron catalysis method appears to give conversion to graphite with a lower chemistry background. An ion source running on carbon dioxide gas is a better long-term proposition, since combustion to CO2 is then the only step required in (b), and there are further advantages (see below). With the use of graphite targets dates of 40–45,000 years are possible. Use of carbon dioxide may allow dates of up to 60,000 years.

2) Improvements in accuracy. The limit of accuracy with graphite targets appears to be around ± 50 years, owing to variations in targets and in beam currents. Dates to ± 30 years might well be possible with the use of a gas source.

3) Reduction of sample size. In the case of bone, sample size will always depend on preservation. At present a minimum sample of c 150 mg is required for dating bone or ivory, even with modern material, since a yield of 30 mg amino acids is desirable. The gas method might allow a final sample of 5 mg amino acids to be dated without problem, and hence make possible bone dating from 25–100 mg for fairly recent and well preserved bone. The iron method of sample preparation also allows a reduced sample size. In some circumstances, as in dating small bone objects or rodent bones, this extra reduction could be very useful.

Further discussions of AMS developments are to be found in the Trondheim Radiocarbon Conference Proceedings (*Radiocarbon,* **28,** A & B) and in the proceedings of a Royal Society Symposium held in London in 1986 (in prep).

15 Dendrochronology

M G L Baillie

Dendrochronology in Britain and Ireland is still sufficiently new for its progress to be traced with relative ease. The subject is dominated by the study of oak as this species is the most commonly preserved timber from most periods. Oak has been used by man as a building timber from Neolithic times onwards.

In order to use dendrochronology as a dating method, reference chronologies must first be constructed. Once a reference chronology is available, for a particular species and a particular area, long ring patterns from archaeological timbers of the same species and from the same area can be placed precisely in time. The principal chronology building programme in the British Isles has been conducted at Belfast. This project aimed to provide a completely independent long oak chronology as a basis for the independent calibration of the radiocarbon time scale. The first section from the present back to AD 1380 was published in 1973. An extended version, back to AD 1001, was available by 1977, and in 1980 notice was published of a continuous chronology back to 13 BC. The Belfast long chronology project was completed in 1984 with the announcement of a continuous, precisely-dated chronology back to 5289 BC. The results of high-precision radiocarbon measurement on oak samples from all periods of the last seven millennia were presented at the Trondheim Radiocarbon Conference in 1985.

The legacy of this calibration exercise is the existence in Ireland of what is currently the world's second longest tree-ring chronology. During its construction important sections of chronology were produced in Britain. These include a chronology back to AD 946 in south central Scotland and English sections spanning AD 825 to AD 404, AD 90 to 247 BC, 381 BC to 1155 BC, and 2661 BC to 3169 BC. To these can be added the numerous precisely-dated 'site' chronologies constructed at various laboratories in Britain which span long sections of the medieval, Dark Age, and Roman periods. These sections have been placed in time by comparison with either the German or Irish independent chronologies. The situation can be summarized by stating that a broad chronological framework exists throughout Britain and Ireland for the last two millennia while one prehistoric chronology has been completed in Ireland back to 5289 BC. Oak structures of all periods back to Roman times are now being routinely dated in British tree-ring laboratories while in Ireland the first calendrical datings for prehistoric sites are beginning to appear.

1 The implications for the next ten years

One important result of the research outlined above is the availability of a continuous high-precision calibration curve for radiocarbon dates. Unfortunately this more refined version of Suess's curve does not significantly improve the interpretation of routine radiocarbon dates as used by archaeologists. It is now understood that the minimum realistic standard deviation associated with a routine radiocarbon date is c +/- 80 years. This can be stated because of the results of interlaboratory studies carried out in recent years. It is also now known that realistic standard deviations of *c* +/- 20 years can be achieved in high-precision laboratories. These new high-precision dates in conjunction with the high-precision calibration curve provide dating estimates dramatically better than conventional routine dates. Archaeologists will have to come to terms with the inadequacy of their existing radiocarbon-based chronologies.

However, even more important than this improvement in radiocarbon technology must be the coming availability of dendrochronological dating in prehistory. In Europe oak chronologies extending back to 4000 BC are available in north and south Germany and in Switzerland. Precise dates are now available for Iron Age, Bronze Age, and Neolithic timber-bearing sites in all of these areas. The resulting improvement in chronological precision will inevitably have profound implications for the existing, routine, radiocarbon-based, archaeological chronologies of Britain and Ireland. The significance of this has become clear as the first tree-ring dates for prehistoric trackways and lakeside settlements in Ireland have become available. It is immediately apparent that other similar sites, dated only by routine radiocarbon analysis, cannot be adequately compared with the tree-ring dated examples. As oak-bearing sites in the Somerset Levels and the East Anglian Fenlands will also be precisely dated in the foreseeable future a European absolute chronological framework will become a reality.

In the first instance this high level of dating precision will apply only to a limited range of site types. It might seem that the impact of precise dating for such waterlogged, timber-bearing sites might not be all that important in overall archaeological terms. I believe this not to be the case. The existence of even a few precisely-dated sites will force greater efforts to be made in the direction of establishing an overall absolute chronology. It will no longer be possible to operate a raw radiocarbon chronology. At the very least all radiocarbon dates will have to be calibrated. That operation will highlight the inadequacy of existing radiocarbon chronology in comparison with dendrochronology and will push archaeologists towards high-precision radiocarbon dating and, where possible, high-precision wiggle matching exercises. It is technically possible, where a piece of timber with more than 40-60 rings is available, to obtain high-precision radiocarbon dates on consecutive blocks of rings from the sample. This short section of 'calibration' can then be fitted to the existing high-precision calibration curve and the date of the sample read off to within a few decades. Such high-precision wiggle match dates will be comparable with tree-ring dates. Indeed they may be the only dates comparable with tree-ring dates.

So, the next decade should see a transformation in British and Irish archaeology from a raw radiocarbon-based chronology to an absolute chronology. Such a move is only common sense and would have taken place from 1970 had it not been for the controversy surrounding the Suess calibration curve. It is to be hoped that the pre-existing raw radiocarbon chronology will allow the formulation of the questions to which answers are required in detail. Dendrochronology and high-precision radiocarbon dating can then be directed towards supplying answers.

2 Some recommendations for the next five years

Dendrochronology is not without its problems. Currently the restriction to oak timbers is very limiting and efforts will undoubtedly be made towards assessing the potential of other species. Unfortunately no other species in Britain or Ireland holds real hope of allowing the construction of long chronologies. As a result, most 'other species' exercises will be intra-site. The approach to dating using species other than oak should therefore be the construction of site chronologies which can be placed in time by high-precision wiggle matching as outlined above.

When dendrochronological research began in Britain and Ireland one major concern was the number of 'tree-ring areas' which might exist. Would one chronology serve the whole of the British Isles or would it be necessary to construct many localized chronologies? Would there be recognizable cross-dating between chronologies from different areas or would some chronologies be mutually exclusive? Fortunately the available results from the work of the last fifteen years present grounds for optimism and these can be summarized as follows.

As a general rule each well-replicated site chronology is observed to cross-date with at least some other site or area chronologies. In many cases a new section of chronology (provided that it is of the order of hundreds of years in length) will be observed to cross-date with most existing chronologies of the same period. Such observations suggest a highly integrated dendrochronological system where consistency is the order of the day. No *area within the British Isles has so far been observed to have an exclusive tree-ring pattern.* The only chronologies which were anomalous in this respect, the art-historical or Type A chronologies, have now been clearly demonstrated to have a Baltic origin.

We also know that a single chronology will not be sufficient to provide optimum dating opportunities for the whole of Britain and Ireland. Although a generalized chronology, constructed by averaging together all available precisely-dated chronologies from the British Isles, has its uses, it is no substitute for well-replicated localized chronologies, which offer the best hope of dating the maximum number of individual, local timbers.

This last statement should not be taken as carte blanche for the fragmentation of dendrochronology into a thousand 'areas'. There is no need for chronologies for every city or every county. There may well be grounds for refining chronology coverage so that eventually about eight localized chronologies exist - two for Ireland, two for Scotland, and four for England. The construction of these localized chronologies will not, by and large, need to be undertaken as discrete chronology building exercises. Rather, they will develop as sections of chronology accumulate, each section being placed in time by cross-dating with pre-existing chronologies. These comments are made in the absence of any full understanding of the nature of the 'signal' which clearly must exist for dendrochronology to operate as well as it does. One important objective of dendrochronological research in the next five years must be a better understanding of the mechanisms behind dendrochronology. The results of such research must be an essential part of, and must influence, the whole approach to optimizing dendrochronological dating for archaeology.

Coupled with enhancement of chronology coverage and understanding there must inevitably be attempts to improve the techniques used to cross-date sections of ring pattern. Clearly this is not necessary for robust sections of chronology and long individual ring patterns, where existing techniques appear adequate. It will be necessary for samples which are currently regarded as marginal for dendrochronology but which would be important if they could be dated. It is likely that the use of more exhaustive measurements may need to be investigated and these could include cell size, density, or isotopic composition. The unequivocal identification of signatures (years where all or almost all trees agree in putting on wide or narrow rings) may also be of use. Signatures of course cannot be identified until chronologies have been built. It is perhaps necessary to stress that there is no guarantee that marginal samples can ever be satisfactorily dated. The importance of dendrochronological dates does however make investigation worthwhile. It will be essential that claims for improved dating techniques be proven by their instigators.

Such statements require some definition of what is *marginal* in dendrochronological terms. If an archaeologist has a piece of oak containing more than, say, 100 rings then, even it it cannot be unequivocally dated at present, what we know about dendrochronology suggests that the sample probably contains enough dating 'signal' to be dated with better techniques. The same argument applies to sections of replicated chronology which are currently undated because there are not enough reference chronologies available. So marginal is defined as ‘intrinsically datable but not yet dated’. Such samples should not be confused with *short samples.* These are samples with relatively few growth rings which present severe methodological problems for the dendrochronologist. To be specific they are samples with so few rings that they are intrinsically undatable. The greatest danger in the foreseeable future is the continued pressure from archaeologists for the dating of short samples because if, as many dendrochronologists believe, short samples are intrinsically undatable, then dates given for such samples can never be proven to be wrong. Thus potentially wrong, short sample dates appearing in the literature would remain unchallenged - a situation to be avoided at all costs. Of course, the immediate question from the archaeologists is always ‘what is the minimum number?’ There is no easy answer, but it is sufficient to say that there are many short samples which cannot be dated by dendrochronology (any sample with fewer than 80 rings should be regarded with the utmost suspicion). The philosophical arguments against even trying to date such samples occupy many pages and cannot be gone into here. This last statement at least hints at the problems which are in store.

In summary, effort needs to be applied to increasing chronology coverage and improving measurements of similarity between tree-ring patterns. An improvement in these areas, coupled with a better understanding of the nature of the ‘signal’ which influences cross-matching, might significantly improve the dendrochronologist’s ability to source individual timbers. If successful, the dendrochronologists could not only identify imported timbers but could make suggestions on trade within Britain and Ireland.

Finally it is necessary to choose one definite objective for the next five years. This must be the completion of one principal English oak chronology well back into prehistory. The most favourable areas, and one where several strands of work are already in progress, is East Anglia. This area has extensive modern woodlands and large numbers, of historic buildings as well as attested waterlogged archaeological sites and the availability of sub-fossil oaks. It is well placed between the existing long chronologies in Ireland and Germany and there can be no doubt that the completion of an East Anglian long chronology would radically improve prehistoric dating potential in Britain. There are two additional factors in its favour. Firstly, the area should contain numerous timbers imported in the medieval period which would enable thorough testing of the dendrochronologist’s ability to recognize imports. Secondly, the area contains both the Godwin Quaternary Laboratory at Cambridge and the Climatic Research Unit at the University of East Anglia. Both of these institutions should allow the ready exploitation of both timbers and chronologies for environmental and climatic research.

16 Thermoluminescence dating

M J Aitken, I K Bailiff, & S G E Bowman

In considering the future developments in thermoluminescence (TL) dating, there are three main aspects to consider:

1 Routine application of TL to appropriate archaeological problems

2 Laboratory research into improvement of the techniques employed (and hence of the reliability and accuracy of the dates obtained)

3 Interdisciplinary communication

In the following paragraphs these aspects are considered separately, though because of their interrelated nature there is inevitably overlap. Mention should also be made of the allied new technique of Optical Dating, based on photostimulated luminescence (PSL); though this is not yet ready for application there is the prospect that this stage is near and the remarks made are relevant to its development also, except that it is too early to be specific about appropriate archaeological problems.

1 Routine application

Thermoluminescence should continue to concentrate on those sites and periods that are not appropriate to Cl4 dating, ie:

a) beyond the range of the latter

b) within the range of the latter if organic material is absent or poorly associated with the event to be dated

c) in periods such as the early Iron Age where calibration of a Cl4 date leads to a substantial uncertainty

d) medieval and later periods where the error limits for TL ages become tighter than for Cl4

It is to be expected that over the next decade TL error limits may routinely approach the +/-5% (of the age) overall accuracy presently considered to be the best attainable. In addition to burnt clay, flint, and ceramics, it is anticipated that the development of dating of wind-blown or water-lain sediments from coastal archaeological sites will provide an important extension of the technique. In respect of pottery, the emphasis should be on sites that are closely linked to well-established post-excavation pottery studies using seriation and fabric analysis.

To implement the above, a dating service should be available for archaeologists, providing quick access to small dating programmes to solve crude chronological problems and to establish the potential for large, high-accuracy dating projects. These latter should be integrated' into a well-conceived dating programme that forms part of a national or regional strategy for chronological studies. It is important that TL dates are, both now and in the future, well disseminated in the archaeological community either by means of published excavation reports or through a national date list (as is presently being prepared by the *Ancient* TL *Newsletter).* It needs to be realized, however, that to be effective a dating service needs a formalized funding structure; experienced, high quality practitioners are necessary, and these are not retainable on the hand-to-mouth basis that would be the case for a service supported only be fee income. Research grant bodies such as the SERC and the Nuffield Foundation have provided sustained financial support for the *development* of TL dating to the point where a service is now available. It is now necessary to find funds for continuity. Recent initiatives shown by Lloyds Bank (Dating Fund) for independent archaeologists and the addition of support for TL dating by HBMC and the SDD for excavations they fund are a step in the right direction, but still leave laboratories in a precarious situation.

2 Laboratory research

An important aspect is the continued refinement of TL dating for routine application in association with a strong research function to enable continued investigation into the mechanisms of TL and the development of new techniques. Research laboratories in Canada, Denmark, and Australia now have an output comparable in quality and quantity with British laboratories (and in addition the Nordic Laboratory in Denmark has an application output for Scandinavian archaeology that dwarfs any other). From having led the world in this field it is now a question of whether Britain can stay in the top league.

The TL dating of sediments has attracted much recent research interest and, though the impetus has been derived from the needs of geologists, this branch holds high potential for archaeologists, particularly on Palaeolithic sites. However, the questions that have ensued exemplify the need for extremely careful and systematic study in future applications of sediment dating. Problems that, so far, have been insufficiently addressed are concerned with:

a) the basic mechamisms (ie transport by wind, water, or soil formation, etc) which give rise to adequate zeroing of TL

b) prescribed procedures for reliable dose evaluation

c) the full chronological range of the technique and its dependence on type of sediment

To some extent dates have been produced on an *ad hoc* basis with a heavy reliance on the empirical approach of comparing TL age with a 'known' age. Although this would be appropriate for certain archaeological periods, the approach has an inherent weakness, since answers to fundamental questions of the type given above have remained substantially unanswered. Great insight into the physical mechanisms concerned could be gained by use of complementary techniques such as ESR, for example. Without such a fundamental approach, sediment work will continue to be a piecemeal affair and in the long term the reliability or usefulness of dates to the archaeologist will be at risk. At the time of writing, the power and potential of this application of TL dating are yet to be fully realized.

3 Interdisciplinary communication

There should be planned cooperative projects between researchers in TL laboratories and (in addition to their colleagues in archaeology) geographers, geologists, and physical scientists in whose fields TL is now enjoying an/ increased interest. The development of TL dating can be greatly strengthened when research is undertaken as the result of interdisciplinary collaboration. One- or two-day workshops and meetings on a national basis would be advantageous in this context, perhaps with financial assistance from SERC, NERC, or the CBA.