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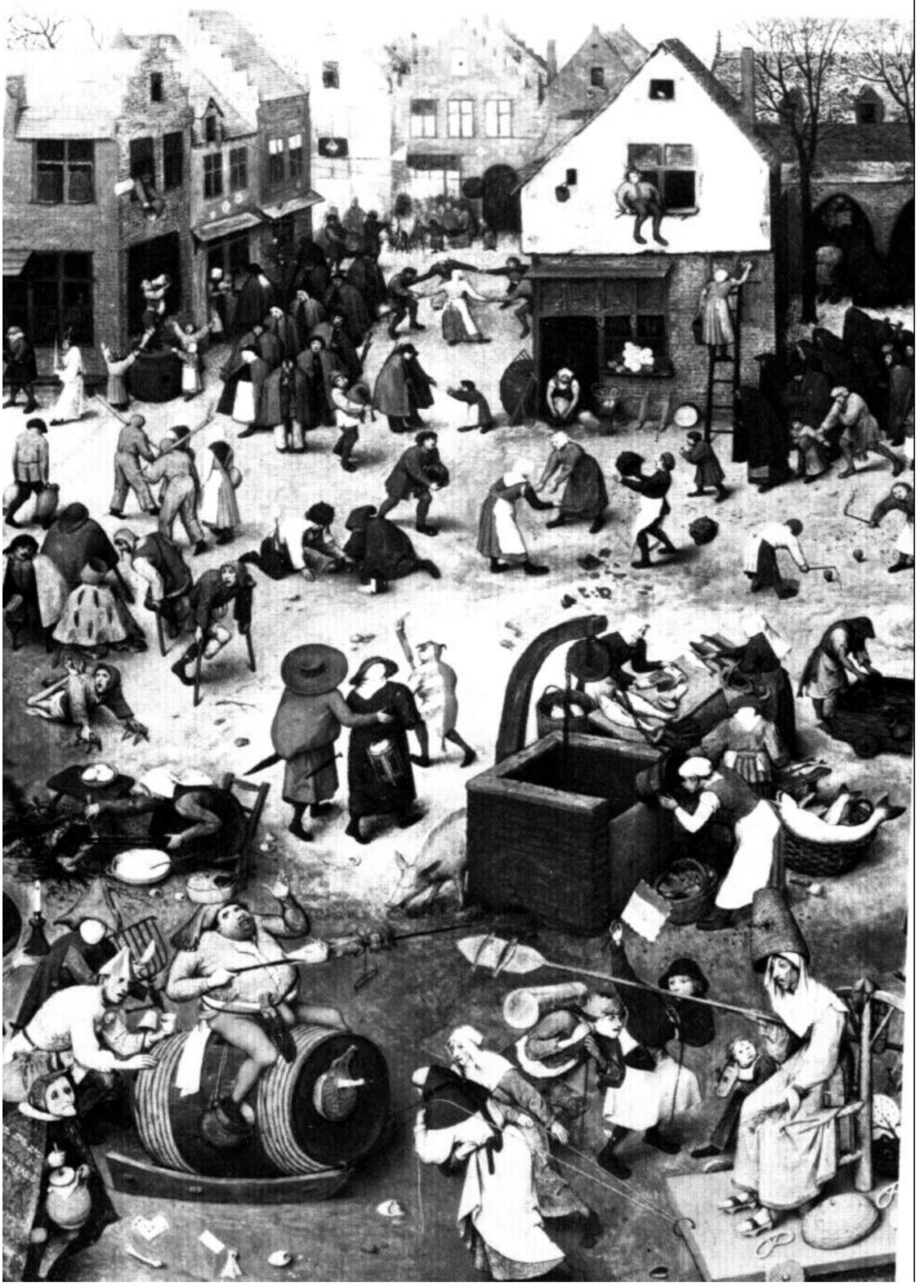
ENVIRONMENTAL ARCHAEOLOGY IN THE URBAN CONTEXT

edited by
A R Hall and
H K Kenward



1982

‘The servants said they would follow the fashion, a fashion grown sacred through immemorial observance: they would scatter fresh rushes in all the rooms and halls, and then the evidence of the aristocratic visitation would be no longer visible. It was a kind of satire on Nature; it was the scientific method, the geologic method; it deposited the history of the family in a stratified record; and the antiquary could dig through it and tell by the remains of each period what changes of diet the family had introduced successively for a hundred years.'

Mark Twain, *A Connecticut Yankee at King Arthur’s Court*

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Contents

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Contributors

P V Addyman, Director, York Archaeological Trust, 47 Aldwark, York YOl 2BX

Dr P L Armitage, British Museum (Natural History), Cromwell Road, London SW7 5BD, and Department of Urban Archaeology, Museum of London

L Biek, Ancient Monuments Laboratory, Fortress House, 23 Savile Row, London W1X 2AA

Dr P Brimblecombe, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ

D R Brothwell, Institute of Archaeology, 31-34 Gordon Square, London WC1H 0PY

Jennie Coy, Faunal Remains Project, Department of Archaeology, University of Southampton, Southampton SO9 5NH

F J Green, Test Valley Archaeological Committee, The Old Fire Station, Latimer Street, Romsey, Hampshire SO5 8DG

J R A Greig, Department of Plant Biology, University of Birmingham, PO Box 363, Birmingham B15 2TT

A K G Jones, Environmental Archaeology Unit, University of York, Heslington, York YOl 5DD

Dr D J Keene, Director, Institute of Historical Research, University of London, London WC1

Harry Kenward, Director, Environmental Archaeology Unit, University of York, Heslington, York YOl 5DD

Ruth Morgan, Department of Prehistory and Archaeology, University of Sheffield, Sheffield S10 2TN

Professor Olaf Olsen, The National Museum, DK-1220 Copenhagen K, Denmark

Dr W Prummel, Biologisch-Archaeologisch Instituut, Postraat 6-9712 ER, Groningen, The Netherlands

D J Rackham, Department of Archaeology, University of Durham, 46 Saddler Street, Durham DH1 3NU

Editors' preface

In January 1979 a conference on 'Environmental archaeology in the urban context' was held, under the auspices of the CBA, at the University of York. The participants included workers in a wide range of disciplines related to environmental archaeology and the emphasis was very much towards practical and theoretical problems, both archaeological and scientific.

During the course of the conference, it was impossible to avoid the impression of a subject largely in its infancy or, in some respects, yet unborn. Not only have the many problems of interpreting results to be faced, but also those of collecting samples which are suitable by being representative of the material from which they are taken and by being amenable to statistical analyses. Few of us working in the field have yet faced the true nature of the 'sample' generally examined, and the concept of the statistically designed 'experiment' has barely impinged upon urban environmental archaeology. With the present emphasis on rescue archaeology, it is often impossible for the environmentalist to escape the strictures of providing a service *for* archaeologists, rather than being one kind of archaeologist working together *with* others. It is to be hoped that all those who attended the conference, and others who read these papers, will be provoked into addressing at least some of these problems.

The editors would like to thank the following for their encouragement and advice during the preparation of this volume: Dr J Clutton-Brock, Dr S Limbrey, and Dr A Turner. A particular debt of gratitude is owed to Valerie Horsler for smoothing a bumpy editorial road.

A R H & H K K, 1980

Environmental archaeology may be viewed in two complementary and overlapping ways. From one standpoint, the intrinsic interest of studies of ancient biological and other remains is sufficient; for the archaeologist, however, there are questions to be answered which 'specialists' may fail even to ask. Towns are immensely complicated both ecologically and in terms of human activity; as a result, biological and topographical investigations of urban deposits are very difficult, but the results may be immensely useful. The potential of urban environmental archaeology from the viewpoint of an urban archaeologist is considered with special reference to York, a town with excellent preservation in deep, waterlogged deposits.

The conference on 'Environmental archaeology in the urban context' has taken place, appropriately enough, in one of the great cities of Roman, Anglo-Saxon, and medieval Britain. Here at York, more perhaps than in most cities, we are constantly aware that we are part of a system in dynamic equilibrium, an ever-changing artefact dependent always on complex and constantly adjusting relationships with the natural and man-made environment. Adjustments to the balance happen all the time. They can result from changes in the city's hinterland, such as new land uses, altered drainage, or improved agricultural methods, or from natural changes. They can result from changes in the city itself, through additions, subtractions, or alterations to the urban fabric, function, or economy.

As it happens, the conference foregathered at a time when York people were peculiarly aware how delicate the balance could be, for heavy rain at the end of December tipped it dramatically in favour of the environment. The city experienced the worst floods for a generation, which cut off the city centre entirely, damaged enormous amounts of property and goods in low-lying areas, and left a desolate and smelly aftermath. The rain caused the floods, but similar rain would have affected Roman York far less. In the intervening centuries man has altered the natural vegetation in the gathering ground for the series of Yorkshire rivers which join to enter the city-all too literally in modern floods-as the broad River Ouse. The run-off is nowadays far faster than it ever could have been before deforestation. Modern drainage systems have speeded it further. Encroachment on the river banks at York itself has filled the formerly wide flood plain with buildings, and further narrowed the constriction formed by the York moraine into a man-made canyon. The result is rapid rise in river levels and a bottle-neck at York which it is beyond the ingenuity of any water authority to widen or bypass (Radley & Simms 1971).

Such changes in the balance between urban man and his environment are the main theme of this paper, as I hope they will be of all environmental archaeology in an urban context. They are the kind of thing which define some of the parameters within which cities exist-and which can affect their history. They are matters which, whatever the attraction of research in the obscurer branches of environmental archaeology, or whatever the beauty of a new experimental method, are really the ones of ultimate concern to the archaeologist in his systematic study of the nature and cultural behaviour of human beings in the past.

Urban environmental archaeology is, of course, a very new and strange discipline; heaven lies about it in its infancy, as the conference papers show. Urban archaeology itself, however, is also pretty new, at least in this country, and at least on a modern and systematic basis. It has only just begun to define its own disciplines. As shades of the prison house begin to close around it, this paper presents a brief and personal review of what urban archaeologists are trying to do in Britain today, and, from the perhaps biased viewpoint of an archaeological beneficiary, what contribution environmental archaeology might have to make towards the attainment of these aims.

Towns by definition are likely to be the most complex sites in the whole of the archaeological record. By definition they are more or less permanent settlements, and many of them have been continuously occupied for as long as any site in the country. By definition they are large or at least potentially large settlements, the result of the mutual association of substantial numbers of people, bound together by common needs for defence, or common interests in trade, or common ideologies; held together by agreed sanctions; urged or inspired to great feats of construction, to the erection of defences and strongholds, of town layouts, of harbours, ports, and waterfronts, of religious and administrative buildings, of buildings to facilitate and encourage trade or for social intercourse or relaxation. Towns are places where there is a specialization of occupation amongst the inhabitants to be found in few other types of settlement, where may be found extremes of wealth and poverty, and varieties of craft, trade, profession, and calling which may give rise to archaeological situations and archaeological evidence of a variety limited only by the circumstances of the urban milieu and the innate ingenuity of man. Towns are places where, because the area for occupation is often firmly limited by defences or other boundaries, there is an unusual intensity of occupation, with crowded buildings and the intense use of every available space. The repeated reuse of the whole area leads to the growth of unusually thick archaeological deposits—some in York, indeed, reach a total depth of 9 metres or more. There is a constant churning, turning over, down-cutting, and up-building resulting from the necessary activities of the townsfolk, such as well-sinking for water and the incessant digging of holes to receive the foundations of buildings, to accommodate installations for various industrial and craft activities, or for storage of the huge range of commodities essential to those industries or to everyday life. And there is hole-digging to provide latrines and rubbish pits for the waste products of all these people and all their activities. There are holes in which to bury the inhabitants at the end of their lives. Each one of us knows how much, in terms of waste, of achievement, of tangible remains of human activity, a single lifetime can produce. If York, as is very probable, had an average of 10,000 inhabitants during each of the 57 or so generations since its foundation in AD 71, we must be dealing, in this little site of under 300 acres, with the archaeological end product of at least 570,000 lifetimes.

But that is not the end to the complexity of a town. The needs of 10,000 people in a generation, many of them specialists with unusual requirements, and all of them with an appetite for two or three meals a day, mean that the presence of a town has an effect on an area far greater than that defined by its walls. It may have had an immediate agricultural hinterland from which fresh vegetables and fruit and milk were supplied, some of it by agricultural specialists—farmers in common parlance—living within the town itself, or by part-time urban farmers. It will certainly have had well developed markets supplied with comestibles from a much greater hinterland: cattle came to York from much of the north in the Middle Ages and, though York is some 40 miles inland, seafood seems to have formed a major element in the medieval citizen's diet. For fuel, the citizen could turn to woodland nearby, though it began retreating very early; he could turn to limited bogland in the Vale of York for peat, or to the Coal Measures some twenty or more miles off. For his raw materials the specialist might have had to go even further—the Viking age jewellers of Coppergate went to Whitby for their jet, to the North Sea or the Baltic for their amber—but where did they go for the trisulphide of arsenic which they used in the form of orpiment to decorate their products?

The study of ancient towns, in Britain at least, is essentially an historical study except, perhaps, in the case of those proto-urban settlements, the late Bronze Age and Iron Age hillforts. Certainly the tradition of their study during most of this century has been for the most part the preserve of historians. On a small scale before the war, and increasingly in the last twenty years, however, techniques of field archaeology and excavation, brought to a high level of sophistication and refinement by prehistorians to answer quite different problems, have been deployed on the archaeology of this country's cities and towns.

The advent of the urban archaeologist has had a mixed effect. Initially historians hoped that archaeology might perhaps answer essentially historical questions, or provide a material back-drop against which recorded events might better be understood. To a certain extent archaeology has done this. In Wessex, for instance, Alfredian *burh* building is now an archaeological fact rather than an historical dispute, and at Winchester, the history of Wessex's capital has been provided with a context which makes the recorded achievements of that kingdom even more impressive. Increasingly, however, historians are coming to appreciate, and archaeologists to recognize, that urban archaeology can produce much more than a back-drop against which historical events are played, or the details of a story whose main events—the significant events, the historian might say—are well known. The last decade has seen urban archaeology move firmly into a phase in which quite new questions are being asked, quite new approaches are being made, the scale and method has changed utterly, and new and undreamed-of ancillary disciplines are deployed. Environmental archaeology is not the least important of the latter.

Let us first consider what questions the urban archaeologist can hope to answer —or, perhaps more relevantly, what problems are worth trying to answer. The first must surely concern the town site in its pre-urban phase. It is worth study for two reasons at least. An aspect of urban archaeology of consuming interest, and of relevance to modern conservation studies, is the ever-changing effect of urban man upon the natural environment. To understand this fully, the pre-urban ecology must be established. The pre-town topography and ecology will, furthermore, be germane to any consideration of the reasons for siting the town in its particular position. Geographical, geological, or edaphic factors or the presence of resources, perhaps no longer apparent, in the environment, may all have played their part. Former river regimes or drainage patterns may have limited the settlement or determined the location or direction of its early development. Such knowledge is fundamental to an understanding of the town, and to obtain most of it the techniques of environmental archaeology will be needed. In York, for instance, the basic relief of pre-Roman York is being established by correlating bore-hole data from existing records, mainly in the City Engineer's Office, and records from every new development. The careful observation of the earliest ground surfaces encountered in both commercial and archaeological excavation is—albeit very slowly—giving the opportunity for pedological studies, to establish for instance the pre-urban soil types and the incidence of flooding before man began his awesomely dispruptive meddling with the river. Pollen analysis and the examination of sediments for other botanical and for entomological data are also undertaken. The results are modest so far (Kenward & Williams 1979; Hall *et al* 1980), but the data will accumulate with time.

Archaeologists are notoriously preoccupied by origins, and urban archaeologists are no exception. Few towns are as lucky as York, with its putative occasion of establishment in the forward campaign of Petillius Cerialis in or about AD 71. Normally, origins are neither so precisely dated nor so emphatic as the establishment of a legionary fortress. The earliest parts of the settlement are, indeed, usually the most elusive. First, they are usually on the most favoured spot, most prone to repeated use; secondly they gave been there the longest, prone to the greatest chance of subsequent disturbance; and thirdly, they are quite probably evanescent and unimpressive, represented by temporary structures eventually destined for replacement, or out up before the true resources of the region had been exploited: that is, they are likely to be very difficult for the archacologist to recognize by conventional means. Nevertheless, the disruption to the natural environment caused by the sudden arrival of urban man should be evident enough if, in the environs of the town, deposits exist in which a natural sequence of pollen was accumulating, and even a study of sediments might reveal the event. With the advent of new dating techniques, study of these basically historical questions through environmental archaeology has potential indeed—of the kind glimpsed long ago in Brian Hope Taylor's work at Old Windsor (Wilson & Hurst 1958, 184). There, the establishment of the royal vi11 could be deduced from the deposits in the mill leet constructed at the time. The foundation of the vill was accompanied by deforestation, as the pollen analysis showed. The mill and its leet were built apparently in anticipation of a considerably increased grain yield from the new arable areas, for which there was ample evidence later on.

The topographical growth of a town has proved of consuming interest to both archaeologists and historians, and it will always form a major theme in urban studies. To establish when, and for what purpose, the various elements of a town were laid out, archaeologists are likely to depend mainly on the conventional evidence of stratification and artefacts. In those very many towns situated on rivers or the sea, however, there are opportunities for particular precision and particular insights into the processes of the exploitation of new town land, through the study of preserved organic remains. Some of the organic remains will, of course, be conventional archaeological material, but soil analyses and the evidence of the flora and fauna can play their part: they have been illuminating, for instance, in our York investigations of the development of the waterfront on both banks of the River Ouse (Kenward & Williams 1979; Hall *et al* 1980). Even the study of diatoms has elsewhere, as at Svendborg (Foged 1978), had its role.

With the origin and topographical growth of the town established, and the circumstances of construction of the main town structures understood, the archaeologist will wish to find out the functions of various parts of the town at various periods. Such research concerns itself first with the broad patterns of use and the concentration of specialisms in different neighbourhoods; but eventually, and indeed to obtain the first, it will also be necessary to establish the uses in much more detail, down to the changing functions of individual properties and, indeed, individual rooms. The enormity of such a task has been strikingly and brilliantly demonstrated in the first volume of *Winchester studies* (Biddle 1976) Here the research team has the benefit of uniquely detailed documentation from which it was possible to establish the ownership and often the use of the majority of the urban properties in Winchester at a variety of dates in the 11th and early 12th centuries. Not only was the range of occupation enormous within quite small areas, but there were significant and quite radical changes of use during the short period studied. To have established the same kind of picture from the evidence of excavation, of conventional and environmental archaeology, would probably have been impossible. Not only is much of the evidence long since destroyed but also the work involved to obtain the information would have been herculean, beyond even the archaeological Hercules who has already addressed himself to the Wintonian stable. It is worth trying, however. No British town is so blessed with documentary evidence as Winchester, perhaps, and archaeology is our only potential source for many towns and for many periods; an archaeological sampling policy, preferably a policy of sampling very large parts of differing regions of a town, should at least give insights into the system of urban land-use, the continuity or discontinuity of various uses, and, in satisfactory detail, the particular uses of a sample series of structures. Such pictures are becoming available now for a number of towns—Lincoln, Norwich, Northampton, Winchester, Gloucester, and many others. Where the area selected is waterlogged—our best York examples are, it is to be hoped that the long-awaited area excavation now underway in Carlisle will be, and future excavations in Lincoln could be—an especially valuable kind of story can be created. Combined study of documentation, of conventional stratigraphic and artefactual archaeology, of soils and sediments, of technological residues, of the imported raw materials, of evidence of the natural environment and the ecology of the building itself, can provide a 'neighbourhood study' of a detail rarely attempted even for a surviving modern community. Such a study is, we have shown at York, possible with an integrated archaeological and environmental team. Is it, however, worthwhile? It may be possible, but is it necessary? If so, can we really afford the enormous expense, first of excavating, then of extracting, processing, and interpreting the information, and finally of synthesizing it? Once or twice it may be, simply to establish once and for all in great detail the practices and living conditions of an historic town in its various periods of occupation.

In addition to the study of sample areas, the urban archaeologist, concerned to carry out a well integrated and well coordinated programme of research, will need to investigate specific buildings which might provide a sample constructional and occupational history for a particular type of structure once common in the city or town: perhaps one of its parish churches, or guildhalls, or hospitals, or mills; certainly one of its cemeteries for each period and each major 'socio-economic group' area. Since the experiment in each case is likely to be very expensive, and can rarely be repeated it is important that full advantage be taken of the opportunities provided by the excavation. One hopes that the site will have been selected not just with historical or conventional archaeological questions in mind, but also taking account of the needs of the environmental archaeologist—the guildhall by the river, for instance, rather than the guildhall on the well drained plateau. Nevertheless, even if the conditions are not particularly propitious for environmental archaeology, it will be far more useful for the archaeologist and historian to have an intensive and exhaustive environmental study of that site than of the common urban tenement. It is the painful experience of excavators that environmental archaeologists have an almost unassailable compulsion to study those sites where the deposits are rich in biological evidence rather than those which are archaeologically important but with sparsely preserved evidence. The attraction of the rich deposits is understandable: to counteract it good informed archaeological advice is essential to indicate the occasions when poor material may be worth studying. This makes particularly regrettable the suggestion by a most distinguished committee of many scientific, and even one or two archaeological, experts, reporting recently to the Minister on the needs for archaeological science (Directorate of Ancient Monuments 1978, 5) that the archaeologist's submitted samples should be sorted out for suitability of study by 'semi-skilled personnel such as experienced technicians and students in training'. Archaeological relevance should be the main criterion, and to establish it requires the attention of the best archaeologist available. It might be argued that it is far more important to have even the merest hint of an answer from a sample considered poor on other criteria than to have the most comprehensive seed list from one of little archaeological significance. The scrapings from within Diogenes' tub will be far more interesting to the archaeologists than the weeds which grew up around it; and even those will be more interesting than the weeds from the next field. One hopes that *relevance* in environmental archaeology will be a theme of discussion in both this and future conferences and symposia, so that proper principles of selection and sampling can be worked out.

But let us return to our considerations of the priorities for urban archaeology. Once the sites have been selected, and it is right that the initial selection should be a rigorous one in which all factors, historical, archaeological, and environmental, and the time available for excavation, have been considered, it is sensible that they should be investigated intensively, laying equal stress on conventional archaeological reconstruction and on the reconstruction of the environmental and occupational history from non-artefactual evidence.

The opportunity provided by excavation to extend natural history back into the past is not a prime concern of the archaeologist. It surely should be to natural scientists, though the possibilities in the various fields, particularly in distribution studies, have only been hinted at in the British literature up to the present. The concern of this paper is to summarize what the archaeologist seeks to know.

Firstly, he will be concerned to learn what conditions of life were like in the immediate locality before the building or activity under investigation began. He will wish to hear what effect the new activity had upon that environment, what conditions grew up as a result of the activity, what working conditions might have been like, both within the structure and nearby, and what effect, perhaps in terms of pollution, infestation, or smell, the activity may have had on the neighbourhood. Secondly, he will be concerned to learn of the activity itself. Here too often, as Leo Biek tells us (Biek 1963), both the archaeologist and the environmentalist overlook the possibility that technological residues, contained perhaps in what the archaeologist dumps on his spoil heap or the environmentalist dumps out of his sieve, can hold the key to the entire interpretation of the structure. There is certainly a case for including a technological specialist in any team of environmental archaeologists, someone who can recognize the evidence for what it is and devise sampling procedures for extracting it and methods for its study. In York we have begun to realize, however, that indirect evidence may be just as useful in defining the activity. The great grain pest infestation which overwheimed a 1st century warehouse in what is now Coney Street, York, and the usage of the warehouse, could be deduced in the absence of a single grain of corn. It makes the contents of the subsequent warehouse on the site, with its abundant surviving charred grain, a study of even more consuming interest. Both the presence of this early Roman warehouse in York, the disaster which overtook it, and indeed the source of its contents and that of its successor, could have considerable importance in understanding the progress of Roman conquest and settlement in the north (Kenward & Williams 1979).

Another subject of interest to archaeologist and historian alike will be the kind of people who carried out the activity. Conventional archaeology may hint at their level of wealth. But what this really means is beyond the scope of the archaeologist. Toll and custom records tell much about some commodities, but the historian can only rarely guarantee that they include reference to all products entering a city, or even provide a true and complete record of those they do mention. Even the palaeoethnobotanist cannot hope to provide a true sample, and reliably define both the range of vegetable and grain products available to the inhabitants and the changing patterns of their use in various parts of the city and as time goes by. How he should go about his attempts, however, is a crucial subject for debate both now (Green below, 40 - 6) and doubtless in the future. What interpretation should be placed on the surviving seeds and grains in any given deposit? Are all these superabundantly rich botanical samples from some of our urban sites—Durham, York, London—really as good an indicator as they might seem of dietary preferences? Can they really tell us more than simply that certain commodities were present, and that certain flora existed in the region? Ought we instead to be going back to impressions in pottery or burnt daub for a 'random' selection? In practice the superabundant deposits probably can be interpreted and made to reveal a meaning: but it will require the application of scientific methods as rigorous as those now used for the study of insect death assemblages (Kenward 1978; below, 71). Such studies are a world apart from analyses on samples derived from a so-called natural environment. They will have to take account of more thoroughly pervasive human factors, and allow for the exigencies of the uniquely complex archaeological circumstances found in towns (Greig below, 47-65, for example). Limits of inference from the data will have to be defined. Reports will be quite different from the naive uninterpreted seed lists which have graced—or perhaps rather disgraced— the typical English excavation report for so long.

In the same way, only the archacozoologist can define for us either the variety or relative popularity of the domestic and game animals and birds in the urban diet. Again the methodological problems are formidable, and compounded on deeply stratified and much disturbed urban sites by the problem of survival and reworking of rubbish. Even the size of the problem can be formidable. Eight years of continuous excavation in York has produced a store of well documented stratified animal bone from AD 71 to the present which, with only 20 seconds devoted to the study of each bone, would take 27 man years to evaluate. Nevertheless it is worth expense and effort. Towns, with their enormous requirements for food, for products made of bone, antler, and horn, for fats, for gut, for leather, are the only places where there will be gathered together a truly representative selection of breed types and environmentally determined animal size ranges for a whole region. Any single rural settlement is unlikely to reflect more than the specific preferences of its own area. In York things were probably always as they are now, when we are wont to see Swaledales in our markets as often as the fatter finer sheep of the Vale of York or of the Wolds. The history of all the varieties, and of their marketing in York, is as relevant to an understanding of York's wealth in early times as any factor we could study. A start is to be made, through a Science Research Council project on cattle and pigs. Another project seeks to establish the role of birds, both domesticated and wild, in the economy of early York.

It is heartening to know that studies of this kind have already been done elsewhere. One has been published by the Council for British Archaeology for another English town, Hamwith, Saxon Southampton (Holdsworth 1980), a knowledge of whose development is just as fundamental to an understading of the origins of urbanism. Such evidence will itself be of even greater significance when the comparable data for Winchester, an inland town ten miles away from Hamwih and in a different world, become available. There is room for some very hard thinking on the part of those who control the funding of archaeozoological research in Britain to ensure that the expensive and time-consuming effort involved in major faunal remains projects is directed where it is likely to produce the best results. Sites must be selected rigorously, and not only from the zoological point of view. Those where bones are sufficiently well preserved to be capable of providing a reliable picture will demand priority. Most importantly, however, the sites must be those for which the historical questions to be answered are worth the trouble. A quick glance at current reports rapidly convinces that the days of more or less meaningless species list are by no means yet past.

In one respect the criteria select themselves. In the study of small mammals and fish there are, even in towns where good preservation is often found, few where the conditions are good enough to preserve not just the most durable, but the lot. Few excavations, moreover, yet adopt sampling procedures adequate to ensure even the recognition, never mind the systematic recovery, of this kind of evidence. The archaeological world would, however, like to have this evidence. The whole story remains to be written for the earlier periods, before the survival of documentation. For later periods sets of zoologically derived statistics to set beside those of the toll and customs records would be of consuming interest. We know at York how many herring passed through Micklegate Bar in certain periods. The potential value of a cross-check, and of data on the commodities which did not interest the toll gatherer, is self-evident.

Studies of the environmental conditions of our cities through the ages, and the range and quality of the diet, are immediately relevant to another of the urban archaeologist's main priorities, the study of the human populations themselves. Urban cemeteries provide impressive incidences of the deficiency diseases and dental disorders directly attributable to diet, and of a shortened life-expectancy upon which a miserable environment must have had its depressive effect (Dawes & Magilton 1980). Once again, the results from one study, in this case by physical anthropologists, make immediate calls on the data of other specialists. Here, the subject is one which has a fundamental importance for historians. Demographic history starts, at present, with the keeping of adequate birth, marriage, and death records at the end of the 16th century: but skeletons provide a way in which at least a sort of demographic history can be written for periods far remote. Undoubtedly there will be an intellectual gulf to bridge between the reports of the anthropologists and their archaeological and historical users: but it will not be long before those users will be turning to their scientific colleagues in other fields to ask what caused these evident changes in life-expectancy, in physical type, in health. It will be they who press for more work on, for instance, the modest shifts in climate which, it appears, had a sufficient effect to be at least a contributory cause of social change, whether through greater prosperity or unrest consequent on periods of stress.

That time is, however, not yet with us. Very few archaeologists indeed felt it necessary to attend the conference 'Environmental archaeology in the urban contex'. It is not idle to speculate on the reasons for this. One may be the problems of communication. Few archaeologists are competent in science, though the advent of several courses in archaeological science in our universities perhaps means that this will not always be so. By the same token, few archaeological scientist have yet learned to express their findings in terms which can be understood by the layman, be he archaeologist or historian. Inevitably one is cautious in the use of experimental evidence which one cannot clearly understand, or which one lacks the capability to criticize. Another reason for the absences may be that, in truth, environmental archaeology in a urban context is still an unformed and unproven discipline, not yet reliable enough to be used as a matter of routine. Nevertheless the papers in these proceedings indicate that it has potential indeed. An especially hopeful sign is the emergence of research teams, in which specialist in various allied scientific disciplines come together to work from their various points of view on problems common both to them and to archaeologist of the more conventional sort. The first results of this kind of cooperation are only beginning to reach the printed or microfiche page. As more are published it will become increasingly evident that a golden age for environmental archaeology lies ahead (Addyman 1980). Perhaps the next conference on this subject will be inundated not by floods of muddy Ouse water, as this almost was, but by floods of archaeologists and historians.

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Quantification in urban environmental archaeology is new, experimental, and not always founded on reliable methodology Examples are given which illustrate the pitfalls of quantification without strict regard for the nature of the evidence that is quantified.

Among archaeologists it is a much favoured occupation to produce distribution maps—sheets with a profusion of small dots showing the occurrence of this or that type of barrow, axe, urn, etc. In a paper published some years ago, I advanced the suggestion that such maps should be banned immediately and totally for a period of at least 25 years.

A joke? Not entirely. Most archaeological distribution maps are misleading because they reflect the incidental occurrence or preservation of a certain object or feature. The producer of the map might realize this and furnish his map with reservations in the text or in footnotes. But when the map is reproduced and re-reproduced by others, such reservations usually disappear. In general, archaeologists are inclined to misuse the maps, as they do not sufficiently consider the basic problem of the *representativeness* of the quantitative evidence. This is, as I see it, one of the most serious methodological problems of today's archaeology.

In recent years, the importance attached to quantification in archaeology has increased greatly. There are many reasons for this. One is that the large excavation efforts have produced an enormous amount of material that cannot be mastered without a certain amount of quantification. Nobody will blame the archaeologist for that. It is also perfectly respectable for archaeologists to take advantage of modern computerized calculations when dealing with a large and complex body of material. But some colleagues are possessed by the pathetic idea that by the mere act of counting their artefacts or barrows and working out percentages they are raising archaeology from its modest place among the arts and transforming it into a social or even a natural science. They forget that while social or natural scientists usually have access to an unlimited amount of evidence, we are confined to work with statistical material which is biased already by the way it is handed down to us, and that we—unlike our scientific counterparts—in most cases are unable to demonstrate the representativeness of the material. Tom Lehrer will forgive me, for twisting his profound remark about Life in saying that, 'Quantification is like a sewer: what you get out of it depends on what you put into it.' Indeed, the water in our sewer is anything but clear.

These introductory remarks might have given the impression that I am against quantification in archaeology, Not at all. I am quite aware of the possibilities and advantages of this kind of work, and personally I am a bit of a microchip maniac. But I do feel that too many archaeologists have a shameless relationship to figures and statistics. I will give below some examples of good and bad behaviour in archaeological quantification most of them drawn from urban archaeology and almost all from medieval archaeology.

In medieval archaeology, quantification is a relatively new phenomenon. This branch of archaeology was once dominated by art historians who were often hampered by their aesthetic prejudices. Frequently, when excavating, they would only pick up objects which were beautiful or intact. So there was really very little to count. But with the rise of urban archaeology after World War II came the invasion of prehistoric archaeologists into the sphere of the medievalists—and with them came the painstaking collection of small finds and all the consequent quantitative problems.

Let me begin with some words about the most omnipresent of all archaeological finds—pottery. Fragments of ceramics are, as Sir Mortimer Wheeler has said, liable to occur in embarrassing quantities at most excavations. Among the specialists dealing with the utilization of excavated potsherds there are two prevailing religions: those who count the sherds and those who weigh them. Both methods have advantages and both are unfair to some part of the material: counting to the solid vessels and weighing to the thin-walled ones. A third religion demands counting the minimum number of individual pots in the find; this has obvious advantages, but as the method is rather time-consuming, this religion has but few followers.

No matter which counting method is used, quantification of ceramic material may solve important problems within the sphere of ceramics, particularly when the pottery is extracted from excavations with a convincing stratigraphy. The quantitative evidence can provide us with a reliable impression of the age, development, and simultaneous occurrence of different kinds and types of pottery. The pottery diagrams in the publication *Arhus Søndervold* (Andersen *et al* 1971, 64-105) are a fine example.

However, serious difficulties arise the moment the archaeologist proceeds from the study of the ceramics as such to the attempt at solving more general historical problems on the basis of ceramic evidence. A favourite target for quantification is the ratio comparing pottery imported from different places found at a certain site. We all know—or believe—that such pottery is an important source for trade history, indicating prevailing trade connections of the town or area in question.

But is this always true? Observations in Southampton invite reflection. Colin Platt has pointed out 'the deceptive failure of pottery to travel the obvious trade routes' by comparing the contemporary historical records on trade in Southampton (which are very rich) with the archaeological finds. In the 15th century, the Italian trade (silk, spices, and dyes) clearly dominated the port. This is evident from the detailed port books of the town, But in the excavations in Southampton, there is hardly one piece of Italian ceramics from before the year 1500, and most of the Italian pottery found in the town is from the 17th century—at which time the maritime trade direct from Italy to Southampton was virtually non-existent (Platt & Coleman-Smith 1975, **1,** 36; **2,** 29 - 30).

Since the 1930s, extensive excavations have been carried out at the Viking age settlement Hedeby (Haithabu) in Schleswig, and an enormous quantity of pottery has been picked up. Only 3% of these potsherds are of the distinct 'Baltic' type otherwise well known in the western part of the Baltic area. But in 1979, excavations in Hedeby moved from the settlement itself to the harbour basin. Here much pottery has been recovered along a jetty—60% of it 'Baltic' (Dr K Schietzel, pers comm). The excavation is still in progress, and it is too early to judge the reasons for this striking difference. However, this example emphasizes the dangers of using percentage calculations when estimating trade routes on the basis of quantification of pottery finds.

From the potsherds we move on to another treacherous object for quantification: human skeletons. In recent years Scandinavia has seen a number of excavations of medieval churchyards. One important example is Westerhus, described in an excellent publication by Nils-Gustaf Gejvall (Gejvall 1960). However, there are many examples of how archaeologists and physical anthropologists have drawn far-reaching historical conclusions from skeletal material with a poor representativeness.

In 1977 approximately 10% of a medieval churchyard in the Danish town of Viborg was excavated. Skeletal remains of approximately 450 individuals were removed, measured, and subjected to statistical treatment (Boldsen 1978, 76 - 85). The investigator stresses that there may be socially conditioned differences between the dead in different parts of the churchyard. Nevertheless, he treats his material as if it was typical of Viborg and indeed of all Denmark during the Middle Ages. This in itself gives rise to criticism. But his investigation is completely derailed when he continues by drawing up a 'population pyramid' to illustrate the age composition of the skeletons and comparing this pyramid with the results obtained in investigations of the life-span of certain Indian tribes in the USA. The comparison is absolutely worthless. The investigator does not realize that the mortality rate of medieval towns was so high that the towns survived only because of considerable immigration from the rural districts. In this immigration adults predominated, and even a reliable 'population pyramid' from a medieval town churchyard will consequently never give a correct picture of the mortality profile of the population.

In another Danish town, Svendborg, excavations have been carried out at the Grey Friar churchyard. Here 135 skeletons have come to light, and the leader of the excavation claims that they form 'a broad, perhaps even representative section of the population of medieval Svendborg' (Jansen 1979, 22). This is an extremely doubtful and very imprudent statement. As in the case of Viborg, the excavated skeletons come from a limited part of the churchyard, and the author does not take into consideration that the monastic churchyards usually only accepted corpses on payment. Consequently, it was mainly members of the upper classes of the towns and the nobility from the surrounding districts who were buried in the Grey Friar monasteries. By his claim of representativeness the excavator has provided the participating anthropologist with false premises, and he is therefore to blame for the untenable main conclusion of the anthropological examination of the skeletons that 'life was apparently good in medieval Svendborg' (Jansen 1979, 126).

From Svendborg we turn our attention to Skanör—a seasonal market place in the province of Scania, once Danish, now a part of Sweden. Here Lars Redin (1976) has carried out a thorough quantitative and qualitative analysis of a totally excavated cemetery with approximately 1250 graves. The main result is a well argued analysis of the chronological development of one particular aspect of the burial custom: the position of the deceased in the grave. To this effect Lars Redin reaches convincing results. But he aspires higher. As shown by the subtitle, 'A cemetery reflecting social structures in Skanör', he wants to write social history on the basis of his skeletons, and for this purpose divides them into three periods. The middle of these, period II, attracts attention. Both in relation to the preceding and the following periods, the middle period has more graves without coffins and an increasing proportion of the graves show interment in ordinary clothes. There is also a higher burial density; even the outskirts of the cemetery are used in period II, which chronologically must fall in the 14th century.

These features give Redin an impression of less care and increased heterogeneity in the cemetery, justifying 'an interpretation to the effect that after an introductory phase of comparative stability the social pattern in the community of Skanör became more disintegrated.' The main conclusion is the establishment of 'a picture of the social pattern which finds expression in the cemetery; the picture reflects a change from stability and social integration via social disintegration and ultimately towards tendencies of a renewed stability.' He phrases this cautiously. However, hardly cautiously enough. It is always extremely dangerous to seek social explanations of changes in burial custom. For instance, an investigator who knows no better might interpret the sudden disappearance of grave goods at the time of the introduction of Christianity as an expression of the impoverishment of society or as proof of the introduction of a communist society! And in the case of Skanör there is reason to be even more cautious.

The excavated cemetery is no average medieval churchyard. Skanör was neither a village nor a town but a seasonal market place, inhabited by thousands of people during the few hectic weeks of autumn herring fishing in the Sound and more or less deserted for the rest of the year. The temporary residents of Skanör were mainly in the fishing trade, young and strong people with a low mortality rate. In normal years, there were probably few burials. The cemetery probably also lost prospective customers due to the practice of salting down and repatriating the bodies of wealthy visitors (cf Roesdahl 1979)—a very obvious procedure in a herring market place. But this state of affairs would be completely disrupted by the sudden outbreak of plague or other dangerous epidemics. It is indeed possible that Redin's period II with its 'social disintegration', ie bodies buried in ordinary clothes and without coffins, is nothing other than the manifestation of a plague during one single autumn season, harrying the otherwise healthy community.

A subject of more immediate interest to these proceedings is the use of animal bones in archaeology. Several papers have dealt with the different methods of quantification of bones: weighing (which gives an advantage to elephants but is unfair to mice), counting the total number of fragments (which exaggerates the number of oxen due to the abundance of marrow-split and dog-crunched bones), calculating the minimum numbers of specimens in the finds (which is very time-consuming), and counting exclusively fragments with joints (which is perhaps the most trustworthy of the methods applied to-day). It is my impression that both zoologists and archaeologists are well aware of the numerous dangers and pitfalls associated with the various methods, which can produce such incompatible figures. Consequently, in this summary I will proceed from the time-consuming act of quantifying (in Århus Søndervold more than 100,000 fragments were identified and analysed) to the question of the utilization in archaeology of the quantification achieved by such industrious efforts.

I would like to take some examples cited in a book studying the fauna of early medieval Lund (Scania) by Jan Ekman (1973), who draws attention to the fact that while his material contains 1780 fragments of cattle bones, 1021 fragments of pig bones, and 880 fragments of sheep/goat bones, there are only 25 fragments of horse bones. This leads him to the conclusion that 'horses are uncommon and would scarcely have been an integral part of a man's property.' In the Swedish summary (which is generally more audacious than the English text) he even claims that the horse seems to have been a rare guest in the streets of medieval Lund. This conclusion would have been justified if horses actually dropped their bones while trotting round the town. This is to my knowledge not the case, and Ekman's reasoning is an object lesson of the dangers of using negative evidence. The lack of horse bones in the rubbish in the streets is easily explained by assuming that the medieval inhabitants of Lund did not eat horse meat.

Another flagrant misuse of negative evidence in Ekman's book appears in the discussion of the fish diet in Lund. He has counted 1370 fragments of cod bones but only 11 fragments of herring bones. So, although he points out the poor conditions for preservation of the fragile herring skeleton in the soil, he concludes (in the Swedish summary) that among salt-water fish the cod was by far the most important for the inhabitants of medieval Lund. However, Lund is only a short distance from Skanör, where incredible quantities of herring were brought ashore and salted—for one particular year we know the amount: 300,000 barrels. This overwhelming wealth of herrings from the Sound must have been felt in Lund.

When dealing with the quantitative evidence of the bones from archaeological excavations, many other sources of error are present. One important consideration is that waste from bone and antler workshops may distort the figures and make all comparison from site to site illusory. So can furriers' workshops, as in the town of Odense, where the skeletons of 60 flayed young cats were found in a pit (Hatting 1971). Another threat to bone statistics is canine activity. Dogs were numerous in medieval towns; for example, in 1444 the municipal dog-catcher in Vienna was paid for the capture of 866 stray dogs in the streets of the town (Wacha 1977) and there can be no doubt that the preferences and appetites of dogs have a strong impact on the composition of the rubbish heaps in towns. The dog bias in statistics must also be remembered elsewhere. In Greenland, a recent archaeological project (Meldgaard 1977, 159-69) tries to compare the conditions of the medieval Norse settlers with those of the contemporary Eskimos through excavation of ruins and rubbish heaps in their respective settlements. However, the difference in the use of dogs—the Eskimos had many for their sledges and for skin, the Norsemen only the few needed for shepherding—makes it impossible to draw realistic comparisons of living conditions in the two ethnic groups from quantitative analysis of the contents of their rubbish heaps.

Furthermore, it is necessary for the bone statistician to consider the quality and aims of the archaeological excavation from which he has acquired his bones. In many cases there is a striking poverty of small animal bones in the finds simply because the archaeologists have refrained from collecting the smallest ones due to lack of time (or inclination). Among the 100,000 bones and bone fragments salvaged in Århus Søndervold, there were only two bones from rats and not even one bone from a mouse or a herring.

If this was a general systematic error in the bone material, the damage to statistics would be of limited extent. However, the zoologist is often introduced to material of widely varying excavational quality from one and the same excavation. One might believe that an archaeologist is a person who loves everything from the past. Nothing could be more wrong. He or she is usually a specialist who devotes his life to the study or a certain period or feature and pays little attention to any other remains from the human past. I suppose that zoologists are pretty much the same; specialists in land snails probably only feel a halfhearted interest in reindeer and bats. But the trouble is that the archaeologist will often be compelled to dig his way through deposits from later periods to reach layers that really interest him. Decent archaeologists will of course try to register what they meet on their way down, but because of limited funds and time, they usually cannot do everything with the same thoroughness, and nobody can blame them for concentrating their main efforts on the central questions of the excavation. Let us take Århus Søndervold as an example. The purpose of this excavation was to find and analyse the remains of Viking age Århus. The deposits from this period were therefore investigated with the utmost care. There was less time for the layers from the later Middle Ages, and the collection of animal bones in medieval deposits could not be as thorough as for the earlier periods. This restriction would mainly affect the small bones, and I am tempted to see the decline in numbers of collected cod bone—822 (8·2% of all the bone fragments) in the oldest layers to 233 (2·2%) in the deposits from the 13th- 14th centuries—as the result of less detailed investigation of the later deposits and not, as suggested by the examining zoologist, an expression of a climatic change which ousted the cod from Århus Bay (Møhl 1971; Møhl does, however, realize that the excavation method might have distorted the figures).

The first lesson to be learned from this is that the biologist who wants to perform quantification of material from archaeological excavations ought to take part in the excavation himself, at least for a short period, in order to be able to realize the limitations caused by the methods applied.

In his contribution to David L Clarke's *Models in archaeology,* E M Jope points out that a medieval community was the focal point of a complex social and ecological system, and that sets of ecological models are required if we are to understand them. He claims that this 'requires excavation on a very extensive scale with a fully programmed assembly of ancillary services to amass significant samples of the data reasonably free from selection and bias' (Jope 1972, 974). This is sheer utopia. Even simple models of features from the past are bound to be full of bias. Complex archaeoecological models *à la* Jope, constructed on the basis of a network of doubtful simpler models, employing large-scale excavation and 'the full resources of computer operation' (Jope 1972, 983) will be foredoomed to such bias that one must question the value of producing them.

This paper, read in a forum of naturalists and environmental archaeologists, is not an attack on quantification as such, but is meant as a word of warning and a plea for calmness and restraint when quantifying. Figures are wonderful tools but it is all too easy to misuse them. With its dependence on fragmentary and biased evidence, archaeology is particularly vulnerable. Even simple tabulations may produce absurd results.

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The effects of climate on cities, and of cities on climate, have largely been overlooked by urban archaeologists and environmental archaeologists. The climatic factors particularly likely to have affected urban man in the past are outlined and discussed, drawing on evidence from a variety of parallels and historical sources. Climatic change and extremes may have had considerable importance to city-dwellers in the past and the existence of cities may have produced substantial changes in atmospheric conditions and quality.

The high level of human activity and population density that characterizes towns and cities has a marked effect on their climate and atmosphere. This much at least is readily accepted, but exactly what the changes are, or what mechanisms bring them about, is still not fully understood. Studies of the climatology of cities in the past are so limited, and gaps in our theoretical knowledge so large, that some meteorologists seem surprised at the suggestion that towns other than those of the 20th century have an urban climate, feeling intuitively that their climate would have differed little from that of the same area had the town been absent. This reaction is based largely on considerations of size: the overall size of the town, the size of its buildings, and its fuel usage, all of which would have been much smaller in the past. While size is certainly an important parameter, modified climates are by no means restricted to large modern towns and cities. However, before the climate of cities can be discussed the climate of the British Isles and its temporal variation must be considered, as this background climate remains the primary control on urban climate, the human factors being but a perturbation of it.

Climatic change in the British Isles

The British Isles enjoy a temperate oceanic climate, which is normal for the western margins of continents at middle latitudes, brought by maritime westerlies. Thus the summers are moderate, with mean temperatures of about 20°C on July afternoons in central England. Such temperatures are comfortable for humans, but somewhat cool for the best growth of some major crops, for example cereals. The winters are mild for such latitudes, due to the transfer of warm water to the western coasts by the Gulf Stream and North Atlantic Drift. Even in winter, freezing is generally restricted to the night except where cold spells set in through the advection of air from the north-east. Rainfall is near adequate in all seasons, but the western parts of the British Isles are considerably wetter than the east. In highland areas, the rainfall has a more pronounced winter component emphasizing the influence of relief, whereas the rain in lowland areas may arise more from thunderstorms or cyclones (Fig 1). It is not simply the amount of rainfall that is important, as communities soon adapt to the level experienced in a particular region; it is rather the variation about this mean which causes stress and may show itself in declining water supply to an urban population or in poor agricultural yields. The coefficient of variance for annual precipitation over the British Isles is shown in Fig 1; though rainfall tends to be more variable in southern England than elsewhere, the variability does not closely follow the amount of rainfall (Glasspoole 1921; Gregory 1955). Extreme rainfall variation results in droughts and floods, which have been discussed in a historical perspective by Brooks and Glasspoole (1928), although interpretation of particular events as droughts is not always unequivocable (Aranuvachapun & Brimblecombe 1978).

Wind can become a particularly destructive meteorological element and again it is extreme events that seem to be important. The distribution of speed of a 'once in 50 year' gust is shown in Fig 2. Interestingly, it has its minimum value in the London area (Shellard 1976). There are numerous other meteorological parameters that are monitored widely throughout the British Isles, but it is doubtful whether a great many of them, such as dew or cloudiness, have any lasting impact on urban populations.

Climate reconstruction

The instrument records of climate, while surprisingly long, cover only a fraction of the last 2000 years and the earlier ones are difficult to interpret. In England, these observations begin with an upsurge of interest in natural science in

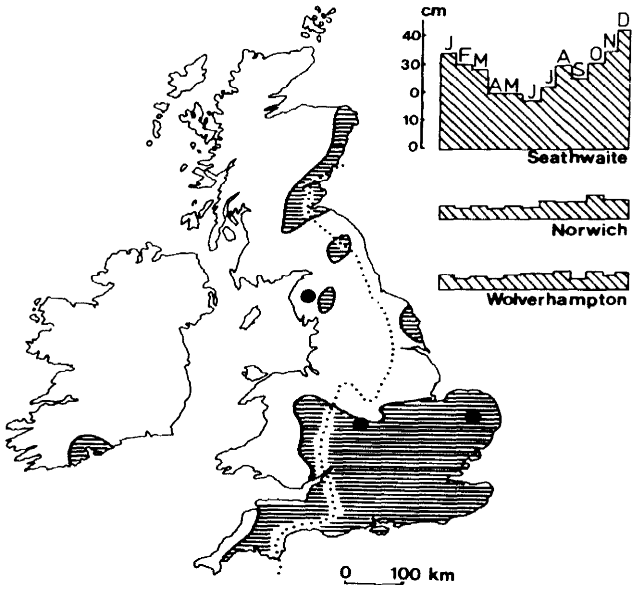

Fig 1 Rainfall of the British Isles where the areas of highest variability are shaded. In these areas the coefficient of variability is greater than 16%; that is the standard deviation of the annual rainfall amount is greater than a sixth the annual rainfall amount. Rainfall to the west of the dotted line amounts to more than 600mm(year. The inset shows the seasonal variation at three sites.

Fig 2 Distribution of extreme wind gusts over the British Isles. The diagram gives the maximum gust to be expected over a 50-year period: heavy shading 40 m s $^{-1}$; light shading 45 m s $^{-1}$; clear 50 m s $^{-1}$

the middle of the 17th century, and it is possible to obtain fairly consistent series from late in that century to the present for a number of important meteorological parameters, for example temperature, atmospheric pressure, rainfall, and wind direction. To extend the climatic record back further, one must use non-instrument observations, and the best of these, daily weather diaries, may be of a very high quality. The earliest such diary for the British Isles is from marginal notes in MS *Royal 7 F viii* in the British Library and probably describes the weather of Oxford for the year 1269-70 (Long 1974). It was followed in the next century by the outstanding set of observations made over seven years (1337-44) by William Merle (Symons 1891). Even in the period for which instrument records are available, the diaries such as those of John Gadbury (1691) or George Smith (Britton unpublished) may be very useful for examining the frequency of non-instrument parameters, such as fog (Mossman 189-7) or to fill gaps in-instrument records (Wales-Smith 1971).

Weather diaries are not common, however, and do not cover the last 2000 years adequately, so less direct methods of using documentary sources have been attempted (eg by Lamb (1 977)). An index of climate can be produced by counting the number of records of extreme events in a given decade; for example, Lamb's summer wetness index is obtained by subtracting the number of years that are mentioned as dry from the number mentioned as wet. Work of this kind has produced worthwhile information about general trends, but it has become increasingly evident that short term climatic changes (taking place in less than 50 years) can really only be studied after rigorous verification of the sources of documentary data such as those used by Lamb and earlier workers (Ingram *et al* 1978). In addition, the numerical techniques of 'contents analysis' are being used more frequently to extract quantitative data from the non-quantitative sources available to the climatologist and to test their statistical validity (Moodie & Catchpole 1975; 1976).

Ingram *et al* (1978) have recognized a number of problems in the use of documents in determining past climate, Firstly, it is apparent that many climatic data are doubtful or unreliable and that trustworthy observations are best obtained from contemporaneous or near-contemporaneous sources. Secondly, these authors point out the sensitivity of Lamb-type indices to random 'noise' in the data, and suggest that indices should be determined from the formula (e—m)/(e+ m), where e and m are the number of extreme events and moderate events respectively. This index should not be as sensitive to 'noise'. They also comment on the problem of the exaggerated frequency of documentary records of extreme events, which has the effect of increasing the spurious observations within a long term series.

Other methods of determining climate have made use of non-climatic observations in documentary records. Economic data on agricultural practices from account rolls can provide excellent seasonal information (Titow 1960; Stern 1979). The study of flowering dates, the movement of glaciers, pollen assemblages, tree rings, and varves provide indirect methods of obtaining 'proxy data' for determining past climate. The Climatic Research Unit at the University of East Anglia has been trying to bring all these methods together to study the general problems of climatic change. Although work is still under way, these new data and research techniques have improved the understanding of the climate of the past.

Temperature variarion

Using mainly proxy data, Wigley *et al* (1979) have examined the temperature changes in the northern hemisphere over the last 3000 years. The data are best used to give an idea of trends rather than absolute temperature, so their analysis gives times and places where cooling or warming was taking place. To gain an idea of the overall trend in Great Britain, the data points from an area bounded by longitudes 10ºW - 20ºE and latitudes 40º-70ºN were taken and plotted in Fig 3 which shows periods in which cooling or warming predominated. The vertical axis represents the percentage of available records with a given trend. It can be seen that around 1000 BC the northern hemisphere was beginning to cool (Neoglacial) after a climatic optimum (Hypsithermal). This cooling, like that of the Little Ice Age (AD 1400 - 1700), was probably a global event. The Medieval Warm Epoch (AD 1000 - 1200) on the other hand was not a global phenomenon.

In the period after AD 1000 documentary material becomes more common, and it is possible that quite detailed decadal pictures of climate will be reconstructed even for such a restricted area as the British Isles. Fig 4 shows some of the modified Lamb Indices that have been obtained after verification of the sources and the introduction of much of

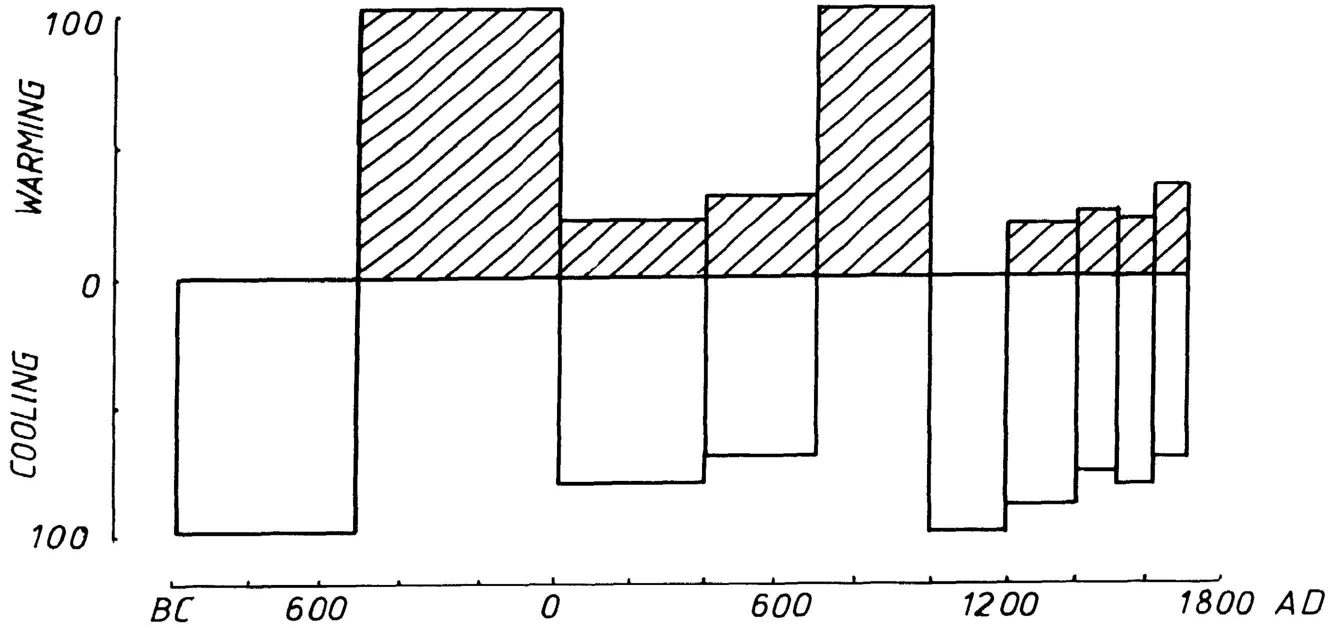

Fig 3 Cooling and warming trends in the sector bound by 10°W- 20°E and 70°N - 40°N. The data are expressed as a percentage of the records that show cooling or *warming trends.*

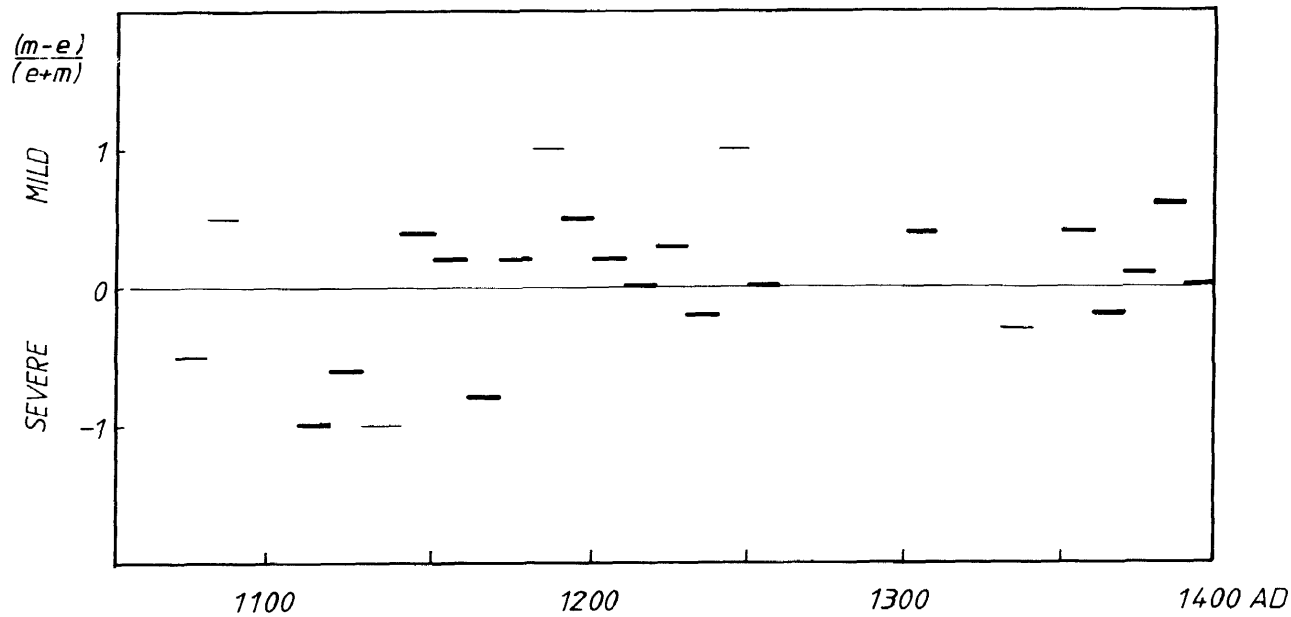

Fig 4 Winter severity indices for European weather (Alexandre 1977).

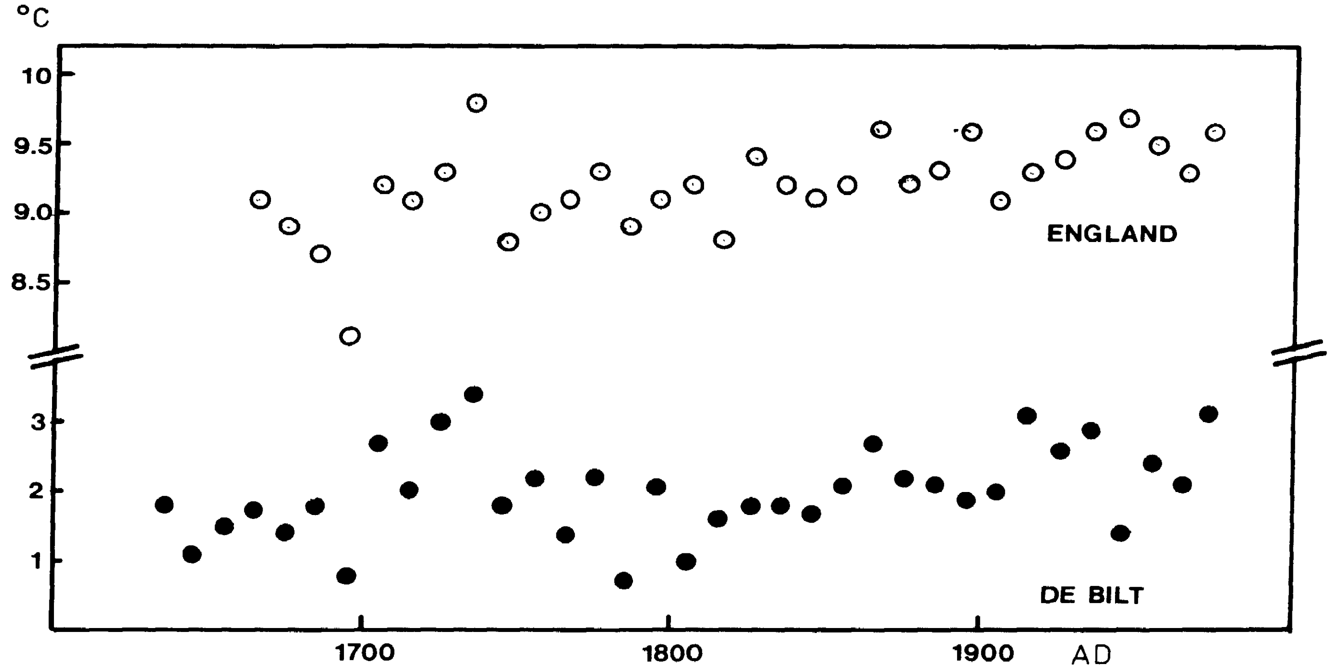

Fig 5 Ten year means of winter temperature at two European locations. The English record is for a hypothetical 'central England' site.

the newer material that is now available from account rolls and other indirect sources. Fig 5 shows two temperature records that overlap the period of instrument records. One is from Manley's (1974) temperature record for central England compiled from a large amount of early thermometry. The other is a similar record for De Bilt in the Netherlands, for which it has been possible to extend the temperatures back to 1634 through the use of administrative records of the freezing of Dutch canals (de Vries 1977; van den Dool *et al* 1978).

Precipitation trends

Documentary sources can also be used to study trends in precipitation over the British Isles. Indices of summer wetness are estimated in much the same way as for temperature; frequently, the number of notably wet July and August months is counted. Fig 6 shows the number of wet summer months in each half century. The dry climate that prevailed through the medieval warm epoch is particularly noticeable. The Little Ice Age seems to be marked by greater fluctuation in summer rainfall rather than a consistent increase. The 'quasi-periodicity' of approximately 50 years may be related to a similar periodicity in the incidence of periods of unchanging weather caused by atmospheric 'blocking situations' (Lamb 1977). The figure would also imply that the early modern period has been relatively wetter than early medieval times. A rainfall series for Kew (1697 - 1970) has been compiled by Wales-Smith (1971) from early observations, and the

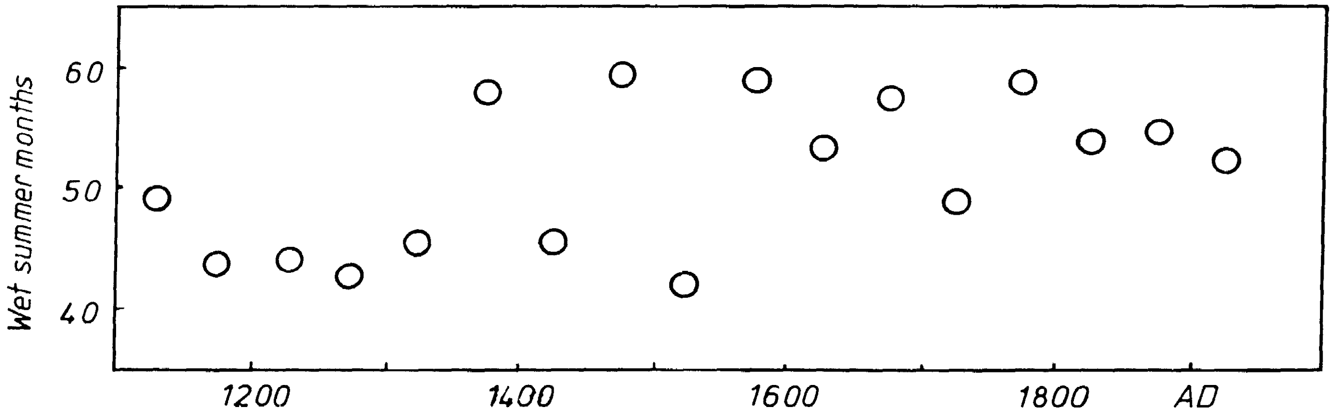

Fig 6 Summer wetness in England expressed as the number of predominantly wet summer months in each 50-year period (from Lamb 1977).

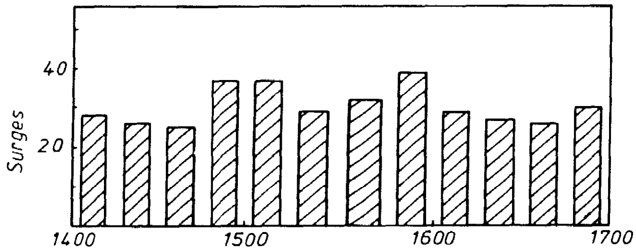

Fig 7 Storm surge index for 15th, 16th, and 17th centuries.

cyclic fluctuations in long-term precipitation have been discussed by Gray (1976).

Lamb (1977) has also commented on the changes in the seasonal distribution of rainfall. There was a marked increase in the wetness of autumns at the start of periods of climatic deterioration (after AD 1300 and the late 1600s). The springs of 1500-1750 seem to have been remarkably wet, but winters show the smallest change in wetness over the last millennium. Perhaps more important in their effect on human lives are storms. There seems to have been a high frequency of extreme conditions throughout the Little Ice Age and there were spells of high storm frequency. Fig 7 shows the index of storm surge frequency calculated by Niebel (1979) from data obtained by Gottschalk (1971-7). The storminess at the end of both the 15th and 16th centuries is particularly noticeable. This is not without historical importance when one considers that storms were largely responsible for the destruction of the Spanish Armada (Douglas *et al* 1978).

The urban climate

A picture of Manhattan from the air serves as a stark reminder of the tremendous effect that man's activities have on his surroundings. Little wonder that the clustering of tall buildings, the use of artificial materials, lack of vegetation, heat output, and air pollution have a marked influence on the climate of towns. Their climates are so different that urban climatology has grown to be an important branch of meteorology in this century, now that such a large proportion of the human population are city dwellers. Initially most research into the climate of cities was concerned with very large conurbations, but interest has gradually spread to smaller cities and towns with the discovery that quite small towns and even 'hypermarkets' may have their influence on the surrounding atmosphere.

Urban temperature

The clearest effect on climate is the rise in the temperature of cities over the rural background. A great deal of research has followed the recognition of the 'urban heat island' by Howard (1833) at the beginning of the last century. He noticed the comparative warmth of the metropolis compared with its suburbs. London appeared to have an 'artificial excess of heat' which amounted to more than two degrees Fahrenheit in some winter months. The increased temperature of the city was attributed to the warmth of its population, combustion processes, and the radiative characteristics of the 'urban surface'. Howard thought that

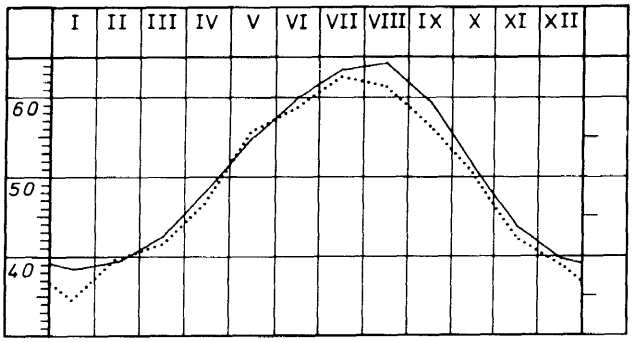

Fig 8 London urban temperature (solid fine) compared with the rural temperature as measured by Howard (1833).

the heated air from fires and furnaces was the major contributor to the urban heat island, but considered that radiation also played a role. This was deduced from an examination of the seasonal differences between urban and rural temperature (Fig 8); even in summer when fires were only used for cooking, the city continued to be warmer than the country. Howard explained this as follows: '(the) country presents for the most part a plain surface, which radiates freely to the sky, the city in greater part a collection of vertical surfaces which reflect onto each other the heat which they acquire.'

The fact that London had a heat island that could be detected even from rather crude observations at the beginning of the 19th century requires that it had a heat island which lay undetected for a considerable period before this. Re-examination of early temperature observations made in London might show this effect, but considering the lack of intercorrelation of thermometers it would be a difficult task. For the period since Howard's observations, Craddock (1972) has compared the temperature of Rothamsted (rural) and Kew (urban) over the interval 1878-1968 and shown the gradual increase in the difference between the two sites.

Fig 9 shows the difference in December temperatures at Kew and Rothamsted. A 1.8°C rise in temperature has

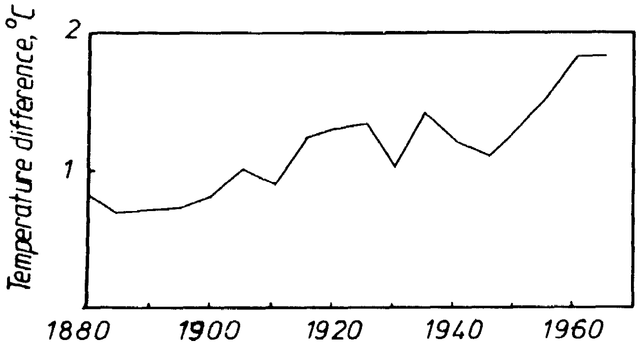

Fig 9 The difference in the December temperature measured at Kew and Rothamsted.

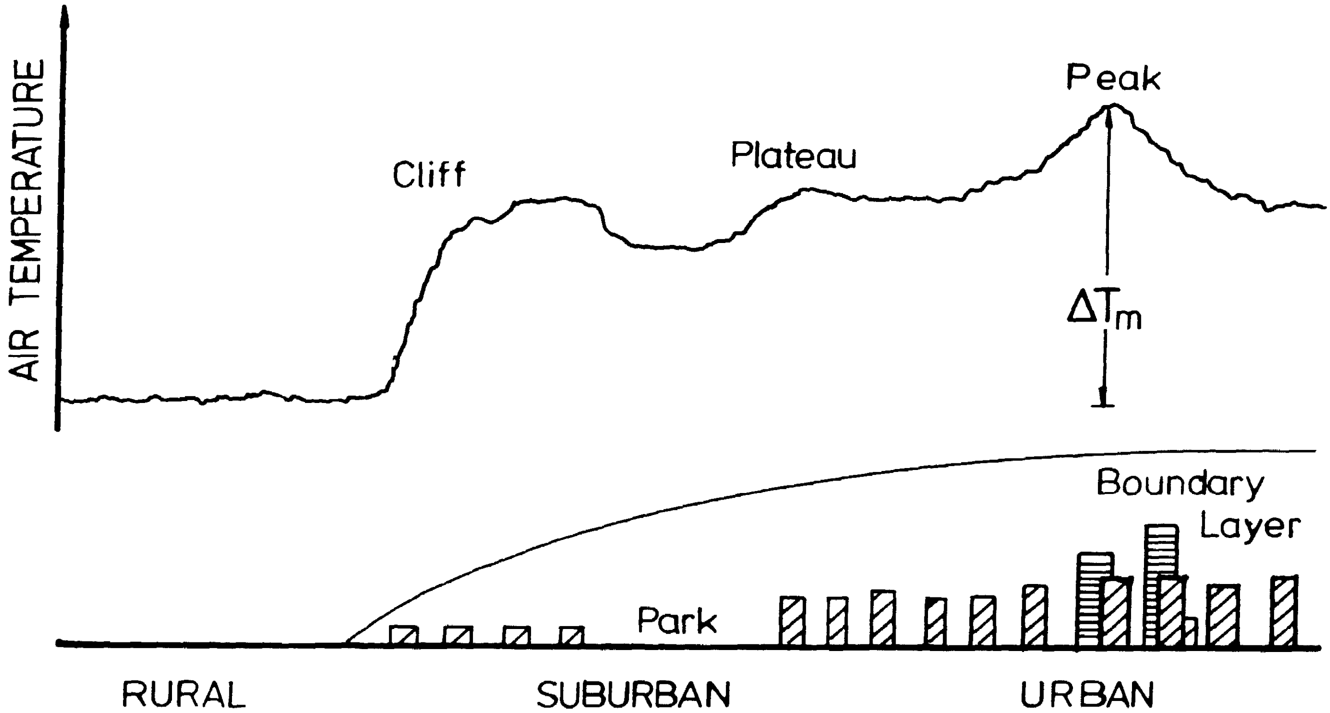

Fig 10 A generalized cross section of the urban heat island showing a temperature cross section and the form of the urban boundary layer (after Oke 1978).

occurred since the beginning of the record, when Kew was rural, to the present day 'built-up' state. The exact configuration of the urban heat island is dependent on meteorological and geographical parameters (eg Chandler 1965), but Oke (1978) gives a generalized cross section of an urban heat island under clear calm conditions soon after sunset (Fig 10). This shows the relatively sharp transition between the rural and built-up areas and the peak temperatures in the denser central city. The air flow in the city is quite different from that of the country, and as this flow moves deeper into the city the extent of the urban effect penetrates higher into the atmosphere. Temperature increases, and pollutants and turbulence will tend to cause mixing within this 'urban boundary layer'. Closer to the ground, the air partly entrapped between the man-made structures of the city is termed the 'urban canopy', and may show an even greater increase in temperature.

Although it has been emphasized that an urban effect on climate can be observed even in quite small communities, it is obvious that the effects will be larger and more noticeable in large cities. The largest persistent heat islands are observed in the biggest cities. Oke (1973) has examined the relationship between the population and the magnitude of the heat island and proposed the following equation for North American cities:

$$\Delta T_m = P^{1/4}/4u^{1/2}$$

where ΔT_m is the maximum difference between urban and rural temperatures, P is the population, and u is the wind speed. The equation shows that the intensity of the heat island is dependent on the square root of wind speed, such that it is greatest under calm conditions where the equation may be given in the following form:

$$\Delta T'_m = 2{\cdot}96 \log P - 6{\cdot}41 \quad \text{(North American cities)}$$

$$\Delta T'_m = 2{\cdot}01 \log P - 4{\cdot}06 \quad \text{(European cities)}$$

The difference between the formulae for European and North American cities may reflect different patterns of urbanization and fuel use. Thus the equations are not general ones. There are good theoretical grounds for believing that such exponential relationships should exist between heat island intensity and population distributions (Oke 1973). The two equations are plotted on a semi-logarithmic scale in Fig 11. The upper boundary is from the equation for the North American case and it is a little surprising that the line is steeper than for European cities (lower boundary), because this means that for a given size European cities will have a smaller $\Delta T'_m$, despite their higher population density. However, Oke (1973) suggests North American cities will have a higher usage of energy, be built of materials that store more heat, and undergo less evapotranspiration than European cities. It is evident that the controls on heat island intensity are complex, but the important ones are summarized in Table 1.

It is likely that heat islands in early cities would be better modelled on present day European ones than North American urban areas. From Fig 11, there would appear to be good reasons for believing that under calm conditions

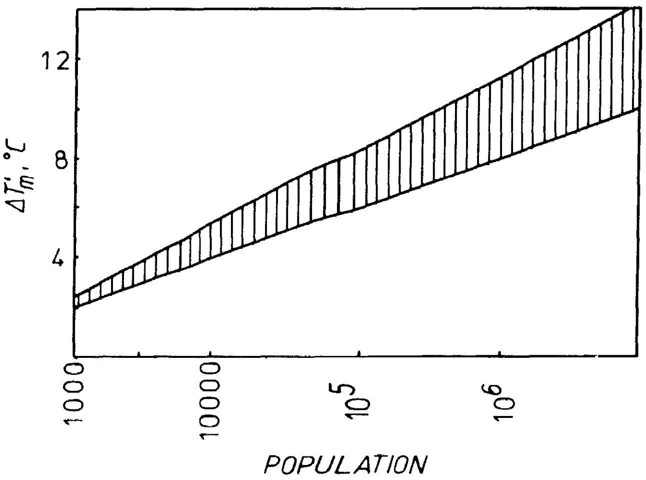

Fig 11 The relationship between urban population and the magnitude of the urban heat island (ΔT'm). Medieval cities probably had heat islands close to the bottom of the shaded area.

heat islands in excess of 4° cannot have been uncommon in cities of late medieval England.

Urban precipitation

While it is quite possible for the presence of a town to induce changes in the precipitation pattern, through the introduction of suspended particles and changes in convection brought about by the urban heat island, the effect is relatively small (about 10% increase) and occurs downwind from the city. Despite this, there is evidence that as early as Elizabethan times there was an awareness that intense convection brought about by large scale agricultural burning could trigger thundersrorms (Evelyn 1661). Howard (1833), with remarkable foresight, considered that the urban plume of warm smoky air could induce cloud formation.

Table 1 Origins of the urban heat island (from Oke 1978)

1 Blanketing effect by pollutants in the urban atmosphere absorbing outgoing longwave radiation
2 Increased absorption and decreased emission of radiation from the vertical urban surfaces
3 Greater heat storage by urban materials
4 Heat produced by human activity
5 Decreased evaporation due to less vegetation
6 Decreased heat loss due to lower wind speeds

The important effects of urban precipitation are not related to any small increases in precipitation amount, but are really related to the properties of the urban surface onto which the precipitation falls. Streets and buildings are more 'waterproof than the country, materials such as brick and stone having a far smaller storage capacity. When a storm hits an urban area the water appears directly as run-off: very little is trapped by vegetation or soil. The discharge through drains closely follows the input from the storm. For this reason storm sewers have to be exceptionally large to cope with this very direct input of precipitation. Without such facilities, flooding during storms may be extensive, so that in early cities, which lacked adequate storm drainage, this may have caused considerable hardship in the low-lying areas immediately after large storms.

The surface flow that occurs during storm drainage is frequently highly polluted and in past times was no less so, picking up contamination from rubbish and foul sewage, and contaminating the drinking water. There are frequent mentions of this problem in medieval documents and a later account appears in Swift's *Description of a city shower* (1711) [kennels—gutters] :

> Now from all parts the swelling kennels flow,
> And bear their trophies with them as they go:
> Filth of all hues and odours seem to tell
> What street they sail'd from, by their sight and
> smell . . .
> Sweepings from butchers' stalls, dung, guts and blood,
> Drown'd puppies, stinking sprats, all drench'd in mud,
> Dead cats and turnip-tops, come tumbling down the
> flood.

In times of drought, quite opposite problems may have arisen. Very low water flows in streams and channels used as open sewers would have allowed them to become blocked and polluted. The occurrence of droughts in England is discussed by Brooks and Glasspoole (1928) and through the instrument period by Wigley and Atkinson (1977).

Precipitation may also accumulate as snow during cold weather. The presence of snow greatly increases the 'albedo' of the urban surface and a large amount of the incident solar energy is re-radiated. This means that the radiative urban heat island may be destroyed, although under such conditions the output of heat from fires may be considerably increased. If there is any wind the snow may drift and the numerous vertical surfaces in the city will favour accumulation of the snow, allowing it to become quite deep in places. An example is shown in Fig 12 where a road with fences on either side would become totally inundated.

Urban wind

There is much evidence that the average wind speed within a city is lower than in nearby rural areas (Frederick 1964; Munn & Stewart 1967; Graham 1968), but Chandler (1965) has shown a significant variation from this rule for London. The difference between rural and urban wind speed depends on the wind speed itself, the time of day, and the season- At night when the winds are light, the speed is greater in the city than on its periphery; when the wind speeds are higher, the rural speeds are greater than the city

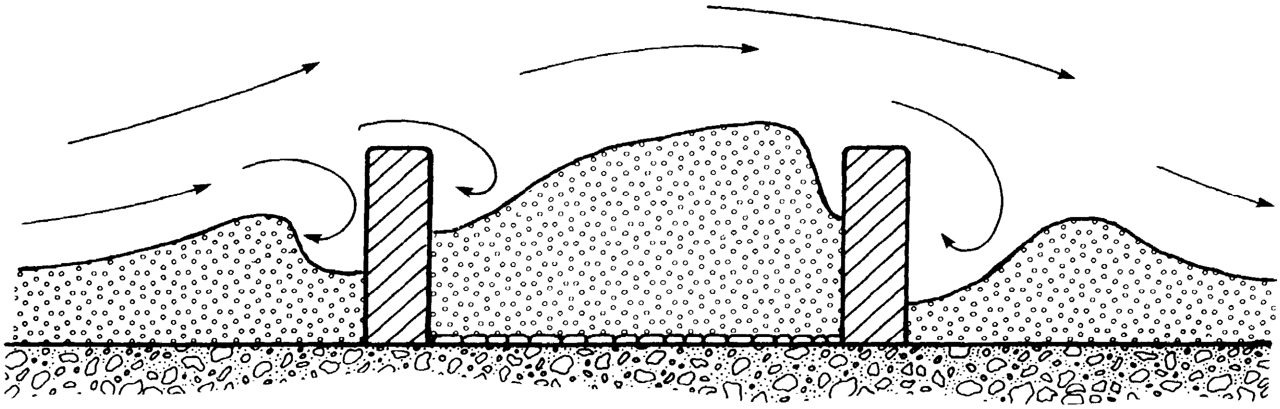

Fig 12 Accumulation of drifts on a walled road (from Oke 1978).

values. The critical value of wind speed which determines whether the rural or urban winds will be strongest varies with season, being about 5 m s^{-1} in winter, during times of high atmospheric stability, and lower during summer and autumn days (3 · 5 m s^{-1}).

These slight changes in wind strength are probably unimportant to the urban dweller. Much larger changes are caused by the modified airflow around buildings. The increased turbulence that results can cause annoyance through the whirling of dust and litter (Gay 1716), but in extreme cases where the buildings are tall a person emerging from a sheltered area may experience a sudden four-fold increase in wind speed (Oke 1978). As the force increases with the square of the wind speed this is potentially quite dangerous. Under conditions of high wind, the eddies created by one building can so increase the force of the wind that those in the lee may be damaged.

Optical properties of the urban atmosphere

Changes in the transparency of the urban atmosphere were among the first to be noticed. This is not surprising, since they do not require instruments for their observation. Evelyn (1661) complained of reduced visibility in London because of its smoke, and travellers complained of the fogginess of London by the late 17th century. The changes in transparency of the urban atmosphere are due to the introduction of the fine particles that generally arise from combustion processes. Their effect is amplified by the fact that in humid conditions water condenses onto these particles, causing fog. 'Great Stinking Fogs' were frequently recorded in the weather diary of the London astrologer John Gadbury (1691). Mossman (1897) has gathered the records of London fogs between 1720 and 1890 and they show a remarkable increase through this period (Fig 13), though there are great difficulties in the interpretation of old descriptions of fog.

While the attenuation of visible radiation is great, that for ultraviolet wavelengths may be even greater and may mean considerable reduction in the exposure of city dwellers to shortwave radiation, particularly in the winter months. The removal of blue light from the incoming radiation gave rise to the browns and yellows of London's atmosphere, which Byron described in *Don Juan* (1819) as a 'dun coloured cupola'.

Climatic change and man

Climatic extremes and climatic change have affected man since the earliest times as is to be seen from Egyptian papyrus records or the Bible in the seven fat and seven lean years (Lamb 1977). Sakamoto (1976) gives a number of examples of the effects of climatic change on past urban

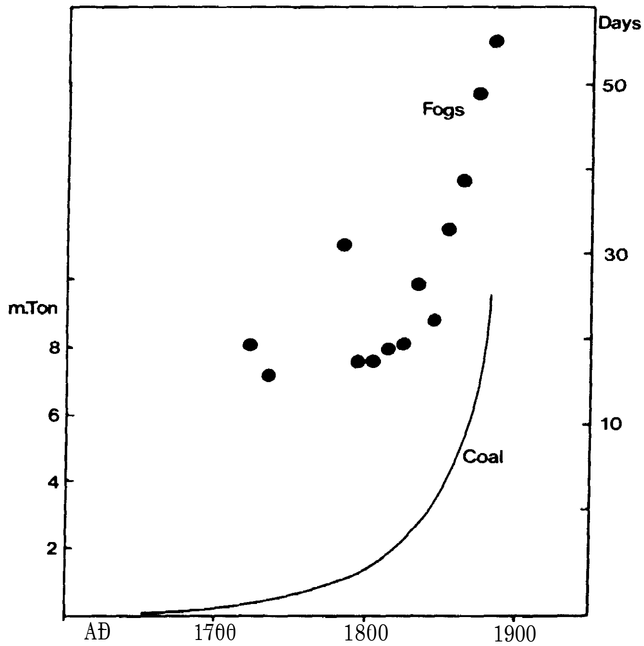

Fig 13 Coal imports into London compared with the decadal means of foggy days per year.

civilizations. It is the extreme events in climate that are noted by contemporaneous chroniclers, while the gradual changes are more easily determined by proxy or archaeological evidence. However, it is important to consider the impact of extreme events on the population. The incredible violence and fury of the elements makes a strong psychological impact today; little wonder, then, that in the past supernatural influences were thought to be at work, though by the 17th century new explanations were being sought. In Robert Harrison's (1682) account of the tempest at Oxford on 31 May 1682 he writes, 'Now because such events, with the vulgar are usually sealed *immediato Dei vel Daemonis Digito,* with the immediate finger of God or the Devil, I shall essay to demonstrate that this *Phanomenon* to be the meer Result of Secondary Causes . . . '.

The Little Ice Age

Relatively few studies have been made of the effect of long term climatic change on urban populations. It is evident that in the past, migration provided the means to cope with this (Sakamoto 1976), although today concern about the probable climate change resulting from the warming effect of increased carbon dioxide arises from the knowledge that migration in response to climatic change is no longer feasible. Haas (1976) has made a study of the social impact of a 2.5°C decrease in temperature on an urban population, which was probably about twice the change experienced in Europe during the Little Ice Age. By the mid 16th century not only were temperatures lower than at present, but summer rainfall was higher (Lamb 1977). This must, for example, have reduced the rate at which roads (totally dependent on the weather and the nature of the soil) could dry out. The tendency for extreme events during the Little Ice Age must have made roads even less passable than usual.

The earlier Tudor governments facing the problem of poor roads had established, under the Acts of 1555 and 1563, a system whereby the repair of roads was the responsibility of each parish and was to be supervised by the parish overseers. While this system may have worked on remote, rarely travelled lanes, it was not sufficient for the maintenance of the more well travelled thoroughfares. London's growing importance and size meant increasing traffic while road maintenance was itself at best static and at worst declining. The Weald of Kent and Surrey was traditionally an important area in supplying London's needs. It is not surprising to find that Wealden roads were described as being 'so miry, that the traveller's horse frequently plunges through them up to the girths of the saddle; and the waggons sinking so deep in the ruts, as to slide along on the nave of the wheels and axle of them'.

Haas (1976) feels that the deterioration of climate changes the family structure, making it more the centre of social interaction. With the increased need to remain indoors there would be more personal interactions and quarrels, more parental and sibling influence, and less peer influence. Political involvement is also reduced under extreme climatic conditions, particular evidence of this emerging in the harsh winters of the early American settlements where blizzards frequently prevented citizens from participating in local affairs. Despite all this, short periods of extreme cold seem particularly invigorating; witness the early development of skating as a sport (MacGregor 1976) and the population turning out to frost fairs (de Beer 1955).

Declining temperatures shorten the growing season and poor weather can ruin crops before they are harvested. The urban climate may counteract this to a small extent as plants benefit from the extra warmth offered by the urban environment. The flowering of some plants under the urban canopy may well occur earlier than in rural areas (Oke 1978). Of particular significance in the British Isles is the persistence of vineyards well into the Little Ice Age (Manley 1952). Manley has also suggested that some increase in temperature may have been brought about in the carefully tended, sheltered gardens, which may have had a mean annual temperature several degrees higher than those in exposed surroundings (Rosenberg 1966). The gain in temperature arises chiefly from the restriction of longwave re-radiation; however, crops in such gardens no doubt benefit from the wind breaking and higher humidity which would lead to lower transpiration loss. Night time temperatures in such shelters tend to be lower than in exposed locations, although if the soil is compressed (by frequent trampling during care of the vines) and well irrigated, nocturnal temperature increases of more than a degree may be realized (Bridley *et al* 1965).

Fogs and other changes

The optical changes to the urban atmosphere have had a surprisingly varied impact on the urban dweller. The most obvious result is the effect of fog on transport. Although we have all read of 'fog on the line' delaying the trains in London last century, there is evidence that fog was inconvenient to road and river travellers within London as early as the 17th century (de Beer 1955). The fogginess of the urban environment has also had its influence on art, as shown by the large volume of poetry, prose, and painting concerned with fog in London (Brimblecombe & Ogden 1977). The opening paragraph of Dickens' *Bleak House* illustrates this:

> Fog everywhere. Fog up the river, where it flows among the aits and meadows; fog down the river, where it rolls defiled among the tiers of shipping, and the waterside pollutions of a great (and dirty) city. Fog . . . .

The gloom the winter fog brought to London made the season particularly cheerless and the particularly high incidence of thick fogs in November has often been related to the high suicide rate, as the French proverb reminds us:

> In October the Englishman shoots the pheasant
> In November he shoots himself.

The need for brightness has been emphasized by those concerned for the psychological welfare of those living in the more polluted British cities (Veitch-Clark 1929), but it reflects a longstanding interest in the relationship between climate and health. Many (eg Montesquieu 1949; Bowen 1969) would try and take these relationships even further and see climate as a factor in the social character of a nation.

The history of air pollution

The increasing pollution of the air in England, and

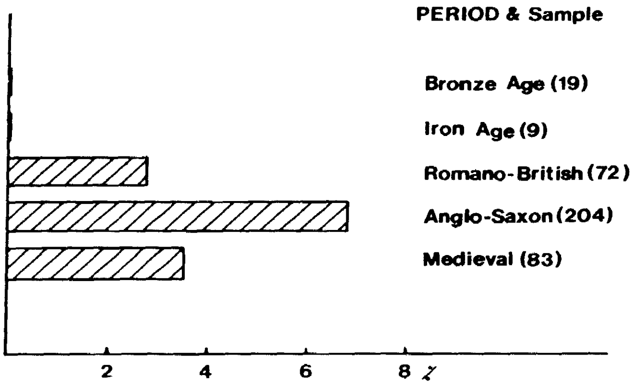

Fig 14 Frequency of sinusitis in skulls from various periods (data from Wells 1977).

particularly London, can be traced back nearly a millennium, through times when overcrowding, new fuels, and economic pressures exacerbated the conditions of the city's atmosphere (Te Brake 1975; Brimblecombe 1975). Until recently, the term 'air pollution' has been synonymous with 'smoke', emphasizing the key role which combustion processes have played in the generation of air pollution. Of course, the stench from sewers and refuse piles has provoked ample comment in historical documents, but writers have somehow found the pollution from burning, particularly of sulphur rich fuels, 'unnatural'. However, it is possible to find evidence of air pollution occurring before cities became established.

In Anglo-Saxon Britain there was a surprisingly high incidence of sinusitis as deduced from close examination of skulls in ancient burial grounds (see Fig 14). While the high levels in this particular period may be attributed to a number of factors such as facial anatomy and climate, it seems likely that pollution aggravated the infections. The ill-ventilated huts of Anglo-Saxon times, and a poor climate, may have had a profound effect on health (Wells 1977). Although no lung tissue survives from early British peoples, mummies from the still unpolluted Canary Islands show anthracosis from prolonged exposure to smoky interiors.

Air pollution in Plantagenet England

Although air pollution was noted in the Rome of Horace's time, it did not really become a problem until the introduction of coal as a fuel. The first documentary evidence of such pollution tells how Eleanor, the wife of King Henry III, was obliged to leave the city of Nottingham in 1257 for fear that the coal smoke would ruin her health (Luard 1866).

Fossil fuel was first brought to London as ballast at the beginning of the 13th century. It was so cheap that artisans responded to price controls enforced by the city's governors and favoured coal rather than the increasingly expensive wood, which had become scarce by the end of the 13th century. The biggest user appears to have been the lime-burning industry, in which as much as 370 tons of coal were used in large scale castle-building operations *(Exchequer K R Accts* 467 No 4). Stocks retained for forging averaged about 4 tons and the few other uses no doubt required only small amounts of the fuel (Brimblecombe 1975).

Building in medieval times was a predominantly summer activity (Brimblecombe 1975), so that lime required for mortar had to be made in this season. Fig 15 shows the lime usage during the construction of Harlech Castle in 1286 compared with the monthly distribution of pollution 'incidents' in Plantagenet London. This summer phenomenon associated with the seasonal work is quite unlike the pollution levels in London in more recent times, which have tended to show a winter peak due to the large amount of coal used for domestic heating.

The medieval traveller coming from the cleaner air of the country was particularly struck by the smoky city air. Criticism by visitors has survived to the present (Ebert 1723; Moritz 1783) despite the brevity of their contact with the London air. In medieval times, the principal danger of air pollution was thought to be its effect on health. This notion seems to have arisen naturally out of popular medical theory of the time which linked disease with 'bad airs'. The concern for the health of the population at large was voiced even in 13th century legislation (Brimblecombe 1976). However, once legal precedents had been established, accusations of pollution could be used to get rid of unruly neighbours and undesirable political groups, or for venting anger at tradesmen such as butchers, brewers, or lime-burners (Brimblecombe 1976). At the same time, householders were astute enough to complain that the smokiness of some localities lowered the value of their properties (Chew & Kellaway 1973).

The legislation of the 13th century was reactionary and tried to force the artisans to return to the use of wood as fuel. There were few other available solutions to the pollution problem at the time, however. The users of coal seemed to be aware that the stable atmospheric conditions at night could lead to severe pollution; even before 1300, a group of London smiths decided not to burn coal after dark

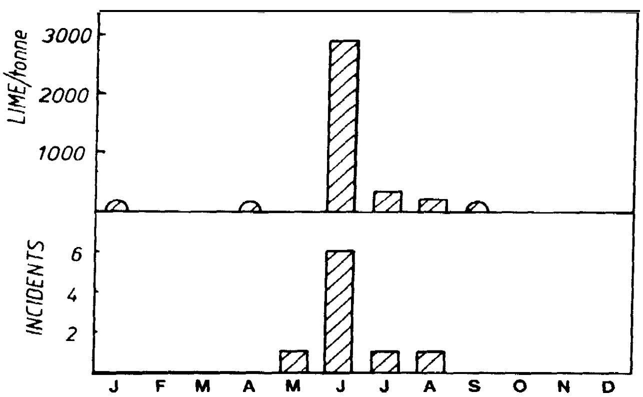

Fig 15 Seasonal usage of lime in the construction of Harlech Castle in 1286 compared with notes on air pollution in 13th century London from parliamentary rolls. Very small lime purchases are designated by semicircles.

(Thomas 1924). Occasionally, some towns tried to persuade kiln-masters to work beyond the town boundaries (Leach 1900) and there is evidence that chimney heights were specified in some London building regulations as early as the 14th century.

Sea-coal as a domestic fuel

It has been widely believed that the transition from wood to sea-borne coal as the main fuel in southern England was brought about by the depletion of the forests about London. However, it is unlikely that the shortage was a national one as implied by Nef (1932). Timber prices in England between 1450 and 1650 rose by just under 400%, while those of all other agricultural products rose by 570%. Timber was thus becoming (relatively) cheaper, but this was not reflected by the cost of fuel in London, where, between 1540 and 1640, the price of timber increased by 780%. The fuel shortage was localized and the increase in price reflected the costs of transportation, exacerbated by poor climate and road conditions. Wood sources near navigable rivers had become totally depleted, so coal brought by the sea from the northern ports could compete effectively.

Despite the undesirably sulphurous nature of coal, it became increasingly attractive as a domestic fuel for Londoners during the early 17th century. It certainly was not acceptable to most citizens in Elizabethan times, but bequests of coal rather than wood were made to the poor. Holinshed (1577) wrote, 'now we have many chimneys and yet . . . then we had none . . . ', suggesting that a technological change had occurred which had increased acceptability of coal as a fuel. Moreover, the accession of a Scottish monarch, James I (VI), used to domestic burning of coal, further enhanced its popularity, such that Howes (1615) could write, '[whilst previously] nice dams of London would not come into my house or room where sea-coales were burned . . . [it was no longer so]'.

Industrial use of coal

The poor condition of the roads in Tudor times meant not only that charcoal could not be transported from the forests, where it was made, into the cities, but nor could the products of forest-based industries (eg glass, alum). Thus these smaller industries moved into the cities causing further strain on wood supplies. The switch to sea-borne coal was inevitable. However, the industrial use of coal came only slowly and, where it was used, the process was often covered by patents granted to noblemen (Kenyon 1967), so here the pressure to use coal arose from the desire for profit rather than fuel conservation.

The problems encountered by industries forced to adopt the new fuel were great. Although parliament encouraged the conversion to coal in order to preserve wood supplies for England's growing navy, experiments on the charring and coking of coal were unsuccessful and the transition slow. It took nearly two centuries before the iron industry could use coal rather than charcoal. It may have been that the lack of industrial use of the fuel delayed agitation against coal burning till the 1650s.

While Charles I battled for monopoly over the coal trade, and during the Civil War that followed, London was often without coal. This allowed some people to appreciate smokeless air, and encouraged accomplished men of the age to write about air pollution and its effects (Brimblecombe 1978a). Sir Kenelme Digby (1658), in his *Discourse on sympathetick powder,* developed a theory for the corroding action of air pollution based on the atomic theory of matter which was then coming into vogue. He considered that the corrosive nature of pollutants arose from their sharply pointed atoms. John Graunt (1662) was convinced that the high death rate among London's population was largely a result of coal burning. The classic work on 17th century air pollution is John Evelyn's *Fumifugium* (1661); it is still a superb description of non-photochemical air pollution and its effects.

The centuries that followed saw the adoption of coal throughout industry and the introduction of the steam engine which marked the beginning of a new age. The pollution got worse, but until the mid 19th century there were only sporadic attempts at control. Interest in smoke abatement began with concern for better control of industrial sources, a concern which only spread to domestic emissions a hundred years later (Ashby & Anderson 1976; 1977a; 1977b).

Atmospheric pollutants

The most frequently recognized pollutant from coal burning has been smoke because of its visibility. The sulphurous odour did not remain unnoticed for long, so the two major pollutants from coal burning were recognized relatively quickly. Demands for abatement tend to have been largely directed against smoke, the more visible although less damaging of the two.

Smoke arises from incomplete combustion and it was the financial loss incurred by not burning coal efficiently that led to the introduction of smokeless grates into industry in the last century, although they never proved particularly popular in homes, where blame was often placed on poor stoking by servants (Anon 1854). The Englishman came to regard a roaring fire and the emission of smoke from his chimney as part of his birthright (Bevan 1872) and a sign of prosperity.

Sulphur dioxide pollution arises from the oxidation of sulphur present within coals, soft bituminous coals having a rather larger amount than the harder anthracite. There is no simple way to reduce the amount of sulphur dioxide produced during combustion, except through the use of a low-sulphur coal.

Smoke and SO_2 are not the only products arising from the combustion of coal; the poisonous gas carbon monoxide may also be produced. While it is unlikely to be a serious problem outdoors, fatal concentrations can build up in poorly ventilated rooms since the gas is odourless and thus undetectable (early example: Frewen 1762). Combustion in a hot flame causes the combination of atmospheric oxygen and nitrogen to form nitrogen oxides. These are normally thought to be the contaminants found in those cities with large amounts of pollution from motor vehicles and the long sunlight hours necessary to yield photochemical smog. However, observations of the trail of air pollutants that stretched to the lee of London for perhaps a hundred kilometres in the 18th century suggest that photochemical processes were already occurring (Brimblecombe & Wigley 1978). Chlorides, ammonia, and heavy metals in fly ash are also released into the atmosphere during the combustion of coal, but it is likely that these and the nitric oxides had only limited effects on the urban populations in English cities until recent times.

Air pollutants arising from non-combustion sources will not be discussed in detail here, although foul stenches must have been commonplace in cities where sanitation was poor. In 1290, the smell from the Fleet River was so bad that the White Friars, some 200m distant, complained that it had killed many of their brethren (*Rot Parl,* 1, 61b). Digby (1658) recognized the difference between the two types of pollution, suggesting that Paris suffered excessively from 'stinking dirt' while London's problems were essentially related to coal usage. We can deduce that the problem in Paris arose from sulphides, for Digby noted the blackening effect it had on silverware.

Past air pollution levels in London

It is possible to use economic data and a knowledge of urban geography to calculate the magnitude of past air pollution levels in cities. This has been done for London (Brimblecombe 1977), but there is no reason why it cannot be repeated for other cities. The pollutants released by the urban area (Q_p) may be imagined as dispersing themselves in a volume of air defined by a city of diameter d, with the mean wind speed ($\overline{u}$) and the height of the inversion layer ($\overline{h}$). The pollutant concentration ($\overline{C}$) can be equated to the pollutant emission divided by the volume

$$\overline{C} = Q_p / d\,\overline{h}\,\overline{u}$$

where the inversion height under conditions of neutral stability is given by the formula

$$h = 0{\cdot}075\,(d/2)^{0{\cdot}68}$$

This formulation is inconvenient because it requires some unusual units for input (eg pollutant output as $g\ s^{-1}$) and a knowledge of the pollutant emissions from a city rather than the fuel usage which is generally more directly accessible. The equation may be modified to

$$\overline{C} = 0{\cdot}00135\,P\,Q_f / d^{1{\cdot}68}$$

where P is the percentage pollutant in the fuel, Q_f is the fuel usage in tons per annum, and d is the diameter in kilometres. The constant also incorporates a mean wind speed of $5\ m\ s^{-1}$. The annual mean concentration of the pollutant $\overline{C}$ is then in micrograms per cubic metre $\mu g\ m^{-3}$). For a pollutant such as smoke, this formula can now be used to calculate the concentration.

The amount of smoke from coal is probably about 1% of its weight (Brimblecombe 1977). In the case of substances which undergo chemical reaction (eg sulphur producing sulphur dioxide), there will be a weight change (eg in determinations of the sulphur dioxide levels in cities the sulphur in coal will have to be multiplied by two to allow for this). Early coals were higher in sulphur than those used at the present day; for London, levels have been estimated by C Scott (pers comm) as:

1200-	1700	2·5-3%
1700-	1800	2-2·5%
since	1800	1·5-2%

These equations may be used to determine the levels of smoke and sulphur dioxide in the London air. The parameters used are given in Table 2; they are slightly different from those used in the model presented by Brimblecombe (1977), particularly the urban diameters which were probably too large in the initial calculations. The calculated concentrations are plotted in Fig 16, which shows the increase in both pollutants since late medieval times. The figures for sulphur dioxide increase sharply with the transition to coal as the major fuel and then less rapidly as fuel with a lower sulphur content was used. Smoke emanations continue to rise until the end of the 19th century when urban expansion lowered the pollution emission per unit area. The decline after 1900 is exaggerated, since the model cannot allow for the large variation of pollutant concentrations throughout the city, which would be at their highest at the centre (Brimblecombe 1978a). It is of interest to compare these estimated pollution levels with those in cities of the present day and to note that they are quite high (see Table 3).

The effects of air pollution

Human health

As has been shown, concern was expressed about the unhealthiness of coal smoke as early as the 13th century. However, the possible effects of continuous exposure to very low levels of pollutants is still a matter of contention.

Table 2 Data used in the estimation of air pollution **in London**

Year	*City width km*	*Population*	*Wood 10^3 tonne*	*Coal 10^3 tonne*	*Sulphur in coal %*	*Smoke $\mu g\ m^{-3}$*	*SO_2 $\mu g\ m^{-3}$*
1300	2.0	40000	40	0.6	3	17	1.5
1500	2.5	70000	70	10	3	25	17
1650	3.0	300000		200	3	43	256
1750	4.5	675000		700	2.25	76	340
1800	5.0	1114000[1]		1350	2	122	488
1850	9.0	2235000[2]		4000	1.75	135	471
1900	16.0	6581000[3]		15700	1.5	201	603
1925	23.0			18500	1.5	129	386

[1]Greater London 1801 [2]1851 [3]1901

Table 3 Modern smoke and SO_2 levels in high density residential and industrial areas of cities, for comparison with Table 2

City	*Period*	*Smoke $\mu g\ m^{-3}$*	*So_2 $\mu g\ m^{-3}$*
London	1885	124-862	
	1952	270	
	1958	150	
	1968	50	
Liverpool	Winter 1968-9	108	210
Norwich	„	81	107
Nottingham	„	162	217
Manchester	Winter 1969-70	126	249

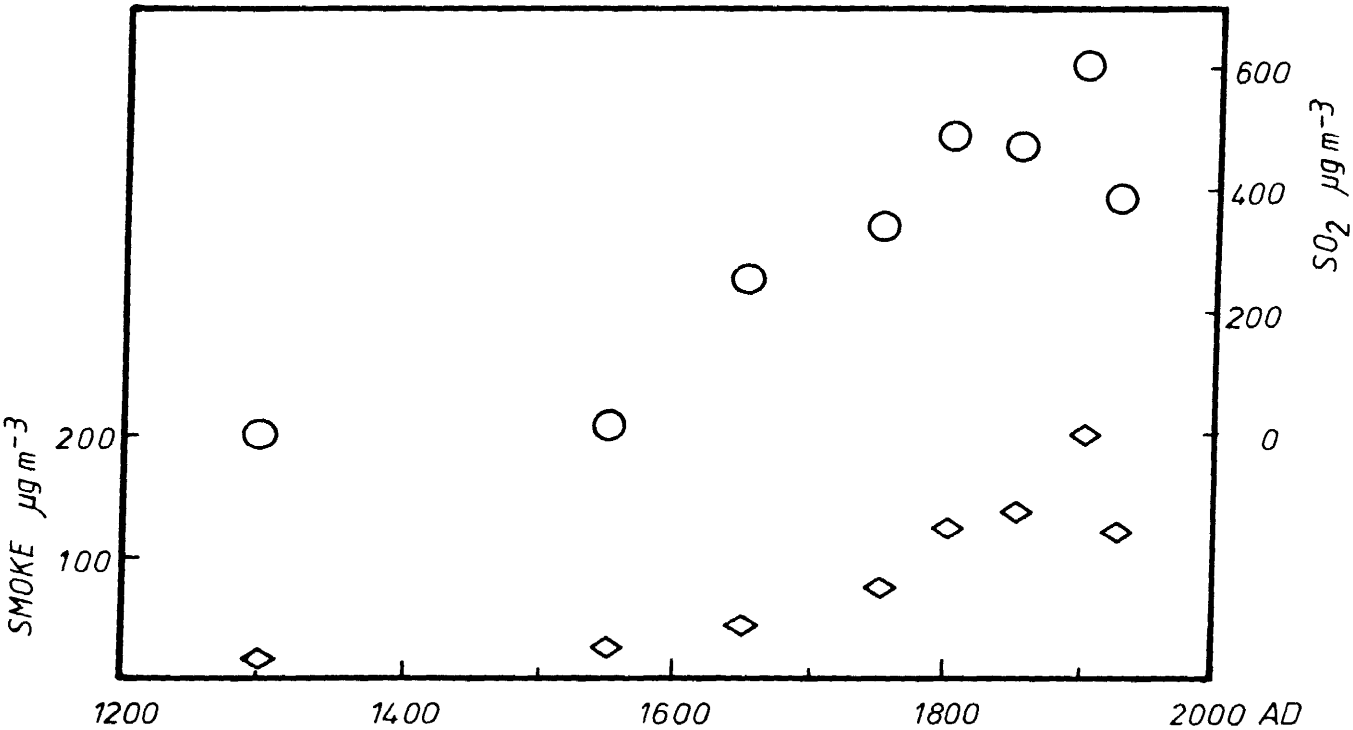

Fig 16 Estimated levels of air pollution in London. Circles SO_2, diamonds smoke.

Lave and Seskin (1977) use a large number of statistics from North American cities to show the far ranging effects of relatively low concentrations of air pollutants on human health, while Bouhuys *et al* (1978) argue that there seems to be little harmful effect. However, there is no disagreement about the damage caused by severe air pollution episodes.

Air pollution incidents can occur under particular meteorological conditions or result from periods of particularly high pollutant emission. Early incidents may have been triggered by single large releases, but recently large-scale episodes have occurred under extraordinary meteorological conditions, where there was almost total stagnation of the air mass into which the pollutants were emitted. While there have been many air pollution incidents, the ones experienced in London are excellent examples; the most famous is the Great Fog of 1952, when London and indeed the whole of the British Isles became covered by fog on 5 December. Wind speeds were low and the fog continued to 9 December. During this episode many people were ill and epidemiology suggests that some 3500-4000 deaths could be attributed to the incident. Death was frequently ascribed to chronic bronchitis, broncho-pneumonia, and heart disease; although recorded for all age groups, the effects were particularly severe amongst the sixty- and seventy-year-olds. Detectable increases in mortality are also associated with fogs in December 1873, January 1880, February 1882, December 1891, and December 1892. Even earlier episodes may be found through careful use of contemporaneous meteorological records and the *Weekly Bills of Mortality.* Digby (1658) and Graunt (1662) both suggest that the sea-coal smoke in London air was responsible for the high death rate in the city, illustrating how early the epidemiological consequences of air pollution were recognized.

Sulphur dioxide and smoke concentrations correlate well with the death rate during air pollution episodes. The pollutants act synergistically, each amplifying the harmful effect of the other. This may be because sulphur dioxide or sulphuric acid aerosols slow down or damage the cilia which clear particles from the respiratory tract (Schwartz *et al* 1977). Once this happens the smoke particles present in the polluted atmosphere can damage the lungs more seriously.

A more indirect effect of pollution is the diminution of sunlight (particularly at shorter wavelengths) by suspended particulates and by higher fog frequency. If this is combined with a diet deficient in vitamin D, rickets and osteomalacia may become more frequent. There is also some modern evidence to suggest that even now this obscuring effect of smoke has a measurable influence on the death rate from femoral fractures among old people (Eddy 1974).

The effect of gloom on the human spirit has already been noted, but the pollution that settles on the fabric of the urban environment may make it particularly drab. The polluted atmosphere has been blamed both for suicides (Veitch-Clark 1929) and drunkenness (Ewart 1902), for example. There is a certain ambiguity in the response to

Table 4 Lichens in Epping Forest and estimated SO_2 Levels (after Hawksworth *et al* 1973)

Survey date	*No of species*	*Estimated winer SO_2 levels*
1784-96	55*	>30 μg m^{-3}
1865-68	120	40
1881-82	86	50-60
1909-19	49	60-70
1969-70	28	70-125

*not complete; 45 speices noted in 1784-96 were absent in 1865-8

Table 5 Corrosion of exposed marble (from Braun & Wilson 1970)

Date	*Exposure year*	*SO_2 penetration mm*	*SO_2 content g m^{-2}*
1440	546	4.3, 6.9	76, 110
1831	133	4.3	34
—	0.17	0.4	2.5

gloom, however. Dickens, while acknowledging the depressing effect of London's pollution, could not suppress feelings of nostalgia for it (Brimblecombe & Ogden 1977).

Damage to plants

Although the urban heat island affords plants in towns an extended growing season, through increased temperatures, pollution may remove this benefit. The damage to plant life by coal smoke was first noted by Platt (1603) in his book *Fire* of *cole-balles.* He wrote that the smoke of London is '. . . a matter of. . . great offence to all the pleasant gardeins of Noblemen . . .'. The problem was so severe by the end of the 18th century that Thomas Fairchild wrote his *City gardener* (1772) in order that people who lived in coal-burning cities could enjoy the pleasures of gardening. The problems were evidently no longer restricted to London.

The increasing air pollution of London can be traced from changes in its vegetation. Thus the poet Thomas Gray wrote in the 18th century that the lime trees no longer blossomed because of the smoke (Toynbee & Whibley 1935). A more continuous record of change is given by the decreasing diversity of the lichen flora of Epping Forest as shown by the surveys conducted since the late 1700s. Hawksworth *et al* (1973) have used these data to estimate the levels of SO_2 in Epping Forest (Table 4).

The toxicity of pollutants to vegetation seems to result from the action of sulphur dioxide as a reducing agent rather than from sulphuric acid; on the other hand, sulphuric acid seems more important in bronchial damage to animals. It is the dosage (defined here as the product of the pollutant concentration and time) that is important when considering the amount of damage to a plant, but the toxicity is often affected by concentration; very high levels of exposure for very short times are more damaging than the same dosage spread out over a longer time. Concentrations of 1000 μg m^{-3} for short times can cause damage and might well have been experienced in London in the late 17th century, but probably occurred in the winter months when plant growth was slow, thus alleviating some of the harm.

The variable sensitivity of plants to atmospheric pollution is considered further by Stern *et al* (1973).

Damage to materials

The acid nature of dissolved sulphur dioxide and its oxidation product, sulphuric acid, damages many urban materials through corrosion. Smoke, its concomitant, disfigures the urban fabric by its blackening and besooting of materials. Acting together, their effect is probably greater than that of either alone. The damage to furnishings indoors was noted as early as 1512 and was remarked upon again by Digby (1658) and Evelyn (1661). These problems became so much part of the London way of life that a visiting ambassador was driven to comment (de Sausserre 1902): 'Hangings are little used in London houses on account of the coal smoke which would ruin them'.

The earliest comments about damage to buildings are more concerned with discolouration (Dugdale 1658), but Evelyn (1661) was well aware of the increased corrosion rates (for both metals and stone) that had become apparent in London by the middle of the 17th century. Braun and Wilson (1970) have examined the penetration of sulphur dioxide into old building stones and note that it is greatest for the older stone (Table 5). This, then, might permit past pollution levels to be estimated. The external appearance of buildings continued to be a worry, and some leases in the 18th century contained clauses which required that the buildings be painted annually.

Clothing became besooted while drying (Digby 1658) and damaged through being 'smoked', to such a great extent that in 18th century London there was a thriving trade in refurbishing such items. These problems also detracted somewhat from the pleasures of walking in the city or its parks (Gay 1716; Lutrell 1820) although parks provided, and still do provide, areas of improved air quality in most cities.

Concluding remarks

The changes which the climate and atmospheric composition undergo with increasing urbanization may be summarized as follows:

Temperature	increase of some degrees
Fog frequency	increase, particularly in winter
Thunderstorm frequency	possible increase
Wind	change in speed and distribution
Radiation	small decreases, particularly of ultraviolet
Snow cover	changes in distribution

These modifications to climate are rather small and it is not possible to find strong evidence that they affected the way of life in British cities of the past. Any noticeable effect on urban populations at the present day is obscured by a multitude of factors to which an urban population is exposed. Any examination of the effects of urban climate from archaeological evidence is bound to be difficult, but such studies are certain to be of considerable interest.

The changes in composition of the urban atmosphere have been much larger than those of climate. The smoke concentration of a city like London in medieval times must have greatly exceeded the rural levels. With the introduction of coal, and its acceptance as a domestic fuel, the sulphur dioxide concentration of the London air must have reached values of several hundred micrograms per cubic metre for relatively long periods of time. In the medieval period it is likely that the background sulphur dioxide concentration was less than 10 $\mu g\ m^{-3}$ so that urbanization would be responsible for a twenty- or thirty-fold increase in atmospheric sulphur dioxide concentrations. It is little wonder that the effects of increasing air pollution were observed relatively early.

Not only were the changes in atmospheric composition larger than the shift in climate, but being chemical rather than physical changes they are likely to have left more permanent evidence of their presence on the urban fabric. Corroded metal and stonework, and dust deposits may give excellent information as to the nature of urban air pollution in the past; studies of lichens or other biological materials may yield information about both the urban climate and atmosphere. This field has received virtually no attention from archaeologists, but cooperation by climatologists and archaeologists will undoubtedly yield much of interest to both.

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The documentary evidence concerning the nature and disposal of rubbish in English medieval towns is briefly reviewed, with special reference to Winchester. This information is an essential background to urban environmental archaeology. Where suitable conditions for preservation have not obtained and where the archaeological record is thus poor the documents may be the only evidence for many activities and for conditions in the town. Where information from biological studies is available, there is the opportunity to compare the two lines of evidence, to the advantage of both.

This paper is primarily concerned with the documentary evidence for the nature and disposal of rubbish in English medieval towns. This will be discussed in a way which should assist the archaeologist in assessing the contents of the layers which he excavates, and the ways in which these deposits were made. There will follow some reflections (from the point of view of a gardener and 'dirt archaeologist' rather than a soil scientist) on the character of urban deposits, principally in Winchester, and on the relationship between them and the evidence of the written sources.

Some of the earliest municipal records concern efforts to control the disposal of human and animal waste; throughout the Middle Ages the problems of rubbish took up a good deal of the time and attention of town governments (Reynolds 1977, 128-9). By the end of the 12th century, London had written byelaws covering sanitary affairs, but even before the Norman Conquest such matters may have been subject of customary controls. The written records include regulations governing the positioning of cesspits, the removal of rubbish, the maintenance of the streets, and the practice of certain trades, together with specific expression of concern about the condition of towns, and the many thousands of prosecutions for nuisance brought against individuals in borough courts. Most of the sources concern conditions in public streets and market places rather than in private houses and gardens, but they nevertheless reveal much of the private activity from which the rubbish originated. The mass of documentation and its repetitious character show not only that by modern standards English medieval towns were extremely dirty places in which to live and work, but also that both municipal authorities and others had a self-conscious concern for the appearance and smell of their towns and made serious attempts to cope with the problems of cleansing. However far they may have fallen short in the attainment of their ideal, the leaders of medieval English urban society had this feature in common with the humanist Leonardo Bruni, who in his panegyric of Florence written in 1403-4 put the city's cleanliness among its chief virtues (Kohl & Witt 1978, 138).

Inadequate surface drainage was one reason fort he rapid accumulation of rubbish and other deposits. At the beginning of the 12th century the 'horrible bog' caused by the flow to rainwater down the steep High Street of Winchester was said to be one of the reason why the city's New Minster was moved to a new site (Dugdale 1817, *Monasticon,* **2,** 435-6). Similarly the neglect or mismanagement of watercourses could be responsible for substantial deposits of muddy silt (Ramm 1971; Keene in press). Valleys containing small or intermittent streams were particularly prone to this problem (Flower 1915, 183; cf Keene in press) and in some towns, as may have been the case in the Square at Shrewsbury (Carver 1973 - 4, 247), rubbish seems to have been tipped there with the deliberate intent of raising the surface level. The Campo in Siena, with its shell-shaped paved area, its range of public buildings set across the valley, and its elaborate provision for the flow of water, shows how the solution of these problems could provide an opportunity for a bold and imaginative exercise in town planning (Guidoni 1965). On prominent ground in towns there was a lesser accumulation or even an erosion of soil. Mud was a constant problem. In the 16th century a foreign observer noted its ubiquity in the streets of London, which he attributed to the climate, poor paving, and inadequate drainage (Williams 1967, 189).

Customs governing the disposal of sewage in towns probably emerged as soon as the towns themselves. In London by the late 12th century the position of cesspits in relation to property boundaries was subject to regulation: the main problems were recognized as seepage and the undermining of neighbours' houses, for stone-lined pits were to be no closer than two and a half feet to the boundary and unlined pits no closer than three and a half feet. Many stone-built town houses of the 13th century and later contained garderobes and had cesspits incorporated into their structures. London and other cities contained numerous public latrines, some of them with many seats and evidently built in order to serve market places. Where possible both public and private latrines were set over running water, and elsewhere the lined structures were probably emptied with passable regularity, a job for which labourers could command well over the standard rate of pay. There were, of course, serious day-to-day problems, such as the garderobes which voided into the street, the cesspools which overflowed into a neighbour's garden or penetrated his cellar wall, and the practice in the 14th century, as in other periods, of relieving oneself at night out of the bedroom window, not to mention the drownings and muggings which were commonly associated with public latrines. The overall impression conveyed by the sources, however, is that this system of sewage disposal, which remained essentially unchanged into the 19th century, was regarded as adequate according to the standards of the time (Sabine 1934; Chew & Kellaway 1973, *passim;* Sharpe 1913, *passim;* Platt 1976, 69 - 72; Keene in press).

The more bulky animal refuse presented a far more serious problem of disposal. Dung and straw from stables were frequently pitched into the streets where they lay in foul-smelling heaps and obstructed traffic. At Winchester the innkeepers were notorious offenders, but many other citizens had stables and byres from which dung flowed into the streets or public streams (Keene in press). Private yards and gardens presumably contained dung heaps whose size was in proportion to the scale of dumping on public ground. In addition to the beasts of burden, medieval towns had substantial permanent populations of animals, notably cattle, sheep, pigs, goats, and poultry, grazed by the inhabitants in their crofts and gardens. Sometimes there were regulations, frequently broken, which restricted the keeping of such animals to the less densely populated areas. Loose ducks and hens were a nuisance in the corn market and frequently invaded neighbours' vegetable gardens- When not chained up, the butchers' bulldogs were a threat to passers-by. Pigs were a particularly serious problem. They frequently attacked and injured children and almost certainly contributed to the muddy condition of streets and gardens. Dead animals, especially horses and cows, seem frequently to have been left in streets and on waste ground. At Winchester there is a 14th century record of a dead cat being swung across High Street and in the 16th century John Stow thought that Houndsditch in London was so called because of the dead dogs which were flung there (Sharpe 1913, xxv, 57; Kingsford 1908, **1,** 75, 128, 185; Keene in press).

Among particular groups of tradesmen, the most serious offenders against sanitary regulations were the butchers. They seem usually to have slaughtered their beasts near, if not actually in, the streets where the stalls from which they sold their meat stood, and this was usually in the busiest and most densely populated part of a town. Blood and entrails were frequently thrown into the streets. During the 14th century in London several unsuccessful attempts were made to compel the butchers to slaughter outside the city, and both there and at Winchester an elaborate system was evolved for disposing of entrails, chopped up into suitably small pieces, in fast-flowing water. At Winchester the entrails, in pieces no more than four inches long, had to be carried 600 yards to the tipping place and in London they were cut up in a special house on the bank of the Thames before being taken by boat to be tipped in mid-stream, where they would not foul the quays (Sabine 1933; Keene in press). The York butchers had a pier in the Ouse downstream of the Friars Minor from which they could tip entrails without fear of contaminating the water to be drawn for brewing and baking (Cooper, 1913, 275). Clearly, disposal in pits was not an adequate solution for the problem. At one time in the 14th century the London butchers near St Paul's were making daily trips to Holborn where they tipped the entrails into specially dug pits, much to the disgust of the local residents. Fishmongers' refuse caused similar problems (Cooper 1913; Sabine 1933; Keene in press).

The trades concerned with the preparation of leather and parchment also appear frequently in the records of nuisances. We learn little of the offcuts, scrapings, and waste tan that they undoubtedly cast away, but much is said of the smell arising from tanning processes, of the skinners' foetid drenching pits where furs were prepared, and of the fouling of the running water in which hides and skins were washed. Among the clothworkers only the dyers, with their exhausted dyestuffs, had a serious waste disposal problem (Maitland 1893, 47; Stevenson, 1882, 273; Keene in press), The study from documentary sources of trade locations within towns, however, may provide the archaeologist with some clues in the interpretation of rubbish deposits. Butchers occupied prime commercial positions, fishmongers less important ones often near to the immediate source of their commodity. Leather and cloth-finishing workers had their establishments near running water, the former downstream of the latter. Tanners and other leather manufacturers, whose business was intimately associated with that of the butchers, were usually to be found well away from the central area of a town on the downwind side (Keene in press). Bearing in mind that such distributions were hardly ever exclusive and that changes in them could occur rapidly, one might expect, sometimes to be able to identify deposits which characterized these activities.

The sources say little of the ordinary household rubbish that undoubtedly formed a major part of the *fima et putrida* deposited in the streets. At Berwick in 1249, however, dust and ashes were listed with dung as items which burgesses were forbidden to throw into the street, the market place, or the River Tweed (Innes 1868, 72) and in the later Middle Ages most town records contain the occasional reference to the disposal of household dust. The bulk of domestic rubbish probably consisted of the litter of rushes or straw which was spread on floors. The domestic conditions which arose from this practice clearly reflected the efficiency or inclinations of individual householders. Erasmus was disgusted by the accumulation of filth on floors of English homes, which were covered with rushes so imperfectly removed 'that the bottom layer is left undisturbed, sometimes for twenty years, harbouring expectorations, vomitings, the leakages of dogs and men, ale-droppings, scraps of fish, and other abominations not fit to be mentioned' (Hoskins 1976, 2). The environmental archaeologist should perhaps be expected to be able to recognize most of these things. Another 16th century visitor, however, noted the neatness of English houses and their 'chambers and parlours strawed over with sweete herbes' (Platt 1976, 72). In this connection archaeologists should remember that the actual use of smaller houses could very rapidly change, so that a building which in one year was inhabited as a cottage could easily be used during the next as a stable and after that as a coal store. Records of the letting and maintenance of both these and larger properties show that it was not uncommon for landlords to have them cleaned out from time to time, in addition to such regular sweeping as we may suppose was undertaken by the tenants. In 1480 - 1, for example, a Winchester labourer was hired for nine days to clear away rubbish and clean the house ready for new tenants (Keene in press). Cases such as this show that interiors were sometimes dirty (although not necessarily much more so than today), but also that minimum standards of cleanliness were observed and that within a continuously occupied building we should not expect there to have been a steady accumulation of rubbish deposits.

Piles of building materials, both timber and stone, were sometimes recorded as obstacles to traffic, but the rubbish from building operations, even including the upcast from digging foundations and cellars, seems usually to have been carted away. Special care seems to have been taken over this in London where conditions were exceptionally crowded and rubbish was carried away from some building operations in hundreds of cartloads (Keene in press; Sabine 1937). Sometimes building rubbish might be used to raise the ground level, as in the warden's garden at Winchester College, where in 1397 - 8 the topsoil was taken up and relaid over a deposit of stones (WCM 75), presumably to improve drainage. It is unlikely, however, that in normal circumstances, as has sometimes been suggested (Platt & Coleman-Smith 1975, 245), pits would be dug specially for the disposal of building rubble, for pits seem primarily designed for the disposal of organic and putrid refuse.

In most towns the majority of buildings were of wood. London records show that chips and sawdust were commonly left lying about after a house had been built (Riley 1859, 259, 335) and a Winchester carpenter was fined for blocking a ditch at the end of his garden with sawdust (Keene in press). Such deposits could substantially alter local soil conditions and so, too, could the massive quantities of clay, marl, gravel, or chalk brought into towns for building purposes (cf Tingey 1904, *passim).*

It was the almost invariable rule that urban householders were responsible for disposing of their own rubbish, either within their properties or by carrying it beyond the formal limits of the town. Many Londoners within the walls took their rubbish no further than the suburban wards or, just as illegally, dumped it into the river or into the Fleet and Walbrook streams (Sabine 1937). The contents of cesspits, like butchers' offal, were treated with particular care. At a house in a densely built-up part of Winchester High Street in 1480 - 1, for example, the labourers who cleared out a latrine were also paid for digging a pit in which to dispose of its contents (Keene in press). In fact a good deal of rubbish was probably carted out of medieval towns and spread on the fields outside (cf Tingey 1904). At Winchester the bishop's officers purchased muck in the city for this purpose (Keene in press). Undoubtedly this could be a profitable activity, but the same difficulties of organization and supply which beset the modern recyclers of rubbish appear to have restricted this medieval enterprise, so that only those with exceptionally large establishments and dung heaps in proportion could expect to sell their rubbish.

The sheer scale of the problem may readily be judged from the quantity of rubbish, perhaps brought from all over the city, dumped behind the advancing waterfront in London and the question may legitimately be asked whether such developments arose from the desire for more efficient access to boats and the water or the need to dispose of rubbish (cf Milne & Milne 1978).

At the end of the Middle Ages municipal authorities, with London in the lead, themselves took an active part in these matters. Officers were appointed to supervise the cleaning of the streets by teams of paid labour and the London authorities hired boats to carry away dung (Sabine 1937). In some provincial centres, the problems of cleansing became less acute with depopulation and economic decline. In 16th century Winchester, for example, an area within the walls, which had once been densely settled, was designated as a public dumping ground; this did not mean, however, that the remaining inhabitants of the city were any more willing than their ancestors to remove the heaps of dust and rubbish from beside their front doors (Keene in press).

The forces which motivated public action on cleansing were the aesthetic objection to the appearance and smell of rubbish, the association between putrefaction and disease, and a sense of pride in the dignified appearance of a town. Thus in both London and Winchester butchers were supposed to cover up their offal while carrying it to the appointed tipping place (Sabine 1933; Keene in press). In 14th century London expressions of civic concern over street cleaning and the regulation of the butchers seem to coincide with outbreaks of plague and murrain among the human and animal populations respectively (Sabine 1933; 1937). Great public occasions made men think of both appearances and disease, and when parliaments were to be held at provincial cities like York or Winchester there was a flurry of local cleansing activity. Kings, too, were concerned that their cities, as an obvious manifestation of the wealth and dignity of their kingdoms, should be clean and sweet-smelling. Philip Augustus was inspired to have the streets of Paris paved, by the view from the windows of his palace of the mud churned up by carts passing through the city gates (Delaborde 1882, 53-4). In 1332 Edward III described York as the filthiest and most foul-smelling city in the kingdom, and ordered its streets to be cleaned of dung for the sake of the health of those coming to the parliament there *(Cal Close Rolls* 1330 - 3, 610). He perhaps had some grounds for comparison, for two years earlier his parliament had met at Winchester. His fastidious grandson, Richard II, issued a general order for the cleansing of towns of dung and entrails *(Statute* 12 Richard II c. 13), and detailed regulations for the management of the London butchers were established as a result of his initiative at the parliament of 1393. This parliament had met at Winchester, where the citizens had made special efforts to clean the city, and it is possible that their well established system for disposing of offal served as a model for that adopted by the Londoners (Keene in press).

In considering the archaeological evidence care should be taken to distinguish the different conditions which prevailed in streets, in houses, and in yards or gardens. The excavated surfaces of streets and lanes in medieval Winchester were characterized by their thick deposits of muddy soil, often of a greenish colour and containing a mass of animal bones and pottery. Such layers seem primarily to have been composed of the stable and domestic refuse cast out from adjacent houses. They were presumably much disturbed by passing traffic and rooting pigs, but were periodically sealed by new layers of metalling. For the archaeologist these layers represent one of the best series of chronologically arranged samples of rubbish deposits in the urban context. At Winchester the streets were usually metalled with flints after the existing surface had been levelled with a bed of chalk. There is evidence that brushwood and hurdles were sometimes laid as an interim measure in order to consolidate the muddy surface. The name of one Winchester street, *Brudenstret,* suggests that in the early Middle Ages it had a planked or boarded surface (Biddle 1976, 233).

The floors of houses and workshops excavated in Winchester seem usually to have been swept clean and it is interesting to note the occurrence of the name *besmere* (broom-maker) among the occupational bynames of the 12th century city (Biddle 1976, 200). There were slight deposits of mud or ash near doorways and in the corners of rooms, but these contained no more than a few fragments of pottery and bone trodden into the floor, in marked contrast with the street surfaces outside. A thick deposit of rubbish within a building, so often described by archaeologists as an 'occupation-layer', is perhaps more likely to represent a period of disuse during which rubbish was dumped there by neighbouring householders. This was a commonly recorded fate for the shells of abandoned parish churches (Cooper 1913, 274; Keene in press).

The soil in yards and gardens contained a good deal of the same sort of rubbish as the street deposits, but not in such concentration. The soil was also much disturbed by pit-digging and probably also by the cultivation of vegetable plots, which were common in medieval town gardens. In these conditions it is exceptionally difficult to identify undisturbed and properly stratified deposits. Pits dug as wells or cesspits or for industrial purposes such as tanning, however, do contain undisturbed deposits of general rubbish. Unlined cesspits seem to have been used for their original purpose only for the relatively short periods during which they remained sweet. They seem then to have been filled with household and stable refuse and with the upcast from the new pits which replaced them. Even when conditions favoured their preservation, the organic deposits in the pits contracted in volume so that the layers sealing the pit fills collapsed onto them, sometimes creating a void which is the first sign to the excavator that there is a pit to be discovered. In these conditions the crucial stratigraphical association between the pit and the ground surface from which it was dug is frequently obscured and in interpreting the contents of such pits great care should be taken to distinguish the successive stages of their filling. Pit-digging, cultivation, and the accumulation of middens probably meant that on a flat site the ground level in the yards and gardens of densely populated areas of towns rose more rapidly than elsewhere, and it was probably to keep pace with this and avoid the run-off of surface water, rather than as a result of squalid interior domestic conditions, that floor levels were built up within houses.

The fill of one industrial pit at Winchester, probably originally used for tanning hides or a related process, vividly illustrates the character of the refuse of a small household of the 11th century (Renfrew forthcoming). When excavated the mass of the fill had the homogeneous, compressed, fibrous appearance of a long-established muck-heap; it contained little pollen. At the time of its construction the pit would have been largely below water level. The chalky silt at the bottom contained a concentration of pollens which had probably sunk there while the pit was exposed to the air and was being used for its original purpose. The solid filling may therefore be identified as a secondary deposit of rubbish. It contained straw, twigs, wood chippings, nuts, leaves, bones (including a deer's head encrusted with puparia), turned wooden bowls, wooden implements, some pottery, scraps of textiles and leather, and fragments of rope and string. Scattered throughout the fill were the shed or pulled hairs of cows, sheep, and goats. It is possible that the pit was used over a considerable period as a deposit for stable refuse and house sweepings, but at present it seems more likely that the fill was essentially a single deposit and that the lenses and crusts within it represent the matted and layered texture which characterizes dumps of stable sweepings and similar material. It seems possible that this deposit was coincident with a change of occupancy in the property, when the pit ceased to be used for tanning or another specialized purpose and the house, which may have been rebuilt, was cleared of its accumulated rubbish (Biddle forthcoming). A pit at a house nearby seems certainly to have been filled on such an occasion and contained numerous items of broken furniture. The upper fills of both these pits as excavated appear to have consisted of the soil which had originally sealed the pit but then collapsed as the organic refuse compressed and decayed.

Deposits such as these were preserved because they occurred in permanently waterlogged conditions. There is, however, a sharp contrast between most Winchester deposits, where the soils are thin and chalky and there is a wide seasonal variation in water level, and medieval deposits in towns like Dublin and Perth, where there is a high degree of organic preservation. Such differences presumably reflect local soil conditions and the drainage characteristics associated with them. In differing conditions the same quantities of rubbish would result in greater or lesser accumulations of soil and this was probably important in determining local practice and attitudes with regard to waste disposal. We have seen, too, how the pattern of relief could play an important part in determining the rate of soil accumulation and how human activity could result in major changes in local topography.

To inquire further into these differences in the nature of archaeological deposits between different towns and between different deposits in the same town requires more expertise than the average gardener has to offer. Even from this short paper, however, it should be clear that urban rubbish deposits contain much to interest the historian and that the excavation of them throws new light on human activity and attitudes in the past, for which we already have some direct and vivid evidence in the written record.

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Tree-ring studies on urban waterlogged wood: problems and possibilities

Ruth Morgan

The value of identifications of wood remains from urban sites is discussed, the problems of dendrochronological work on urban sites outlined, and the relevance of tree-ring studies to palaeoclimate and the calibration of radiocarbon dates considered.

Introduction

The abundance and complexity of timber remains in the waterlogged levels of many current urban excavations emphasize the great importance of wood as a building material in the past. There are two main aspects of the study of this wood: firstly, the investigation of the use of different trees according to function and of the availability of the various species, and secondly, the determination of the date of the timber and often of the structures with which it is associated.

Wood was used in a great variety of ways, but only a small proportion of it survives today. Standing structures, like buildings, are rarely preserved to any extent but pile foundations and sill-beams often remain to indicate the method of construction and the species of tree exploited. The walls may have been of planks or wattle, only the lowest section of which may have survived. On the other hand, features dug into the ground—pits and wells—are usually perfectly preserved under waterlogged conditions, with their plank or wattle lining.

The potential of waterlogged wood for determining man's use of the available woodland resources, as well as for dating, has only been truly appreciated in the last decade (see, for example, Schweingruber 1976). Samples of waterlogged timbers, which decay rapidly after excavation unless treated and stabilized in some way (Coles 1979), were rarely kept for analysis prior to this. Wooden objects which were kept, usually artefacts for display (such as dugout canoes, coffins, buckets, and bowls), now lie hard and cracked in museums and are of little value for analysis. Yet dendrochronology, the science of dating timber by comparison of the variations in ring-width, has a long history in the USA and West Germany (reviewed by Ferguson 1970 and Huber & Giertz 1970 respectively), back to the early years of this century. Its applicability in Britain was long doubted, for it was believed that the complex maritime climate here could cause such local differences in tree growth pattern as to make correlations impossible (Baillie 1978). This has proved to be largely untrue. It is now known that oak *(Quercus)* tree-ring curves over 50 years in length can generally be dated accurately, and suitable timbers have been recovered from many archaeological contexts (see, for example, Hillam forthcoming; Morgan 1977a). An experimental approach is still being applied to species of wood other than oak, and to immature material less than 50 years old.

The aim of this paper is to outline the value of identification and tree-ring analysis of all types of wood from urban excavations, and to assess how informative the different classes of material may be. Aspects of studying urban material and the problems encountered will be discussed in a section on dendrochronological dating, which is followed by a brief description of the relevance of tree-rings to climatic studies and the calibration of radiocarbon dating.

The identification and use of different wood species

Qualities of size, strength, and durability have made oak by far the most usual constructional timber, and vast quantities must have been required for the timber-framed buildings which almost exclusively employed this wood in all periods (Salzman 1952). In addition, ship-building (Holland 1971), riverside revetments (Schofield 1975), wells (Rogerson 1977), and coopering (Kilby 1971) relied mainly on oak. It was valued sufficiently to reuse for another purpose, for example the use of barrels with heads removed for lining wells at York (Webster & Cherry 1977, 248). The woodland resources must have been vast to cope with this scale of exploitation without showing serious signs of depletion (in some areas at least) until the later medieval period (see Rackham 1976, for further discussion). Some woods were probably clear-felled for intensive activities such as iron-smelting, lime-burning, and ship-building in the Roman and medieval periods (Hart 1966), while other woods probably continued to support local building activities, the slower pace of which would have allowed time for some regeneration. Accessibility, in view of the difficulties of transport, was no doubt an important factor. There was little thought of replanting to replace the depleted woods until John Evelyn's book *Sylva* appeared in 1664, which advised woodland owners of the problems and how to go about replanting on their land.

Oak is also ideally suited for tree-ring dating, firstly because of its potential life span of 200-300 years, and secondly because it has a ring-porous structure in which the spring and summer zones of wood formation are clearly distinguishable and almost certainly annual in nature (Jane 1970). Longevity and clear annual rings are two of the criteria for successful dating.

Other species, such as ash *(Fraxinus)* or elm *(Ulmus),* were occasionally used for building and piles, and are superficially similar in structure to oak. Over the last three centuries, imported conifers have been increasingly used for floor-boards and rafters; they have clear, but not always annual, growth rings. Their identification in pre 17th century contexts must almost always indicate importation, for example the silver fir *(Abies)* and larch *(Larix)* barrels from Silchester (St John Hope & Fox 1899) and spruce *(Picea)* boards from King's Lynn (Clarke & Carter 1977).

The diffuse-porous woods do not show seasonal division within the growth rings. Identification of these species and resolution of the ring boundaries are less easy than in the ring-porous woods, and their life span as trees is generally short. They do, however, have their uses in determining the local woodland composition and methods of woodland management (see below).

Despite these difficulties, two diffuse-porous species, beech *(Fagus)* and l ime *(Tilia),* have recently proved suitable for ring-width measurement and cross-dating (Morgan 1979a; 1980). These species rarely occur as timbers in archaeological contexts, although beech boards from late medieval deposits in Hull (Hillam unpublished) and Exeter (Morgan 1980) have been examined. Of the other diffuse-porous woods, alder *(Alnus),* hazel *(Corylus),* and birch *(Betula)* have all been used widely as brushwood, and for wattling and piles.

In addition to the processes of identification and tree-ring analysis, the way in which the timber has been converted from the tree can be studied. The value of examining early carpentry techniques lies in assessing the carpenters' understanding of the very different properties possessed by each wood species—or example, the ease with which it can be split in different directions and the degree of shrinkage and distortion which can occur under certain conditions along different axes of the tree. The curvature of the growth rings and the recognition of the bark edge (the outer surface of the trunk below the bark, which quickly becomes dislodged) enables the diameter of the original tree to be estimated. The quality of the timber is revealed by the straightness of the grain and by the average widths and the variation of the rings; in oak, for example, uniform wide rings produce a stronger timber because of the higher proportion of dense latewood in each ring. As this information is accumulated, the traditions and variations in carpentry standards and techniques through time can be better understood.

Possibly the greatest use of local wood in the past was for fuel, for both domestic and industrial purposes. It is estimated, for example, that two oak trees would have been needed to fire an iron forge for a week (Hart 1966). From this it can be calculated that about one hectare of mature woodland must have been removed every 15 weeks or so for a single forge (assuming the present average density of about 30 standard trees to the hectare).

Identification of charcoal from hearths may demonstrate whether collection of firewood was random, or whether certain species were being selected for their. particular burning properties (Edlin 1974, 155 - 65). The growth rate (indicated by ring width) may also suggest the conditions under which trees were growing in the local woodland (Salisbury & Jane 1940). Where selection of particular trees is not suggested by the range and proportions of charcoal species, they may be the best guide as to the structure of the local woodland, including material picked up from the woodland floor and cut from the underwood as well as the waste from the conversion of timber for construction.

Tree-ring dating

For identification, all types of timber, from massive beams to the smallest twigs, must be sawn or broken to permit the cutting of transverse and longitudinal sections; this requires only a small cube of wood. Tree-ring dating, on the other hand, demands a larger specimen and at the Sheffield DoE dendrochronology laboratory, for example, a section of about 50-100 mm in thickness is required.

The surface treatment needed to expose the structure and growth ring boundaries differs according to the condition of the wood:

1 Waterlogged wood may be extremely hard ('bog oak') or very soft like butter; the first type may defy even a chain-saw, while the second falls apart very easily and may need bandaging before sawing. Subsequently, both are treated alike. The sections in polythene bags are deep-frozen for about a day and then, when held in a vice, can be given an excellent surface with a plane (Stanley 'Surform is recommended).

2 Dry wood from buildings is usually quite sound unless badly attacked by insects or fungi. Thorough sanding of part of the surface, covering a wide arc along the longest radius, is satisfactory. The dried waterlogged wood often found stored in museums is usually too cracked and fragile for any treatment; slow controlled drying can, however, result in a manageable section which can be sanded. Powdered chalk rubbed on the surface will show up the large spring vessels clearly.

The ring-widths are then measured (with a tolerance of 0·1 mm) by placing the wood section on a stage with a long travel below a binocular microscope. Attached to the stage is an electronic device (linear transducer) which records the distance travelled across each ring; the output—the ring-width—is shown on a digital display, and is read off and recorded manually. In the future, the system could be linked to computer facilities for complete automation of data collection and processing, but initial visual examination of the rings is essential to allow for idiosyncrasies in growth type, rate, and direction. Thus, for example, the large vessels in oak somerimes vary misleadingly in number or size; the growth rings may flare out suddenly, particularly around a knot; or the rings may not be exactly aligned on either side of a ray, so that a ring may be 'lost' or an extra one 'added'. In a mature tree (which is often said to be growing more slowly but may in fact be adding the same volume of wood around the increasing circumference of the trunk) almost no latewood may be formed between the lines of vessels. Hence the vessels of consecutive rings almost merge together so that they cannot be separated into annual increments.

The recorded ring-widths are plotted on semilogarithmic recorder paper of a type used by most laboratories, thus enabling all records to be compared on the same scale. The resulting jagged graph, illustrating the annual variations in ring-width, is known as a 'curve' (see Figs 17 and 19). The semilogarithmic scale is used in order to lessen the effect of wide rings and increase that of narrow rings; the latter are thought to be more valid indicators of stress caused by climate and thus more likely to be useful for cross-dating (Huber 1970, 177 - 8).

The recorder paper is also translucent, so that curves can be overlaid and one slid along the other to look for visual similarities, allowing an overlap of about 50 years. Visual matching requires some practice; not only are corresponding wide and narrow rings sought but the general trend of gradually increasing or decreasing ring-widths may be important. To give an objective value to any

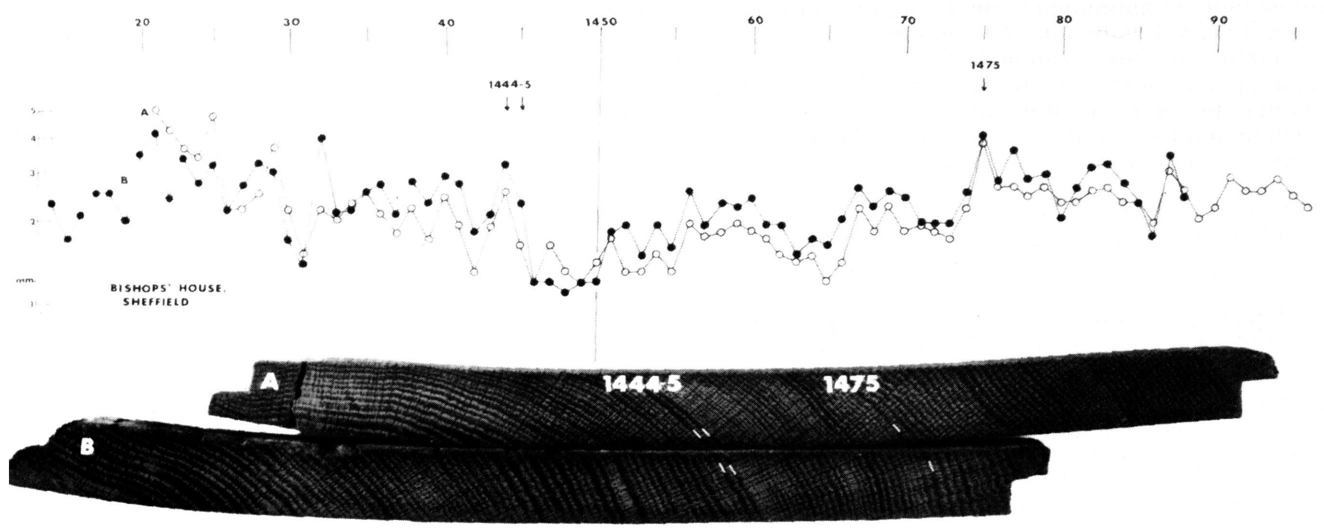

Fig 17 The cross-sectional surface of two floor-boards from the Bishops' House in Sheffield (Morgan 1977b) illustrates how significant rings, such as the wide ones for AD 1444 -5, can sometimes be matched on the wood itself. Above are the plotted ring-width curves for each board, on a semilogarithmic scale. The match is excellent and it is possible that they were sawn from the same tree. (Reproduced with permission from Vernacular Architect, **8** *(1977), 811.)*

positions of match, the data are fed into a computer, which carries out a very similar procedure. The printout lists the degree of similarity between two curves at each point of overlap; in one program widely used in Britain (Baillie & Pilcher 1973), this is measured as a Student's *t* value, quoted as for example $t = 4{\cdot}73$. A *t* value of more than 3·5 is said to be significant; in practice, however, visual matching may lead to the rejection of a *t* value higher than 3·5 or conversely the acceptance of a lower value. This illustrates the absolute necessity to check any matches suggested by the computer by visual means. An example of a pair of matched curves is given in Fig 17; the *t* value for this pair is 7·66.

Given a site which has produced many timber samples, it is usually possible to match some of the individual curves; these can then be combined by simple averaging into a 'mean curve'. At this stage, the scale will still be in arbitrary 'floating' years, ie unrelated to calendar years. Little progress can be made if none of the individual curves match, as is sometimes the case. After the production of a mean curve, it may prove possible to add further individual curves; many will match an average pattern better than any one curve taken alone.

The final mean curve (there may be several of them) is then compared with other curves for that region and period, but which have been absolutely dated—that is, for which each ring has been allocated a calendar year. These are known as 'reference curves'. Absolute dating is achieved initially only by extending back from the present day, from ancient live trees or timbers of known felling date, and then through progressively older material, by overlapping each group of curves and adding to them. Having established one reference curve, others from medieval buildings or artefacts in areas nearby may be dated, thus initiating another reference curve which is not directly linked to the present day. This may be very useful in areas where timber is scarce for one reason or another, as in 17th and 18th century England, from which extensive searching has so far revealed only immature timber (see, for example, Morgan 1979b).

Regions of western Europe are now widely connected by reference chronologies. Curves for Ireland and Scotland extend back to about AD 800 (Baillie 1977a; b; c), prior to which there are long floating chronologies back, to about 6000 BC (Pilcher *et al* 1977). England has no continuous and directly dated reference curve, but many shorter chronologies dated by comparison with curves from Ireland and Germany (eg Hillam 1979a; Morgan 1977b; Fletcher 1977). In various parts of West Germany, long chronologies extend back to about AD 800 (Eckstein 1978b; Becker & Delorme 1978; Huber & Giertz 1970); material can be absolutely dated back to *c* 700 BC, and a full chronology has now been published (Hollstein 1965; 1967; 1980). Roman or prehistoric tree-ring chronologies until recently relied on radiocarbon dating and on the links between 'floating' chronologies from various sites.

It is not yet clear over how wide a geographical area characteristic growth patterns within one species may occur, and so to what extent chronologies may be used for matching in different regions. Correlations sometimes occur over very long distances, or curves from the same area and period may fail to match. Very thorough comparisons must be made to ensure that every possibility of dating has been explored.

This stage of cross-matching and dating is undoubtedly the most time-consuming and demands experience, while the initial ring-width measurement is relatively quick and easy. The process is greatly aided by the provision of detailed archaeological information about each timber—details such as the context from which it came (type of structure, function), the approximate date of the associated deposits, relationship to other sampled timbers, and so on. For example, it is quite common to receive a batch of perhaps twenty samples from an archaeological site, with no more than context or sample numbers; perhaps the information is extended to 'medieval' or 'late Roman'. In the absence of adequate records, the curves from each timber would probably be compared with every other and with local dated reference curves. But with access to the archaeological information, it may be determined, for example, that the majority of the samples were from posts of a single structure, which was several centuries later than the remaining samples of boards lining a particular pit. Comparison of all curves would have wasted much time and effort, even if the same result had eventually been achieved.

Were the dendrochronologist fully acquainted with the details of the excavations (preferably by being present throughout), it is likely that much more precise results could be obtained from timber analyses. Detailed information would be invaluable in interpreting rates of deposition and in typological studies of associated artefacts. If the resources are available for analysis, total or at least extensive sampling naturally produces the most reliable results on a large and complex site, where an internal chronology is important. The benefits of this are illustrated by the results of Haithabu (Eckstein 1978a), Dublin (Baillie 1977a), and the Somerset Levels (Morgan 1979a).

This ideal is, however, currently impracticable, and a compromise must be made between regular site visits and laboratory work. Detailed archaeological information must then be made available to fill the gap. The fullest possible sampling should be aimed for; superfluous or unsuitable samples can always be discarded at the laboratory stage.

Another sampling difficulty involves the conflict between the need to conserve the most significant and well preserved examples of early carpentry, and the value of such primary material for accurate tree-ring dating of the structure. It has, however, proved feasible on several occasions to saw a thin slice from the timber, to analyse it with the minimum of damage, and then to replace the section. 'Carbowaxed' (ie impregnated) timbers show very little trace of such treatment. In the long term, precise tree-ring dating must surely take priority over the attractions of museum displays (Morgan *et al* 1981).

The value of tree-ring analysis of brushwood and timber

Brushwood

In an urban context, most wood must have been brought into the settlement deliberately, possibly from quite some distance if it was being rapidly cut for fuel and building with little time to allow regeneration. The identification of the species present in brushwood, small stakes, and charcoal can indicate the trees available for exploitation and those that were selected. Counts of growth rings and measurements of diameters of a large number of stems from wattling or brushwood show the rate of growth and the age range of the woodland being cut down. Random collection of available branches and stems results in a wide range of age, size, and species, while selection and management are reflected in concentrations of age, size, and species. This is discussed further below.

Coppiced hazel and other species were regularly woven into wattle hurdles or basket shapes, which have a multitude of uses and appear often on urban sites-for lining pits and drains, for boundary fences and house walls (as at Coppergate, York (Hall 1978)), or for pathways (as at Perth (Bogdan & Wordsworth 1978) and Dublin (O'Riordain 1971)). Wattle was formed by weaving flexible rods, whole or cleft, between upright posts (sails); usually the rods were of hazel, but the sails could include many species, the range from the medieval site at Saddler Street, Durham (Donaldson 1979) including hazel, oak, ash, holly *(Ilex),* birch, and a *Prunus* species. The neolithic Walton Heath trackway in Somerset (Coles & Orme 1977a) included sails of hazel, birch, willow *(Salix),* alder, and oak, while in the contemporaneous Rowland's track (Coles & Orme 1977b) all the sails were hazel. Detailed examination of wattle reveals not only the wood species in use, but also the different traditional weaving techniques, for example the interval length between sails, the number of rods taken over and under the sails, and the methods of finishing the edges (Coles & Darrah 1977).

It is becoming clear from work on the Somerset Levels brushwood and hurdle tracks that it is possible to determine the extent to which a woodland was being managed. This might have been by coppicing (cutting back of the stems on a regular cycle down to ground level to produce a constant supply of long straight rods or poles) (Morgan 1977c) or by pollarding (cutting back above grazing level). Coppicing

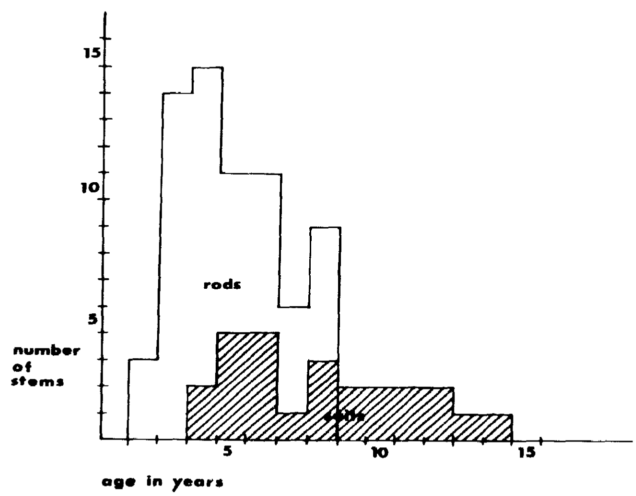

Fig 18 Histogram illustrating the age range typically found among the stems used in wattling, based on information from the Somerset Levels (Morgan 1977c). The rods, invariably of hazel, tend to be concentrated between about three and eight years in age; often peaks of four/five and eight years occur suggesting the possibility of a four year coppice cycle. The age range of natural hazel woodland would be much more varied (as would the growth rate). This information, and features on the wood surface, indicates coppice management. The sails around which the rods were woven tend to be of various wood species and of variable age and size.

can be recognized from features of the wood itself (Rackham 1977), from the rate of growth (ring-widths), and from the age range of the total assemblage. The histogram in Fig 18 shows the typical age range of rods and sails in a hurdle, based on evidence from the Somerset trackways; the rods are mostly between three and eight years old, while the sails tend to be older, at four to fourteen years. Age concentrations in both hazel and alder have been found in material from several trackways, often at four/five and eight years, suggesting the possibility of a four-year coppice cycle. There is thought to be no mechanism which could produce such quantities of even-aged stems under natural conditions, and the implication is that cutting was done in a regular and deliberate manner.

Small brushwood and twig material, used perhaps for consolidating soft ground, is not very informative other than through its species composition; identification of twigs is also more difficult than of mature wood since the structure may differ. However, the season of cutting may be determined on much of the brushwood by examining the stage of growth of the outermost ring below the bark: a complete or wide ring indicates winter cutting, while a narrow or incomplete ring *may* suggest summer cutting. This assumes that brushwood was cut live and did not consist of dead material.

It is unfortunate that very little close examination of young rods, poles, and branches has been carried out on samples from urban sites, largely owing to the time-consuming and often tedious nature of the work, and lack of expertise. Attention has naturally focused on larger timbers. This leaves a large gap in our knowledge of the appearance (or at least age-distribution and species structure) of the woodland landscape around settlements, a gap which is hardly filled by documentary evidence.

Timber

Dendrochronology may play an important part on complex urban sites, where there are several levels of deposits, perhaps with stakes and piles passing through many of them. Here, it might be used in its usual role of *absolute dating,* the allocation of a date in calendar years to the felling of the tree and thence to the date of construction. Only beams and boards from mature trees with more than 50 growth rings can be used for absolute dating. However, some of the smaller piles and stakes may be valuable for *relative daring,* the establishment of the difference in time between two structures or levels, unrelated to calendar dates. The precision of such relative dating would be difficult or impossible to match from the archaeological records, since tree-ring dating under ideal conditions is exact to the year.

The timber on urban sites is often of poor quality for absolute dating, since it may represent only the supporting members of structures, below or at ground level, or pit- and well-linings. For all these, low-grade and possibly reused timber would suffice. Experience has shown that most timbers on urban sites have less than the requisite 50 growth rings, and these may be wide, erratic, lacking in variation ('complacent'), or otherwise unsuitable. The ring-width curve for such a timber is shown at the top of Fig 19; the sudden decrease in ring-width, perhaps caused by defoliation of the tree or waterlogging around its roots which reduced the tree's rate of growth, makes comparison with other curves difficult. Such a curve is unlikely to be datable, but if a number of timbers show a similar pattern, it may be evidence that they originated in the same tree or group of trees. This, in itself, may be valuable information.

Timbers which are likely to be ideal for tree-ring dating include quartered trunks and boards which have been split radially from the tree, since these must of necessity have originated in mature trees to achieve the dimensions necessary for their usage. There should be measurements across at least about 50 rings and preferably over 100 (see Hillam & Morgan 1979), in order to provide sufficient overlap with at least one other curve and for the match to be statistically certain. The ring-widths must also vary to some extent from year to year (ie show 'sensitivity'). A good example is shown at the base of Fig 19.

Attempts to match curves from immature trees, which have rings rapidly decreasing in width, with curves from mature trees with a steady growth rate, as in Fig 19, are difficult both visually and statistically. In practice, curves from one site may be grouped on this basis, until the creation of two separate mean curves from each group allows more reliable cross-matching. Computer comparison may compensate to some extent by smoothing the curves, removing the random variations, and reducing each to the same base-line.

Rural sites, often dated to a single period, tend not to show such great variability of timber quality as urban sites, the economic organization of which must have been more complex. A similar contrast between Roman and medieval urban sites is becoming clear; the Roman material is often of excellent quality, apparently all from the same woodland, and rarely reused, while the medieval is poor in quality, from immature trees and probably from varied sources. Presumably by the medieval period, extensive felling had reduced the number of good-quality mature trees growing near settlements. Timber thus became more difficult to obtain, more valuable, and thus worthy of reuse.

Some site examples

London

The revetments of the north bank of the Thames in the City of London (Hobley & Schofield 1977) are a good example of contrast in timber quality. The Roman revetment at New Fresh Wharf had been constructed of massive oak beams, all of which were converted in the same way to serve similar purposes. According to archaeological evidence, the sections had been prefabricated. The very similar patterns of narrow sensitive rings in each timber suggested that they had originated in a small group of trees in the same woodland, which had evidently suffered little interference. It also suggests that the trees had been felled deliberately for the purpose of revetting the riverbank, and were not taken from a store of timber. The resulting floating tree-ring curve of almost 300 years, which included almost all the timbers examined, is radiocarbon dated and also linked to curves from other London revetments (Morgan 1977a; Hillam & Morgan 1981a). It has now been dated to 73BC-AD209 (Hillam & Morgan 1981c).

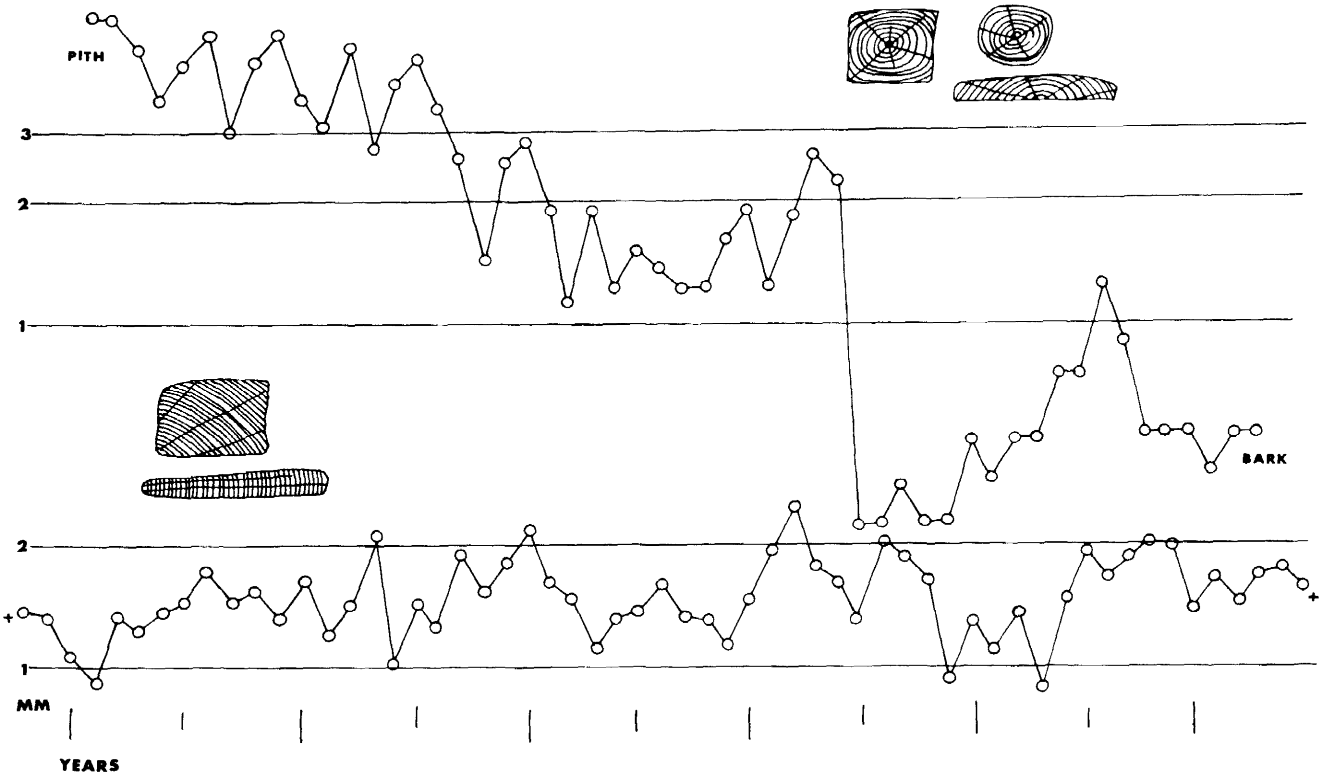

Fig 19 The types of timbers and ring-width curves which might be found on an urban excavation. Above are stakes, piles, small beams, and thick boards split right across the tree. They often originate in immature trees, the example shown being only about 50 years old. Its growth curve presents considerable problems for matching, not only in length but in the sudden decline from rapid growth to a stress condition. Smoothing-conversion to indices- would enable correlations to be attempted, but absolute dating is unlikely to be possible. The lower diagram shows the typical timbers and growth rate of a mature tree of 100-200 years. Large oaks were regularly quartered or split into radial boards; the rings are on average between 1 and 2 mm wide but vary sufficiently for cross-dating. There is every likelihood of dating this curve. (The vertical scale is logarithmic, the horizontal marked off ever-v five years.)

Similar features of uniformity and good growth conditions have been noted on other sites of Roman date, for example, Gloucester (Morgan 1975) and Droitwich (Hillam & Morgan forthcoming), but there are also exceptions, for example Carlisle (Hillam & Morgan 1978; 1981b).

By contrast, the medieval revetments of the Thames are much less substantial. A 13th century braced structure, one of the series of three examined at Seal House (Schofield 1975), was made of timbers cut in several different ways though they were to be used for the same purpose-braces were made from complete trunks, quartered trunks, or even thick boards. Widely differing growth rates and patterns were apparent, and less than half the timbers examined from the three revetments (20 out of 43) could be dated, and then sometimes only after extensive study (Morgan 1977a and forthcoming). Several timbers were known from the archaeological evidence to have been reused. It seems that the demand for timber in such an urban environment was so great that anything available was used, regardless of its quality and size.

York

The dendrochronological interpretation of results from the site at 16-22 Coppergate, York, is likely to be much more difficult. Cross-matching even of curves from timbers in the same structure is often impossible. This has been noted not only at Coppergate, but at other Anglo-Scandinavian and medieval sites in the city, and in wood from timber-framed buildings (Morgan unpublished). At 16-22 Coppergate, Hillam (1979b, 275) has found that of 77 timbers examined, 42 were suitable for measurement; of these, only one group of nine have been matched and dated, and another group of three matched, despite many of the curves being of suitable quality. Similar difficulties in cross-matching have been found in later medieval material from Exeter (Morgan 1980), and in samples from timber buildings from north and west Yorkshire and the Lincolnshire—north Nottinghamshire area (Hillam & Ryder 1980).

Interpretation

The variability in timber quality and the ease with which growth patterns can be matched appear to be regional, since in some areas no such difficulties are encountered. However, interpretation is still uncertain. The micro-environmental effects on tree growth of very local climatic and soil changes are as yet little understood, and could have affected the growth pattern adversely in some areas, with the result that cross-matching is impossible even between one woodland and the next.

By the medieval period, carpenters' workshops in towns were doubtless organized on a complex basis, either selecting and felling particular trees for a specific purpose or buying prepared timber. During rebuilding operations, much suitable timber must have been salvaged for reuse. Some freshly felled trees would be sawn and then stacked for seasoning, for better quality boards; several more years might be spent on a stockpile. Obviously different treatments (such as stockpiling, seasoning, and reuse) given to the timber will affect the interpretation of the relationship of the date of felling of a tree to the date at which its timber was used; only a *terminus post quem* can be given to associated archaeological deposits. The date of actual use is unlikely, however, to be more than a few decades after felling.

Tree-ring and documentary evidence from German structures (Hollstein 1965) indicate that timber was rarely seasoned—it was used green for buildings and such structures as the piers of bridges. In these cases, the establishment of a tree-ring date for the outermost ring of the timber also enables the construction date to be ascertained to the year.

The sapwood is crucial to the interpretation of tree-ring dates. Sapwood is the outer zone of the tree trunk below the bark, which is active in carrying sap; it is present in all trees but not always distinguishable. In oak, however, it is paler in colour and slightly different in structure from the inner heartwood (Jane 1970). The importance of oak sapwood lies in its regular width of about 20 mm or about 25±10 years (estimates differ between authors), depending on ring-width and tree age. The presence of only one sapwood ring on an archaeological sample enables the approximate year of felling to be determined by the addition of about 25 years. The total sapwood and bark edge gives the exact year of felling. When the sapwood has been completely removed or has decayed, exact dating is impossible since an unknown amount of heartwood may also have been lost. The date can then only be given as *at least c* 25 years after the date of the final ring measured. Thus sapwood is very important, particularly on urban sites where precise relative dating may be required, and every effort should be made when sampling not to damage the wood surface where traces might be preserved.

Trees of fine quality were often split into radial boards for use in boat-building, making panels for paintings, or for furniture, doors, and wall-panelling. These would undoubtedly have been seasoned to avoid warping, and the sapwood removed as far as possible. While the long series of sensitive ring-widths usually found on such boards may be easier to date absolutely (eg Fletcher 1977; Fletcher & Morgan 1981), the exact date of felling of the tree or date of use of the board are often impossible to ascertain. This type of material is useful for building up a reference chronology, except that the source of timber is generally unknown. Such chronologies can then be applied to dating more modest archaeological material and timber-framed buildings. However, as a means of dating structures which are in any case well documented, it is of less value.

The extent of timber transport also affects tree-ring dating, in that regional patterns will be distorted by the introduction of 'foreign' material. The literature suggests that the scale of early transport may be under-estimated, with the assumption of plentiful local timber supplies. By the reign of Ethelred the Unready in the 10th century, timber was already being imported into London (Whitelock 1968). By the 13th century, wine and other commodities were being transported on a large scale around western Europe, and the oak barrels which line wells in ports such as York (Webster & Cherry 1977, 248) and Hull could have been made of French or even the much-prized Baltic oak. The timber trade has always been particularly important in Hull (Davies 1964): oak wainscot—originally Dutch oak for making wains or wagons, later coming to mean boards for doors or screens (Salzman 1952)—was brought from the Baltic, Holland, and Germany throughout the medieval period.

There is also ample documentary evidence for the transport of oak overland, such as a gift from the Forest of Dean to the Archbishop of York in 1244 (Hart 1966), a gift from the Forest of Galtres to the Sheriff of Nottingham in 1272-despite the proximity of Sherwood Forest *(VCH* 1907, 502), and by wagon and oxen from Engleby in Cumbria to build Castle Bolton in Wensleydale in the 1380s (Raistrick 1969).

It is clear, then, that while local supplies may have served the modest needs of local building, finer quality boards and timbers for special purposes would be obtained from elsewhere, whatever the cost. This suggests a fairly widespread shortage, or inaccessibility, of the straight-grained and slow-grown mature oaks needed for important structures. The reduction in quality of timber used even in small buildings later in the medieval period also attests to difficulty of supply. The transportation of timber may help to explain some surprising tree-ring correlations between widely separated regions (see for example Fletcher & Morgan 198l), and also the failure to achieve good correlations between timbers found very close together.

The relationship of tree-rings to climate

Under certain climatic regimes, very clear relationships exist between the amount and density of annual tree growth and levels of precipitation and temperature. In arid areas, tree growth is governed largely by rainfall, at high altitudes by temperature. However, the climate and terrain of the British Isles are so varied and complex, that an assessment of the relationship between tree growth and climate is only beginning to be made.

Many factors other than climate affect the growth rate of an individual tree, for example, soil type and depth, quantity of fruits produced each year, degree of insect defoliation and competition with neighbouring trees. To remove the effect of these factors, the tree-ring data must be based on many individual trees (with two or more samples per tree) and must be standardized to remove trends unrelated to climate. The resulting indices, which can be calculated by a computer program (INDXA, Fritts *et al* 1969), are then analysed using various statistical tests in order to extrapolate climatic 'signals' from the variations in growth.

Modern tree-ring data can, of course, be compared with monthly records of climate, which are not available for most areas prior to the late 19th century. The results so far available suggest that clear climatic responses can be found in the tree-ring data (Hughes 1978; Hughes *et al* 1978; Pilcher 1976); when sufficient evidence of the relationship has been collected, it may be possible to infer some data concerning climatic change from earlier tree-ring chronologies based on archaeological timbers. At present, however, no precise information on climate can be obtained from medieval or Roman tree-ring chronologies; to postulate that narrow rings are only and always the result of droughts, for example, is simplifying the relationship to an extreme.

The effects on tree growth can be separated into those caused by climate and those influenced by the amount of growth over the previous few years. Figures available so far attribute about 60% of the variation in tree growth to climate and about 15% to prior growth in Britain (Hughes *et al* 1978), and about 26% to climate and 36% to prior growth in north Germany (Eckstein & Schmidt 1974).

The calibration of radiocarbon dating

The establishment of a tree-ring chronology extending over 7000 years, based on living and dead samples of the bristlecone pine *(Pinus longaeva)* in California (Ferguson 1969), has proved without doubt that radiocarbon dates are not as accurate as had previously been thought. The level of carbon-14 in the atmosphere has fluctuated in the past, both in the short and long term. The measurement of the amount of carbon-14 in bristlecone pine wood samples which had already been absolutely dated has indicated the scale of this fluctuation. Radiocarbon and tree-ring dates roughly correspond back to about 600 BC, prior to which the radiocarbon dates become progressively later than the absolute dates. By 5000 BC, some 800 years must be added to a radiocarbon date to allow for this discrepancy. Tree-ring dates are labelled BC, while uncorrected radiocarbon dates must now be labelled bc to distinguish them.

This discovery led to widespread concern among archaeologists who had come to rely on radiocarbon dating, particularly for early prehistoric contexts where the age difference proved to be greatest (Renfrew 1971).

Corrections can be made on a *calibration curve,* either a graph or a table on which the radiocarbon date can be converted to a calendar date. The first calibration curve was produced by Suess (1970); since then, many new versions have appeared (Clark 1975; Renfrew & Clark 1974; Pearson *et al* 1977, among others) all of which show the long-term divergence but differ slightly in detail. Controversy centres on the smaller 'wiggles' or variations in the curve, which reflect short-term fluctuations in radiocarbon; for some periods, they prevent the reading of a single calibrated date as wood of several absolute dates may provide similar radiocarbon dates. Very short-term variations of the order of several years may affect the choice of samples for radiocarbon dating (Baxter & Farmer 1973), bearing in mind the relative life-span of, for example, a wheat grain and an oak tree. However, the reliability of the bristlecone pine as an indicator of radiocarbon variations is questioned, in view of its slow growth and the high altitude at which it occurs (Harkness & Burleigh 1974). Further studies to check and confirm the calibration have been carried out on European oak (Pearson *et al* 1977; Suess & Becker 1977; Suess 1978); the same trends are apparent.

If the 'wiggles' exist, as they seem to according to both published and unpublished evidence, it may also be possible to match floating tree-ring chronologies against them, in order to provide a more reliable calendar date in cases where absolute dating is likely to be impossible. This is achieved by calculating radiocarbon dates on a series of wood samples from known intervals (perhaps every 30 years) of a floating tree-ring chronology. The relationship in time between each sample is thus known and can be plotted with the radiocarbon dates, which may produce a slight curve in alignment with the calibration curve. The figures from both can be used in statistical comparisons (eg Clark & Renfrew 1972; Clark & Sowray 1973; Ferguson *et al* 1966; De Jong & Mook 1979). A series of radiocarbon dates, as opposed to a single one, also gives a more reliable final date because the accuracy of the estimate may be improved.

When submitting a wood sample for radiocarbon dating, the position within the tree must be ascertained and taken into account when interpreting the result. A date from the inner rings of an oak could be up to 300 years older than 'expected' (Coles & Jones 1975).

Conclusion

Tree-ring analysis embraces a wide range of studies extending from woodland management and carpentry techniques to dating at all levels, and to the study of climatic change. Results cannot always be guaranteed, and the interpretation of information from archaeological timber is not always easy. However, the date obtained will generally be much more precise than dates arrived at by radiocarbon assay.

The very limited horizontal extent of many urban rescue excavations and the complexity of their deposits may result in few wood samples being available from each phase or structure. Dating based on only one or two samples is always less reliable than a more extensive survey, and the collection of more material must be urged. Given thorough sampling and detailed archaeological information, tree-ring analysis can offer an increasing amount of detail on absolute and relative dating, and on local woodland resources, for the urban archaeologist.

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Problems of interpreting differentially preserved plant remains from excavations of medieval urban sites

Francis J Green

The problems associated with the interpretation of the plant remains (fruits and seeds) from medieval urban sites are reviewed. The biases of natural and cultural transformations that have resulted in the observable archaeobotanic assemblage are considered, and the commonest types of preservation encountered on such sites: waterlogging, carbonization, mineralization (calcium phosphate replacement), are discussed. Problems of sampling, contamination, and the methods used to recover such diversely preserved plant materials are also examined. It is shown that the range of plant materials surviving on a site can be directly linked to the type of preservation encountered, from which a misleading impression of the importance of one plant group over another might be deduced. The existing methods of assessing the economic importance of plant remains are examined briefly, using carbonized cereal evidence as an example of how the archaeobotanic and surviving documentary evidence can be evaluated. The complementary nature of the two sources of information has been exemplified by recent work undertaken at Winchester.

The following arguments have been formulated as a result of the author's research on urban and rural sites in Wessex, and are based on the examination of macroscopic botanical material recovered from Winchester, Southampton, and Gloucester, and from a range of smaller urban settlements, mostly in Hampshire.

Before indicating the types of preservation and discussing the problems of interpreting differentially preserved botanical materials, it is necessary to consider the questions being asked of the botanical evidence. The main aims of archaeobotanic research have been succinctly outlined by Dennell (1978, 17). He has considered that they are to establish the plants used by past society, indicating which were of major importance to the society's economy, how the plants were differentially exploited, and how they 'interacted' with the rest of the economy. He considers that other aims include monitoring the long-term effects of exploiting a particular species or group of plants (eg cereals, legumes), and the effects of such exploitation both in terms of the environment and the plant species concerned.

It is clear that the most fundamental aim is to establish the range of plants used, what they were used for, and how the botanical assemblage can be viewed in terms of economy. However, waste disposal mechanisms have to be fully evaluated before any reconstruction of plant utilization and, ultimately, economy can take place. The botanical material recovered from a site has to be related to the type of context within which the material has been found, since different contexts may have had different functions in waste disposal terms (Dennell 1978). For example, the study of only hearth deposits from a site would give a very biased view of waste disposal and preservation, and would therefore give a biased view of the activities associated with the site. Such an analysis could provide a completely misleading interpretation of the importance of the plant products recovered, since plants accidentally burnt during food preparation, or plant fragments, such as chaff and crop screenings, deliberately burnt as fuel, might be represented. Of course the assumption here is that the hearth is a domestic one; it could simply be the remnants of a bonfire or an industrial process, both of which might preserve a similar or a different range of evidence. As will be seen, some of the aims outlined by Dennell (1978, 17) may be too ambitious for the present state of archaeoboranic research on medieval urban excavations, where the total number of contexts examined and the overall sample may be generally too small for detailed statistical appraisal.

Types of preservation

Preservation of plant remains, influenced by human activities and chemical and biological factors in soils, has been recognized since the pioneering work of Oswald Heer (1866), who recorded that botanical material was preserved by carbonization and waterlogging. Essentially, material preserved in these ways still forms the bulk of botanical evidence especially from sites in north-western Europe.

Other modes of preservation are, however, important (Green 1979a, Keepax 1975). Besides plant impressions found in a range of materials (such as pottery, daub, and moulds for casting metal objects) fired in an oxidizing environment, botanical evidence can often be obtained from carbonized remains in pottery, daub, and mould materials fired in a reducing atmosphere. Mineralized plant remains (calcium phosphate replacement) have been recovered, especially, from garderobes and cess pits as well as from general refuse pits on urban sites, for example from Southampton and Winchester (Green 1979a). On some sites, mineralized material has been found in about 30% of all pits examined, and has often accounted for up to 70% of all botanical material from such features (Green 1979b). Mineral replacement of plant materials in the vicinity of bronze and iron artefacts has been a type of preservation recognized for a considerable period, even though encountered rarely relative to remains preserved in other ways (Biek 1963).

Plant materials can also be preserved by desiccation in daub, especially in standing medieval buildings. Where dating evidence is reliable, such material can provide important evidence of cereal rachis fragments and the other non-seed elements of cultivated plants that are rarely preserved in soils on archaeological sites.

Other forms of preservartion involve the inhibition of bacterial and fungal action in soils with a high tannin (polyphenol) content (Biek 1959) or where corrosion products, in particular from bronze objects, have leached into the surrounding soil.

Differential preservation

Although plant remains may be preserved in different ways, within a single preservation medium they have a greater or lesser chance of being present as a result of their inherent differential ability to survive. Woody seeds generally have a greater chance of surviving changing soil conditions, such as fluctuating water table, than delicate materials such as straw or mosses. Preservation of carbonized plant remains, though unlikely to be affected by soil conditions after deposition, may be biased in favour of those that can better withstand particular burning conditions (Jones 1978). Such factors bias and distort the original distribution patterns, which are clearly complex, simply from the selective activities of past populations as well as factors not connected with man, without being complicated by differential preservation. Unless soil conditions are monitored separately from the plant remains, by detailed field observation, chemical analysis, or assessment of past fungal and bacterial action (Green 1979b), it cannot be assumed that the deposits being examined have been subject to the same chemical and biological activities.

Sampling

Recently sampling has become a major issue of discussion amongst archaeologists (Mueller 1975, Cherry *et al* 1978). In particular, sampling methods have been used at various levels when examining landscapes, individual sites, and groups of artefacts, especially where time and money have limited the potential for exploration. Methods of sampling applied to the recovery of archaeobotanic materials are not new. However, most sites have yet to be examined in totality for such evidence. Even if total recovery could be achieved, one would still be dealing with a sample, and perhaps a very biased one, of the original assemblage. Most forms of archaeological sampling for biological remains, especially plant materials, have until recently been totally subjective. Methods of sampling have been imposed by many excavators in a haphazard way, often in the hope than such samples might give more information on contexts that were particularly difficult to interpret. This kind of sampling is of limited value, since it is difficult to establish how far the deposits examined are typical or atypical of similar deposits on the site and, as a result, no archaeological classification of the feature is available independent of the biological assemblages it may contain.

To be able to assess reliably the botanical component of the soils recovered from archaeological sites, well thought out methods of sampling have to be supplied. Unless the method of sampling is uniform and both negative and positive evidence can be properly assessed, the importance of one plant species or crop relative to another may be misrepresented. This possibly indicates the main problem of sampling, that, if the strategy is not imposed on all deposits in a uniform fashion, variation in the observed plant assemblage may result from bias introduced by the method of sampling, and could be taken as indicating variation in plant disposal, environment, and economy.

Moreover, the archaeological site is not homogeneous and therefore methods of random sampling cannot be undertaken, especially where complex preservation conditions and the selectivity of past population occur. Thus it can be said that, unless the same type of features are examined, both in time and space, there is a considerable risk that the differences being monitored through time may represent different aspects of what essentially may be lateral variation between different types of deposit.

To assess the density of plant remains within archaeological deposits, a standard unit is required so that deposits can be compared and control exercised over the data (Mueller 1975, 37). As will be seen, it was found impossible to define a standard unit to cover all eventualities (Asch 1975), since the differences in concentration and variability of plant remains within a deposit and between deposits are enormous (Keeley 1978). A choice has to be made between using weight or volume as the basic measure of soil removed from a context. The problem has been indicated by Jones (1978, 197), who chose a volume measure in preference to weight. For recording purposes, samples consisting of a block of unexcavated soil from a deposit are more useful than a unit of weight. As will be seen (page 45), direct comparison of the volume of soil sampled to the volume of the original layer or context is particularly useful. Establishing such a ratio on a weight basis would be extremely difficult since it would be almost impossible to calculate the entire weight of a deposit due to the differential weight of soil constituents and moisture content. It is impossible to give direct measurements of dry weight of processed soil, since to dry samples prior to the recovery and examination of botanical materials would cause considerable damage to most classes of botanical evidence.

Practice has shown (Green 1979b) that volume units of 5 litres are a useful size for processing in the laboratory for the recovery of carbonized and mineralized remains where either one or several types of preservation occur in a single deposit. For recovering waterlogged or anaerobically preserved plant remains a sample unit of 500 ml has proved useful. Often a single sample of the above volumes (depending on preservation) may not be sufficient for a particular type of analysis. Such a sample unit will not, of course, provide the full range of species contained within the deposit. In such instances more sample units should be removed until continued work provides little additional information.

Unfortunately, on most excavations, such an ideal situation does not exist and a sample unit often represents all that is available for study. A single sample unit, because of its uniformity, can provide the basis for comparing the density of seed material between deposits and at a fairly unsophisticated level can provide information about past disposal and depositional mechanisms on the archaeological site, based on the concentration of different plant components in the soil examined. Jones (1978) has pointed out that this does have limitations when examining plant remains from ditches, where considerable lateral variation may be encountered.

Depending on the information required from an excavation the level of sampling will vary (Green 1979b). The level of sampling, where large populations of a particular species are required for detailed morphological analysis, may involve the processing of even larger quantities of standard sample units. The only way the ideal sampling system can take place is by the removal and analysis of samples while excavation is in progress. It is only by feeding back the information recovered at all stages in the excavation that the quantity of samples required for the different levels of analysis can be recovered. As will be appreciated, this is not very likely to occur on urban rescue excavations where time and money are limited. Even the time-lag of a day or two, while initial processing is being undertaken, may be too long for the remainder of a deposit to survive from which further sample units could be removed. The ideal situation rarely if ever occurs, so the best has to be made of what may be available.

Contamination

Contamination could, in theory, be a serious problem when interpreting plant assemblages from medieval urban sites. The problems of modern seed evidence contaminating archaeological deposits, described by Keepax (1977), have not been widely observed on the sites discussed here.

Contamination between adjacent deposits may take place, although in many cases this would be virtually impossible to establish. By examining deposits in detail, it is sometimes possible to show that species composition and seed density between adjacent deposits may be so different that contamination of one deposit to the next can be assumed to be small or non-existent. However, the converse result, where two associated deposits contain the same range of remains, does not of itself argue in favour of contamination. In such circumstances it might merely be hinted at. An example showing that contamination between deposits is slight can be taken from recent work undertaken by the author in Winchester, where many Saxon and medieval deposits cut features of Bronze Age, Iron Age, and Roman date (Qualmann forthcoming). The kinds of wheat recovered from the earlier features included brittle-rachis hulled forms such as *Triticum dicoccum* (emmer wheat) and *Triticum spelta* (spelt wheat), whereas the Saxon and medieval deposits contained exclusively *Triticum aestivum/compactum* (bread wheat/club wheat)—free-threshing wheats. If contamination existed between the earlier and later contexts, some evidence of the brittle-rachis hulled cereals ought to have been present in the later ones. Thus, in this case, contamination can be discounted. Well sealed contexts, such as deep pits of a single period, are less likely to be contaminated by residual or more recent material (resulting from worm, insect, and small mammal activity) and pose fewer interpretative problems. Clearly the degree of contamination has to be assessed on each site or even between and within each context examined.

Problems of recovery techniques

A problem or bias that particularly affects the interpretation of plant assemblages is that caused or introduced by the method of recovery. The use of chemicals to disaggregate soils may have serious effects on plant materials preserved in different ways, in particular waterlogged material (cf Williams 1976). It is clearly best to establish the types of preservation encountered within a sample before subjecting it to chemical solutions, as suggested by Renfrew *et al* (1976) and Streuver (1968, 356, 357), that might damage or destroy some materials.

Methods of recovery such as the use of seed machines, which can be of immense use on prehistoric sites where only carbonized material survives and the soil is sufficiently friable to disaggregate in water, may introduce a bias into the recovery of certain classes of botanical material (Renfrew *et al* 1976). Large dicotyledonous seeds such as peas and beans often shatter, destroying valuable morphological features important for identification, whereas small weed seeds may be under-represented, having become trapped in the soil matrix and sinking to the base of the flotation cell. Simple manual water sieving and flotation in the laboratory can solve most of these problems, though such methods may not be suitable for the recovery of large assemblages of carbonized and mineralized plant remains for detailed analysis (Green 1979b, 47).

All the biasing factors of preservation, sampling, and recovery have to be reduced to a minimum or have to be allowed for in any interpretation of plant remains from archaeological sites, especially where two or more forms of preservation (mineral replacement, carbonization, waterlogging) may occur within a single deposit.

The types of botanical evidence

The types of botanical evidence preserved in different ways have been discussed in greater detail by the author elsewhere (Green 1979b). From this work, mainly in Winchester and Southampton, it has become apparent that associations of waterlogged or anaerobically preserved plant remains are possibly the most difficult to interpret since, in theory, such deposits can preserve material from natural sources and from human activities associated with a site. The problem is particularly confined to the interpretation of the large numbers of species and often large numbers of seeds of ruderals and wild plants. It is difficult to separate background noise and flora introduced to the site by natural agencies from those directly introduced by the inhabitants. Thus small mammals, birds, and insects may have all introduced material to the site. Weeds and ruderal seeds may also have been incorporated in animal faeces, either in dung or the gut content of animals butchered on the site. Seed material might also be transported inadvertently by man in the collection of bracken, gorse, moss, heather, rushes, and reeds, as well as within crop products, hay, straw, etc, used for various industrial and domestic purposes. The site itself might contribute to the plant assemblage with weeds growing around open pits and features. The flora of the wider locality might also be represented by those seeds that are particularly suited to aerial dispersal, and of course weed seeds might be transported on the fleeces of animals or human clothing. Thus when dealing with such complex assemblages, theoretical methods of analysis employing modern studies of ecology and phytosociology may be the only ways of examining such material. For this purpose, plants are grouped into habitat or association types, so that variations between features can be made by group rather than single species analysis (Green 1979c).

Ultimately, assuming that refuse disposal patterns and other depositional processes remain fairly constant throughout the medieval period in a particular locality, in that the same types of materials are deposited in the same type of feature, then differences can be monitored between feature types in both space and time, allowing for constraints imposed by preservation, sampling, and recovery. Waterlogged deposits can often give a far better picture of certain 'crops', such as *Prunus* spp. and other stone-fruits, which invariably survive better and in larger quantities under these conditions than under any other. Often, small quantities of cereal fragments, in particular rachis and glumes, may be recovered. Such waterlogged evidence from Winchester and Gloucester has provided important information about the different species of crops grown in the Saxon period, evidence that could not have been evaluated on carbonized grain morphology alone (Green 1979c, 186-90). This information has provided the basis for understanding regional diversification in cereal crops in the late Saxon period.

Carbonized botanical material is biased in favour of those plants that require processing in the vicinity of fires, where accidental burning can take place. This includes, in particular, those crops such as the cereals that are parched or malted. However, carbonized remains also include material deliberately burnt either as part of a crop-cleaning process or the burning of household refuse. Some may even be material carbonized in a catastrophe, such as the destruction of a granary. Obviously some material may also originate from non-domestic, non-agricultural, industrial activities. Apart from cereals, most of the pits examined from Winchester contained very small amounts of other carbonized material. Almost invariably, this was less than 10% of the total assemblage. An exception to this was the carbonized material recovered from garderobe and floor deposits; in the former case this probably reflects function (to contain excrement) and in the latter, perhaps activity such as trampling and cleaning, under which only the more robust items such as nuts would survive. The range of species and the composition of carbonized deposits suggests that the weed seeds recovered from them may have originated as crop contaminants (Dennell 1978) rather than from the local environment. Small concentrations of carbonized waterloving and calcicolous plants which occur may represent the background flora of the site.

The techniques employed for studying carbonized plant assemblages have been more widely discussed by Dennell (1972; 1974; 1976; 1977; 1978), and though this is in relation to evidence from prehistoric settlements in Bulgaria, the principles involved are essentially applicable to medieval urban sites in Britain. Carbonized cereal evidence from granaries and stores provides the most important information about the nature of the weeds growing within crops, from which it may be possible to deduce processes of crop cleaning, such as sieving out seeds smaller or larger than the cereal grain and the removal of chaff and small weed seeds by winnowing. Equally, it is possible that the type and quantity of certain weeds may indicate if the crop was spring or autumn sown. In some cases, weeds may give an idea of the nature of the land on which the crop was grown.

Mineralized material is biased in favour of plant remains incorporated in faecal deposits (Green 1979a; 1979b), commonly encountered in stone-lined garderobe pits from the 11th century onwards in Winchester and from pits of the 8th century from the Hamwih excavations at Southampton (see above, p40). This material and in particular the woody seeds that can survive the passage through the human alimentary tract can provide important information about diet. Other plants, not eaten but found in association with faecal deposits, may also be preserved by mineral replacement resulting from the calcium phosphate content of the surrounding deposits. Mineralized faecal material can provide important information about the dietary habits of different social groups within an urban community, and can thus provide information of an economic and social nature. Mineralized remains are particularly important for providing evidence rarely preserved in any other way. Unlike other sources of botanical evidence, most of the mineralized remains seem to have been eaten prior to deposition. Unfortunately, at the present time, not enough of this material has been recovered in a systematic fashion to use it for the above forms of social and economic analysis.

Methods of assessing botanical evidence

To illustrate the problems of assessing botanical material, carbonized cereal evidence has been chosen, because in many ways, as has been indicated above, this presents fewer interpretative problems. Since some 90% of all evidence for cereals on the urban excavations examined was preserved by carbonization, and since cereals account for over 70% of all carbonized material (Green 1979b, 50), it is clear that this is the best material for studying cereal usage and possibly economic activities.

As with all archaeobotanic work there are several problems of assessing the importance of one cereal type relative to another and, of course, assessing the role of cereals in the total economy. Particular problems are the current methods of statistical representation and of course the interpretation of the statistics. Various methods of calculation and diagrammatic representation have been adopted in an attempt to estimate the relative importance of plant materials on archaeological sites in the past. The most comprehensive survey and summary of the different techniques is to be found in Dennell's work (1978, 22). Briefly the different methods he discusses can be described under the headings 'Dominance' and 'Presence.'

Dominance analysis has been used by a number of workers trying to evaluate the importance of plant species within an economy. It involves establishing the major plant type within each deposit and then estimating the importance of a species from the percentage of samples in which it was the dominant plant. As Dennell (1978, 22) has pointed out, this suffers from the disadvantage that it includes all species from the deposits on a site and that a single species would have to be dominant in at least one sample to be considered in the analysis. Thus a species consistently present but never dominant would not be considered in the assessment and a crop weed could, if represented in high enough quantities, appear to have been deliberately sown.

As indicated above and as can be seen from Fig 20, it is probably best to select a group of plants such as the cereals and study the relationships, through time, of the different species. Instead of estimating which plant was dominant, as described by Renfrew (1973, 21), all the finds of a single cereal species from a particular feature type (refuse pit) and a specific phase of the site were added together and then presented as a percentage of the total cereals recovered from that particular phase. Clearly this adaptation of dominance

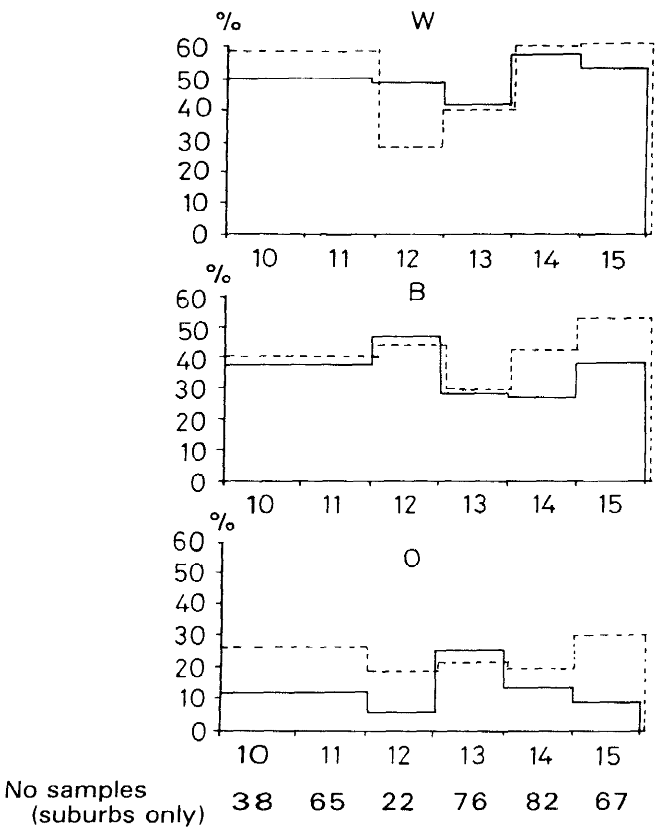

Fig 20 Percentage presence and percentage dominance analysis of cereals recovered from medieval pits in Winchester. Horizontal axes: centuries (AD); —— : dominance curve; ----: presence curve; W: wheat; B: barley; 0: oat.

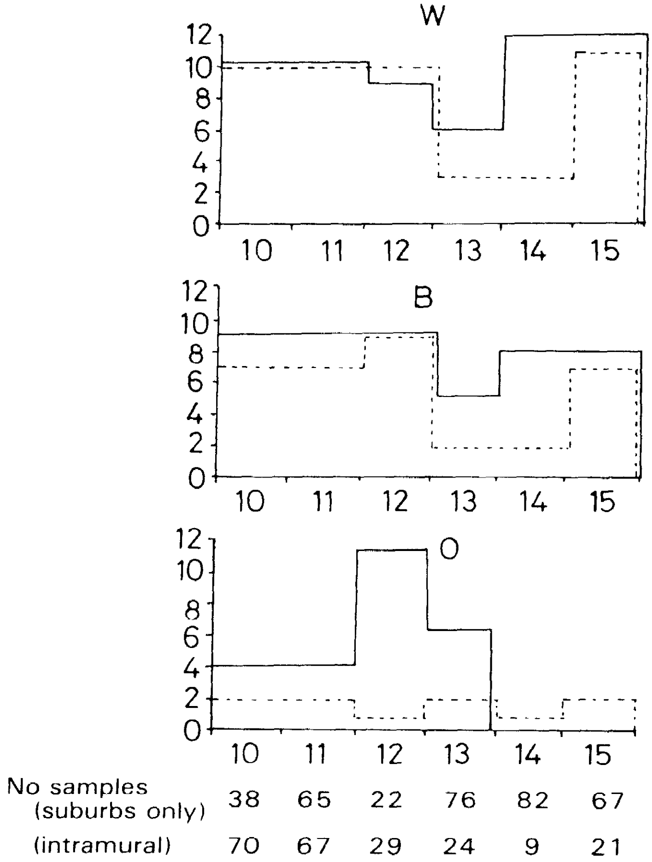

Fig 21 Analysis of cereals recovered from medieval pits in Winchester. Horizontal axes: centuries (AD); Vertical axes: number of seeds per 10 l of soil examined; —— : intramural sites;----: suburban sites; W: wheat; B: barley; O: oat.

analysis can also be applied to other plant groups, for example *Prunus* spp., to see how the different species preserved relate to one another. However, in any such analysis all large grain deposits, that is deposits which contained over 200 ml of grain per 5000 ml of soil examined, were excluded since such deposits would have biased the overall results. Such a deposit, although rare, might well produce over 3000 cereal grains (cf Green 1979b, 46), which if included in the different analyses such as those given here (Figs 20 and 21) would produce very misleading results. For example, if the 10th century suburban sites had produced a pure wheat deposit of 3000 grains then on dominance analysis the percentages would read: wheat 91%, barley 7%, and oats 2%. Presence analysis would of course not noticeably change, whereas the wheat component within the seed concentration analysis would increase to 174 wheat grains per 10,000 ml of soil examined.

Presence analysis is also discussed in detail by Dennell (1978) and Hubbard (1975). It is particularly useful in that it can be applied to published plant assemblages where it is impossible to establish the criteria of sampling and recovery used by the different workers and archaeologists concerned. The importance of a plant resource is estimated from the number of deposits or phases that the species occurs in, each occurrence being given a score of one and the total scores given as a percentage of the number of contexts or deposits examined. Dennell (1978) has indicated the weakness of this particular method; it ignores differential preservation of plant materials and the variable behaviour of past populations, which may have selected specific types of feature for disposing of certain classes of refuse. Once again this method of assessment, because it tends to be applied to all species recovered from a deposit, phase, or site, provides no way of distinguishing actual plant foods and resources from potential resources.

Because of the limitations to obtaining reliable information using this method, it was only applied to specific plant groups as described for dominance above. The evidence produced in this way has been illustrated in Fig 20, where the histogram may be compared with that derived from the same data by dominance analysis.

Seed concentration analysis

Since many of the urban sites examined were sampled very thoroughly on a volume basis, it was possible to work out the numbers of seeds per unit volume of soil for a particular species and to plot variations through time. The histograms produced by this method (Fig 21) are based on the data used in the construction of Fig 20. It can be seen that by excluding large grain deposits the average quantity of seed per 10 l of soil examined was extremely low.

The concentration analysis provides an absolute method of examining deposits, since it does not rely on percentages as both dominance and presence do. Only when more medieval urban sites are examined in this way will it be possible to be clear about what is actually being monitored by these methods of analysis. It is thus desirable to keep better records of the quantity of soil removed from a deposit, so that seed concentrations can be calculated.

It can be seen from Figs 20 and 21 that there are points of similarity between the three different methods of analysis. Obviously the concentration of seeds reflects complex human and preservation factors, methods of plant utilization, and disposal, as influenced by past populations as a result of economic and social functions. It is only by internal analysis of as wide a range of contexts as possible (Green 1979b) that the different uses of the plants recovered and therefore their different importance in the overall economy can be evaluated. This is, in fact, what Dennell (1978) has advocated. However, in the case of medieval cereal evidence, the availability of documentary sources makes interpretation in some ways simpler, though as a result, more emphasis has to be placed on the differences between the two types of information (archaeobotanical and historical) and the cultural and economic activities that account for the differences between the two observable forms of data.

By reference to the seed concentration diagram (Fig 21), based on the recovery of carbonized cereals from intramural and extramural Winchester sites, certain clear patterns emerge—in particular the decrease in wheat and barley in 13th and 14th century pits. The differences between the intramural and extramural evidence can probably be accounted for by the method of sampling imposed by the Winchester Research Unit, in which there was selection of anaerobic material and the taking of samples of an inadequate size for the assessment of carbonized and mineralized evidence; this may be contrasted with the results from the more recent excavations, mostly concentrated in the city's suburbs. The results from the 12th century deposits may be misleading bearing in mind the small overall sample used.

From Fig 21 it can be seen that wheat was consistently disposed of in slightly larger quantities than barley, which was discarded in larger quantities than oats. Clearly this particular relationship does not change significantly through time. However, changes in the occurrence of all cereals can be seen through time. Because the data have been presented as an average of all refuse pit deposits of a particular period, social variation in cereal utilization and disposal should be minimized. Observable changes through time have to be explained in terms of depositional formation processes (Schiffer 1976, 27-41) which may be influenced by the abundance or scarcity of a resource. However, such patterns do not of necessity reflect the agricultural production of a region.

Fig 21 shows that fluctuations occur particularly in the 13th and 14th centuries. This may be linked with a general decline in the economic and social role of Winchester at this period (D Keene, pers comm), though the increase in the concentration of plant remains in the 15th century cannot be accounted for by trends in the city's prosperity, which had certainly declined by this period. However, the actual amounts of cereals produced and the fossil carbonized cereal evidence can reasonably be expected not to be in direct proportion because of the several processes of production, distribution, utilization, and destruction, which are difficult to evaluate. However, having said this, Winchester is particularly fortunate in having some of the best documentation available in the form of estate records for the manors belonging to the Bishop of Winchester and the Priory of St Swithun in Hampshire. On the Bishop's estates, oats were more important and were produced in greater quantities than wheat or barley (J Z Titow pers comm). Wheat and barley were of near equal importance, with very little rye or legumes being cultivated. Although considerable quantities of oats appear to have been cultivated on the Priory estates near to Winchester in the earlier (pre 14th century) period, during the later Middle Ages wheat becomes the most important crop, followed by barley and then oats, in the same proportions or certainly comparable with the archaeological evidence in Fig 21. Rye and legumes, it is significant to add, are rarely mentioned in the documentary records or recovered from the archaeological sites.

The lack of oat remains from archaeological deposits in Winchester may simply be accounted for by their being used for animal rather than human consumption. Even if used for human consumption, they may have been processed in such a way that little evidence survived. The difference between the archaeological and historical information in this particular example is difficult to evaluate. If good documentation on agricultural production existed for the periods either side of 1200 and 1350, it might be possible to see if the discrepancies between the two types of information (documentary and archaeological) were consistent. It would be interesting to know whether or not the pattern of agricultural production prior to 1200 was the same as that from 1200-1350. If the same, then the discrepancies between the two sources of information remain consistent. However, if the production was different, the archaeological evidence has to be explained in another way. Instead, the observed discrepancies during the period 1200 to 1350 may, in fact, be due to demesne agriculture which prevailed during this particular period, or even to other known factors such as the particularly bad harvests in the early 14th century and even of course the economic effects of the Black Death in the same century. Both sources of data have limitations, but used in conjunction must give a clearer picture of the role of cereals within the medieval urban environment. Further work needs to be undertaken, in particular the reconciliation of historical and archaeobotanic information by historians who will need to examine available evidence more critically. Until this is undertaken many of the questions posed by archaeobotanists will remain only partly answered. Equally important in any assessment is the need to be able to examine botanical material from rural sites adjacent to the urban centres so as to establish the methods of crop processing and production in an attempt to understand the problems posed by the urban evidence.

It can be seen that detailed examination of preservational conditions and inter-context variability can provide important information of botanical and archaeological significance. Negative botanical information from contexts is obviously important, and therefore both intensive and extensive analysis of deposits for plant remains from medieval urban sites still needs to be undertaken. More than 5000 soil sample units have been examined from medieval sites (10th-15th century) in Winchester since 1974, and yet the overall sample of pits and other features of a particular century or phase is still inadequate for detailed and reliable statistical analysis. However, it is to be hoped that such studies undertaken here and elsewhere (Green 1979b; Buckland *et al* 1976) will provide the integrated basis for future social and economic interpretation.

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Investigations into a variety of urban archaeological deposits have shown two main types of pollen spectrum. The first is rich in Gramineae (grass) and Compositae (Liguliflorae), apparently the result of more or less natural transport and deposition; this type often comes from well fills and buried soils. The second type is rich in Cerealia and sometimes also in Ericales pollen, which has apparently come from whole plant matter deposited by human activities rather than by natural means. In some cases, cereal pollen may have come from food remains, and the presence of parasite ova may demonstrate the presence of faecal matter. Archaeological material is often of rather mixed origins and therefore hard to interpret and the interpretation of pollen from urban deposits is best done in conjunction with studies of other biota such as plant macrofossils and insects, so that there is complementary evidence.

Introduction

The definition of an urban site

It is difficult enough to define what is meant by the expression 'urban site' in purely archaeological terms: the status of many settlements such as those dating from the Roman period (Rivet 1975) is hard to assess, while sites like tells and lake villages, dating from other periods, could be regarded as being urban or rural according to viewpoint. In biological terms, however, the expression 'urban site' becomes even harder to define, since what is regarded as a town on archaeological criteria might not appear so on the basis of its flora and fauna—waste ground in modern towns fairly quickly acquires a 'rural' flora and fauna, while in the past any settlement, such as a farm, which radically altered part of the landscape, could have given rise to a flora and fauna hardly distinguishable from those of a town today.

Because of this difficulty in differentiating 'urban' and 'rural', this study has not been restricted to sites which would be considered 'urban' in archaeological terms, but has also included archaeologically 'rural' sites in an attempt to detect any biological distinction.

Previous pollen studies of urban archaeological deposits

Pollen from urban archaeological deposits in Britain has been studied from time to time in, for example, material from Godmanchester (Hunts) (Dickson *et al* unpublished), Shenstone (Staffs) (Godwin & Dickson 1964 - 5), and York (Cundill 1971). Pollen analysis has also been integrated with the study of other remains such as plant macrofossils and insects at York (Buckland *et al* 1974; Greig 1979a; 1980). Pollen analysis of urban archaeological material has also been carried out on deposits from the Feddersen Wierde (Körber-Grohne 1967) and Hedeby (Haithabu) in Germany (Behre 1969), and Bergen in Norway (Krzywinski & Faegri 1979). Apart from these few examples, palynologists have almost exclusively studied naturally formed deposits, so the general attitude towards the study of pollen from archaeological deposits may possibly be best summarized in the words of Godwin & Bachem (1959, in a report on plant material from Hungate, York): '. . . it was thought unprofitable to examine the pollen content . . '. This lack of interest in pollen from archaeological sites may result from the greater complexities of this kind of work compared with conventional studies of naturally-formed deposits like lake sediments and bog peats. One problem is that there is much less information on the ecology of urban plant communities than there is on rural ones (eg Tansley 1939). Also, most of the information on urban pollen deposition comes from studies of pollen and hay fever, which are not very relevant to archaeological work. On the other hand, many studies have been made of modern pollen deposition in natural habitats to aid the interpretation of pollen diagrams from natural sites (see, for example, papers in Birks & West 1973). There is also some difficulty in many towns in finding deposits in which pollen is sufficiently well preserved. Human habitation tends to favour well-drained sites whilst pollen preservation is favoured by waterlogging or acidity, or, in rare instances, by copper corrosion products (Greig 1971; Beal *et al,* in prep), conditions only occasionally found in towns.

Pollen dispersal and representation

It is important to discuss some aspects of pollen production and dispersal to set out the theoretical background, before considering how pollen from urban archaeological deposits can be studied. Pollen dispersal (Tauber 1965) and relative pollen productivity and representation (Andersen 1970) have mainly been studied in natural forest vegetation to aid the interpretation of pollen diagrams. Urban deposits, however, necessarily date from a time when the landscape was already much altered by human activity, and come from a place where such activity was concentrated, so it might be predicted that pollen dispersal, relative productivity, and representation in towns would be different from that in forests. Although studies on pollen dispersal and deposition in populated landscapes are proceeding (eg Berglund 1973), there are so far very few results available for towns, apart from those presented here.

Some possible pathways of urban and rural pollen dispersal are shown in Fig 22 to illustrate how the principles arising from work on rural sites could be extended to towns, and to summarize some of the results discussed later. The land around this town is shown as a mosaic of pasture and arable land supporting a range of crops. The fields could be enclosed by hedges or fences, or they might be managed on the open field system with fewer boundaries (Bennett 1947). There would probably also be some scrub and wasteland, and perhaps places where the soil had become so degraded that it would only support heathland. There is likely to have been woodland near most towns, too, maintained to provide valuable natural resources such as firewood, fencing, pannage, and timber. In this form it would have been very different from the original forest cover; the last essentially primeval forest is believed to have disappeared by about 1150 AD (Rackham 1976).

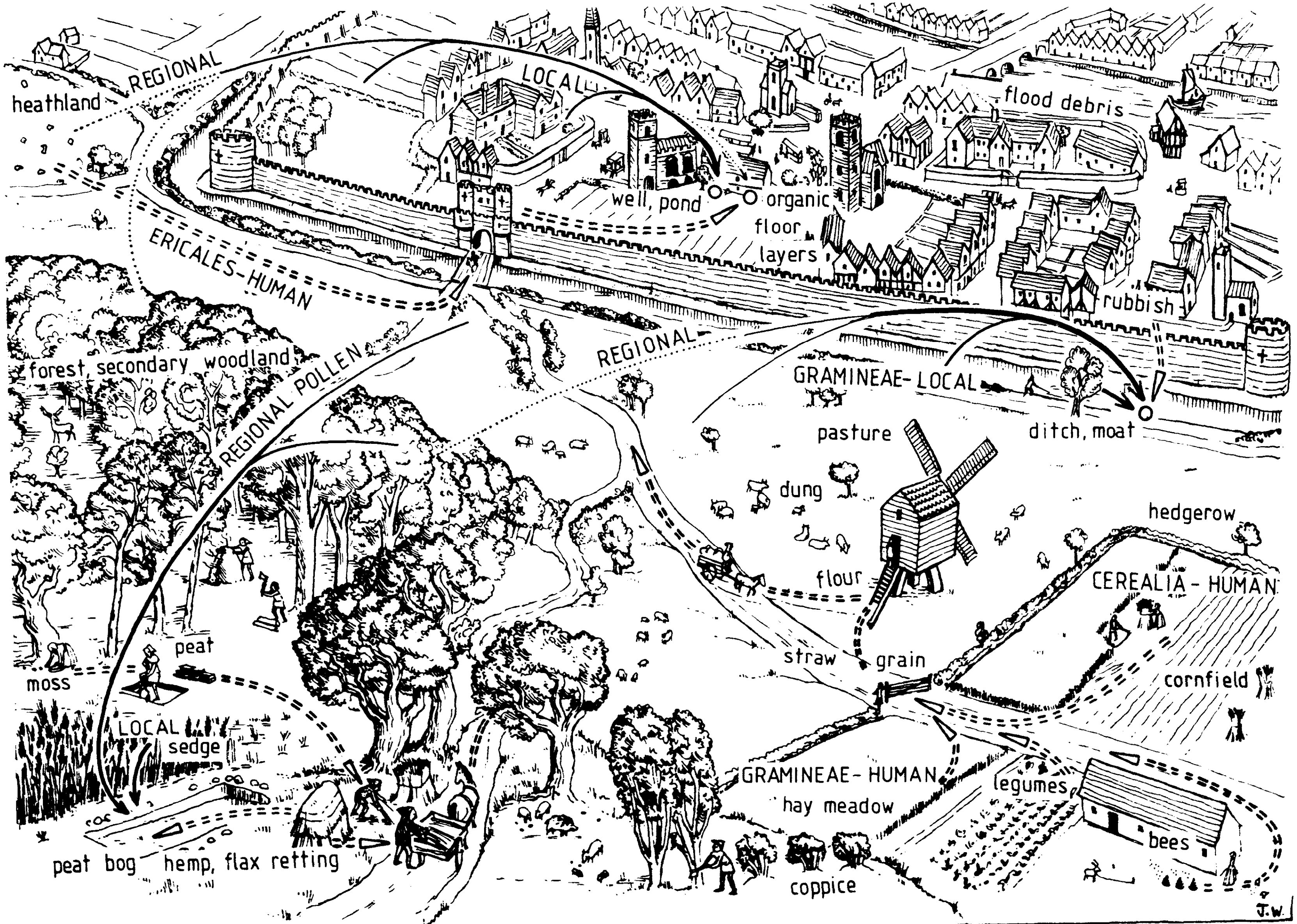

Fig 22 A model of urban and rural pollen dispersal. This show the main features of a town set in a landscape containing natural woodland bog, scrub, heathland, pasture, and arable land. Possible sources of the pollen arriving by natural means at particular sites are shown by single lines, and pollen dispersed by human agency by double dashed lines. The pollen components are in capitals (see text). The picture is intended to show the generalities of pollen dispersal rather than any particular site or period.

This varied landscape with its wide variety of vegetation would produce pollen of many different types which could become dispersed in various ways. The relative amounts of the various kinds of pollen carried by the wind, for example, would only bear an indirect relationship to the relative abundance of the plants producing them. For example, *Quercus* (oak) and *Alnus* (alder) produce about eight times as much pollen per unit area of their canopies as do *Tilia* (lime) and *Fraxinus* (ash) (Andersen 1970, 80). There are fewer data for the pollen representation of herbs to compare with those from trees, but wind-pollinated plants like *Rumex* (docks, sorrels) and *Urtica* (nettles) produce large amounts of far-travelling pollen compared with insect-pollinated ones such as *Rubiaceae* (bedstraws etc) or *Geum* (avens) (Bradshaw 1981). Thus there is a general scarcity of pollen records from entomophilous plants in most pollen diagrams from natural deposits.

Some of the pollen from the vegetation of a landscape like that in Fig 22 would be carried by the wind for a considerable distance from its sources and might be mixed with other pollen and distributed around the whole region; this is the 'regional pollen component' (Tauber 1965). This term was originally applied to the pollen, mainly from trees, which was blown above a forest canopy and could then travel for some distance in the wind before settling. The term may also be applied to pollen which is well dispersed around a landscape like that in Fig 22.

The composition of the regional pollen landing at a given point would depend upon the proximity of the various types of vegetation and the nature of the pollen dispersal of the plants in it. For a natural site like a peat bog surrounded by woodland (Fig 22, lower left), the regional pollen rain would be rich in tree pollen, with smaller amounts from more distant vegetation such as fields. Many pollen diagrams for deposits formed in the last few thousand years show a large pollen component which could be regional pollen of this kind. Pollen diagrams for urban deposits, however, may be expected to have a regional pollen component which is different (Fig 22, top left, centre right).

Not all kinds of pollen are widely dispersed, and many plants liberate small amounts of pollen which may only be at all abundant in the immediate vicinity of the parent plant. The pollen from many insect-pollinated plants, for example, is poorly dispersed in the wind. Another factor influencing poor pollen dispersal is the habit (growth form) of a plant, for low-growing plants are often sheltered so that little pollen is carried into the mainstream of the wind. Such pollen, which has only travelled a short distance prior to deposition, is termed the 'local pollen component'. In natural deposits this pollen usually comes from plants growing, for example, in a lake or on a bog (Moore & Webb 1978-'autochthonous pollen') and it falls directly into the accumulating deposit where it can be preserved and later recovered and detected (Fig *22,* lower left). In such a case the local pollen can often be distinguished from the regional (in natural non-fluviatile deposits) by examining macrofossil remains which may confirm which plants were growing there. The local pollen component may be expected to be harder to identify in urban pollen spectra. Some features, like moats and ditches, may have supported wetland vegetation, so that the presence of both pollen and macrofossils of wetland plants in their fills may be a sign of local pollen deposition there also. Human activities, however, make the understanding of archaeological deposits much more difficult than natural ones.

The local pollen component in urban deposits can also come from dry-land vegetation growing nearby. Towns would have provided many habitats for various kinds of vegetation, such as weed communities. The scale of this man-made mosaic is much smaller than that which is usually resolved in interpretation of pollen from natural deposits, which adds to the problems,

A third component which is likely to be important in spectra from archaeological deposits is that which has been transported, either directly or indirectly, by human agency. This can be termed the 'human component' in the absence of a suitable pre-existing term, for words like 'anthropogenic' are rather ambiguous and others coined from Greek and Latin tend to be obscure. This 'human component' would include pollen transported with a range of plant materials such as flowers or other plant parts in the many plant products used for building, food, etc. It would also include pollen transported by domestic animals, for example in the gut of herbivores. The main characteristic of this component is the presence of pollen in circumstances that cannot adequately be explained in terms of local or regional natural deposition. Some of the possible sources of the 'human pollen component' are shown in Fig 22 and the transport is indicated by double dashed lines. Even deposits which may appear to be of wholly natural origin can have a 'human component', for example when there is evidence that flax or hemp has been retted in a lake or bog (Tolonen 1978; Hall *et al* 1979; Bradshaw *et al* 1981).

Another example of the 'human pollen component' comes from the results of the pollen analysis of samples in a succession which included the occupation layers of a Swiss lake village (Welten 1967). In these cultural layers there were unusually large amounts of pollen of *Tilia* (lime), *Acer (maple),* and *Hedera* (ivy). These were interpreted as evidence that leafy branches (together with the flowers) had been brought to the site for cattle fodder. *Ulmus* (elm) branches were probably also gathered in this way, but since the flowers would have fallen by the time that the leaves had fully developed, no corresponding peak in elm pollen would be expected. The 'human pollen component' as identified in the present study is discussed further below.

Another pollen component which has been studied in some deposits is thought to result from the activities of insects such as bees (Bottema 1975), which selectively gather pollen and take it back to their nests. This may be termed the 'insect component', and is also discussed later.

Methods

Avenues of research

There are several ways of studying urban archaeological pollen spectra. One method is to compare spectra from as wide a range of deposits as possible and then to note the similarities and differences between them, to see whether any pattern can be identified. The results from urban and rural archaeological deposits can be compared in this way,

Table 6 Sites and samples discussed

1	York, Church Street (Roman sewer). Excavated December 1972, pollen analysis from three samples by J Greig, average Σ 200, results: Greig 1976, excavation: Whitwell 1976, finds: Macgregor 1976.
2	Askham Bog, near York (SE 570 480) (peat bog). Excavated July 1976 (cores 1 & 2) and July 1977 (core 3), pollen analysis by J Greig, seven samples from AB1 presented here, average Σ 373, results: Kenward *et al* 1978, Hall *et al* 1979, and unpublished.
3	Stafford, King's Pool (SJ 925 234) (peat bog). Excavated May 1977, 0 - 350 cm, pollen analysis by S M Colledge.
4	York, Skeldergate (? pre-Roman buried soil). Excavated 1977, pollen analysis of three spectra by J Greig, average Σ 267, results: Greig 1980.
5	York, Coney Street (Roman buried soil). Excavated 1976, pollen analysis of one sample by J Greig, Σ 495, results: Greig 1979a.
6	Cowick, near Snaith, Humberside (SE 652 206) (medieval moat). Excavated May 1976, 110 cm profile sampled every 5 cm, five spectra presented here, analysis by J Greig, average Σ 457, results unpublished.
7	Birmingham, Smithfield market site (medieval/post medieval moat). Excavated May 1975, 60 cm section sampled by S Limbrey, six samples presented here, analysis by J Greig, average Σ 431, results: Ancient Monuments Laboratory report 2919.
8	Droitwich, Worcs, Friary Street (Hereford & Worcester County Museum, site No 600) (? medieval brine pit) Excavated October 1977, 24 cm section samples every 2 cm, pollen and macrofossil analysis of one sample by J Greig, pollen analysis of nine samples by S M Colledge (average Σ 206), unpublished. Archaeological interim report, Worcester Museum News Sheet, 1979.
9, 16	Hibaldstow, Lincs (SE 957 027) (pond in small Roman town). Excavated 1977, 60 cm section sampled every 10 cm by P C Buckland. Pollen and plant macrofossil analysis by J Greig, average pollen Σ 472, results: Ancient Monuments Laboratory report No 2678, insect analysis by M A Girling, unpublished.
10	Fisherwick, Staffs (SK 187 082) (ditch associated with Iron Age settlement). Excavated April 1975, pollen and plant macrofossil analysis by J Greig, Σ 250, results: Greig 1979b, insect analysis: P J Osborne in Smith 1979.
11	Alcester, Warks, Bull's Head Yard site (? Roman and later pond or river channel). Excavated March 1977, 60 cm profile, sampled at 2 cm interval, pollen analysis by J Greig, seven spectra presented here, average Σ 527, unpublished.
12, 15	York, Ebor Brewery site, Aldwark: Ebor Deep Trench (? pond deposit: see King 1975). Excavated November 1974, 230 cm profile sampled at 5 cm interval, pollen analysis by J Greig, twelve spectra presented here, average Σ 322, unpublished.
13	Tamworth, Staffs, 71 Bolebridge Street site (medieval ditch). Excavated April 1978, single sample from Layer 87 sampled, pollen (Σ 410) and plant macrofossil analysis by S M Colledge, unpublished.
14	Nantwich, Cheshire, 'The Crown' car park site (medieval ditch). Excavated June 1978, 70 cm profile sampled at 5 cm interval, pollen (average Σ 439) and plant macrofossil analysis by S M Colledge, interim report: McNeil Sale 1979.
17	Alcester, Warks, Coulter's Garage site (? Roman pond deposit). Excavated May 1979, 150 cm profile sampled at 5 cm interval by P Booth, pollen (average Σ 313) and plant macrofossil analysis: Woodwards 1979.
18	Droitwich, Worcs, Friary Street Bowling Green site (Hereford and Worcester County Museum site No 600 (Roman ditch)). Excavated June 1978, single sample from Feature 530, layer 559 collected, pollen (Σ 396) and plant macrofossil analysis by J Greig, unpublished.
19	Worcester, Sidbury (Hereford and Worcester County Museum site No 177) (Roman ditch). Excavated August 1977, 50 cm profile sampled at 5 cm interval, pollen analysis of three samples so far completed (average Σ: 406) by J Greig, unpublished.
20	Alcester, Warks, Bleachfield Street, Explosion site (Roman well). Excavated April 1977, Layer 182 L sampled, pollen (Σ 737) and plant macrofossil analysis by S M Colledge, unpublished.
21-24	Barton Court Farm, near Abingdon, Berks (SU 506 973) (wells). Excavated 1976, Feature 832 spits 4 & 5, Feature 950 layer 5 (Roman), and Feature 1083 layer 4 (Saxon). Sampling, plant macrofossil and insect analysis by M Robinson, in press, pollen analysis (Σ 306) by J Greig: Ancient Monuments Laboratory Report No 2846.
25	Rudston Roman villa, E Yorks (TA 089 668) (Roman well). Excavated 1966, sampling and insect analysis by P C Buckland, pollen (Σ 359) and plant macrofossil analysis by J Greig, results: Stead 1980.
26	Worcester, Inner Relief Road site (medieval barrel latrine). Excavated December 1975, pollen (Σ 243, ova 450), plant macrofossil and parasite ova analysis by J Greig, insect analysis by PJ Osborne, cloth studied by E Crowfoot, interim results: Ancient Monuments Laboratory Report No 2439.
27-30	Hen Domen, Montgomery (SO 214 981) (pit in motte and bailey castle). Excavated August 1974, sampling, pollen (average Σ 362) and plant macrofossil analysis by J Greig, insect analysis by M A Girling, flies analysed by P Skidmore, results: Greig *et al* in press.
31-33	York, Lloyd's Bank site, 6-8 Pavement (Anglo-Scandinavian floor layers). Excavated March 1973, pollen analysis (average Σ 318) by J Greig, plant macrofossils by D Williams, insects by P C Buckland, H K Kenward, preliminary publications: Buckland *et al* 1974, Kenward 1978. Final reports in preparation.
34	Stafford, Clarke Street site (Saxon occupation site). Excavated August 1975, pollen (Σ 200) and plant macrofossil analysis from sample 1215 by J Greig, unpublished.

and also those from natural deposits like bog peats. The model of pollen transfer illustrated in Fig 22 can then be tested in the light of such information. This 'extensive' approach (Dimbleby 1962, 7) has proved very useful in the present work.

Another approach is to obtain series of pollen spectra from each deposit and to integrate the results with other evidence such as that from plant macrofossils, insects, molluscs, etc. This 'intensive' approach (Dimbleby 1962) is necessarily very time consuming, and may involve collaboration with several specialists as well as with the archaeologist concerned, but the results can be extremely rewarding (see, for example, Greig 1979b; Greig *et al* in press; Kenward *et al* 1978).

The study of modern pollen transfer is also very important because it can supply practical demonstration of ways in which particular pollen spectra could have arisen (eg Fig 26 and Krzywinski 1979). This work is still in its earliest stages, and it will take a long time to assemble evidence to validate or disprove the various aspects of the proposed model of pollen transfer (Fig 22). It is not always straightforward to study modern pollen transfer for this purpose, because plant communities in the past may have differed from their modern counterparts. Thus some cornfield weeds such as *Centaurea cyanus* (cornflower) which used to be common are now rare.

A final approach, which has not been adopted here, is the use of statistical techniques to detect patterns and to examine the data more objectively. Pollen analysis '. . . despite all the commendable attempts to place the interpretation of pollen diagrams upon an objective plane . . . still remains largely an intuitive process' (Moore & Webb 1978, 118). It remains to be seen whether statistical analyses prove useful in this field in the future.

Sites and deposits examined

The results discussed here are from the analysis of 103 samples from 26 archaeological sites; the details of these are given in Table 6. The 'extensive' approach is based on results from sites, both urban and rural, mainly in the Midlands and Yorkshire/Humberside regions of Britain and dating from the Iron Age to the post-medieval. The 'intensive' approach is based on the results from the studies of pollen spectra, plant macrofossils, insects, etc from seven sites. The results so far available from studies of modern pollen are discussed in a separate section.

Field and laboratory methods

Sampling for pollen analysis is normally carried out by the palynologist, who is best able to consider the problems of sampling technique and the recording of the relevant stratigraphy and other data. Many of the results discussed here come from series of samples taken from profiles at vertical intervals such as 2·5 cm, 3 cm, or 5 cm. The practice of 'column sampling' with aluminium boxes of 25 x 10 x 10 cm allows a complete profile to be sampled in segments. The boxes are pushed or hammered into the section to be sampled, labelled with details of depth, and the top end marked. They are then dug away with the contained blocks of sediment, and wrapped in polythene. This method makes it possible to do much of the sub-sampling and sediment recording under laboratory conditions; this is useful if time, weather, water inflow, or works make sampling and recording difficult in the field. Larger bulk samples of about 2-5 kg are usually collected in addition to the columns, for the recovery of large assemblages of macrofossils. Single pollen samples can also be collected by cutting out a lump of the sediment which may be subsampled by cutting out a block of about 1 cm^3. However, it is more desirable to replicate sub-samples from a given deposit to determine the variability of pollen content.

Pollen preparation methods are too well known to need further elaboration here (see, for example, Moore & Webb 1978, 22 - 7), save for a few points which are important in the preparation of archaeological material. Disaggregation of samples is improved by the addition of liquid detergent, and this treatment may also be applied in the final wash to prevent clumping. Hydrofluoric acid treatment (to remove silicates) is usually necessary and may have to be repeated when material is rich in silt and clay. Acetolysis, on the other hand, does not always seem to be necessary.

It is important to record the state of pollen preservation during counting, because it can vary considerably and affect the interpretation of the results—poorly preserved material may appear to have a greater proportion of robust pollen grains if the more delicate ones have disappeared, a case of differential preservation. Another aspect of pollen preservation is the size of the grains; sometimes pollen in archaeological material is shrunken and crumpled, and this can make the use of size characters in identification difficult; however, the microstructure can usually be used as the basis for identification, especially when phase-contrast illumination is used.

The pollen reference collection necessary for this kind of work must be extensive, since a much wider range of pollen types may be encountered in archaeological deposits than in more conventional work (on, for example, acid peat material). Apart from pollen and spores, parasite ova and soot particles can provide valuable evidence and should therefore be recorded.

Presentation of results

The data to be considered are complex. Apart from the large number of pollen spectra themselves, plant macrofossils (mainly seeds) and insect remains from the same deposits provide useful evidence, and there are the archaeological circumstances of the various deposits to be considered too. This potentially unwieldy mass of information has been presented with a view to clarity: the pollen analyses have been summarized in the form of histograms (Figs 23 and 24), the original preparations and pollen count sheets being available for checking at Birmingham. Macrofossils results for Compositae are presented in another histogram (Fig 25), modern pollen results in Fig 26, and the conclusions are summarized in Fig 27. Insect and archaeological data are presented in the text at the appropriate points.

Results

The pollen evidence

This is summarized in Figs 23 and 24 and discussed briefly here, because the results of pollen analysis are much more significant when compared with data from plant macrofossils and insects, than when considered in isolation. The most important features of the pollen data are discussed in more detail in the interpretation section.

The pollen results are discussed in the same order in which they appear in the histograms. First are the records of *Quercus* (oak), *Tilia* (lime), and *Ulmus* (elm), which have been grouped together because they may be regarded as indicators of forest, since they were the principal trees of the original 'wildwood' (Rackham 1976). In most cases *Quercus* (oak) is the most abundant pollen type, but there is one spectrum with a high value of *Tilia* (lime) (1) and another one with high *Ulmus* (elm) (8).

The amount of forest tree pollen in the spectra varies considerably from site to site: those spectra with larger amounts (>*c* 4%: 1, 2, 3, 6, 7, 8, 9, 10, 11, 21) come from natural type, sediments like peat bogs and from archaeological deposits in ditches, ponds, and wells, both urban and rural. It is surprising that some of the archaeological deposits in towns can contain as much forest tree pollen as do sites in more natural surroundings, where fairly undisturbed forest might be expected to have grown nearby. Thus the relationship between the forest tree pollen values and the type of deposits does not appear to be a simple one.

The pollen spectra with the least forest tree pollen (with values as low as 1%) are, as might be expected, mainly from urban deposits such as ponds and ditches (16 - 19) and wells (20, 23 - 25), and from organic occupation deposits (26 - 30, 32, 33). The low forest tree pollen values could be a real reflection of the lack of such trees in the vicinity of the sites, or they could result from swamping by relatively large amounts of non-tree pollen from other sources—the local pollen component, or pollen dispersed by human agency (the 'human component'). Layers like floors which accumulated inside buildings (Fig 22, top centre) might have been shielded from atmospheric pollen fallout by their roofs and so less tree pollen might have been deposited there.

Pollen values of other trees and shrubs seem to vary in a similar manner to those of the forest trees described above, with high and low values in spectra from both urban and

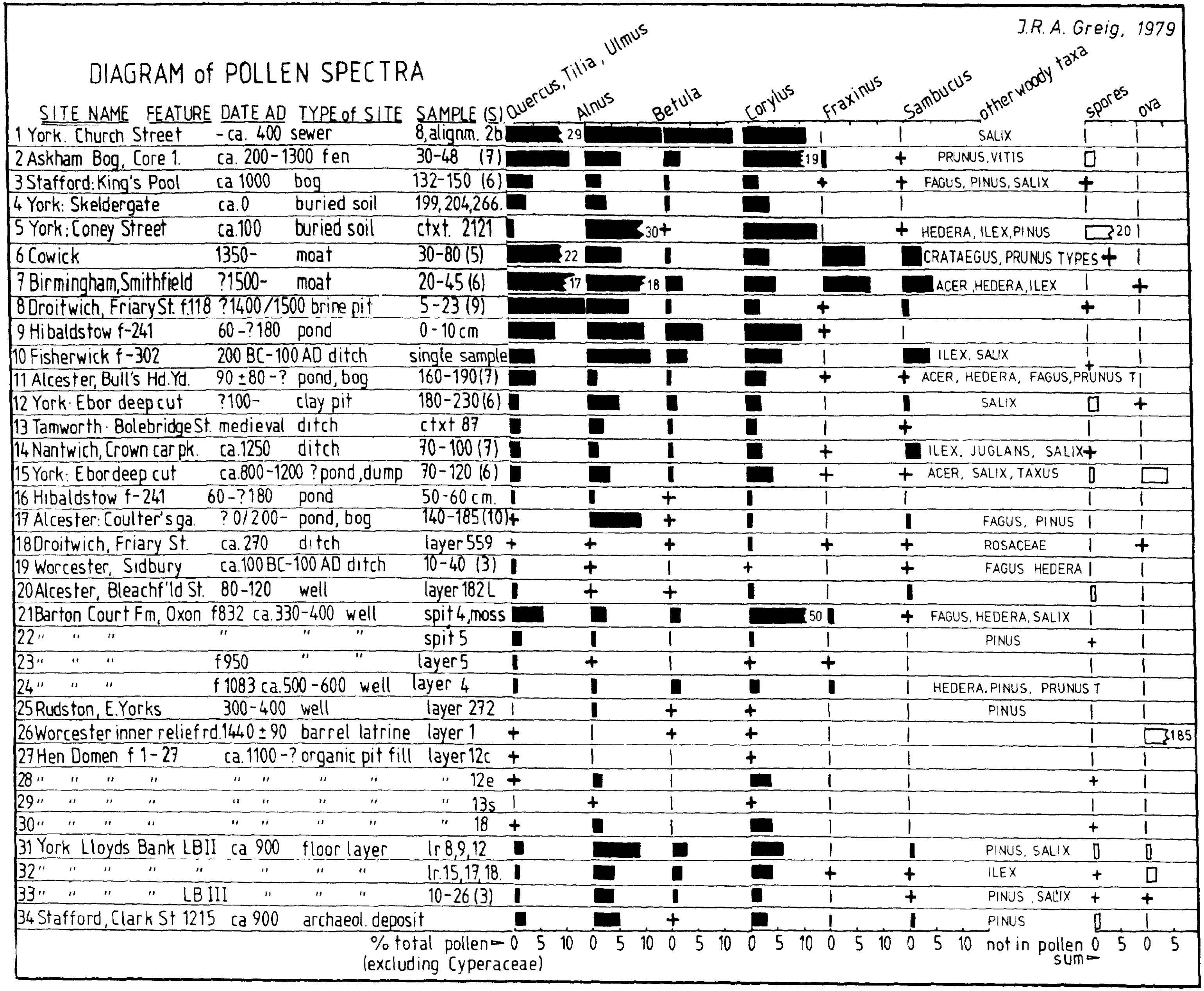

Fig 23 Details of pollen spectra examined. The sample order is determined partly by the type of site (more 'natural' at the top) and partly by tree pollen values (high at the top). Results from some sample series with the same type of pollen assemblage have been averaged. Thus in sample 2, '30 - 48 (7)' shows that the results presented here are the average from seven samples, 30 - 48 cm depth in the profile.

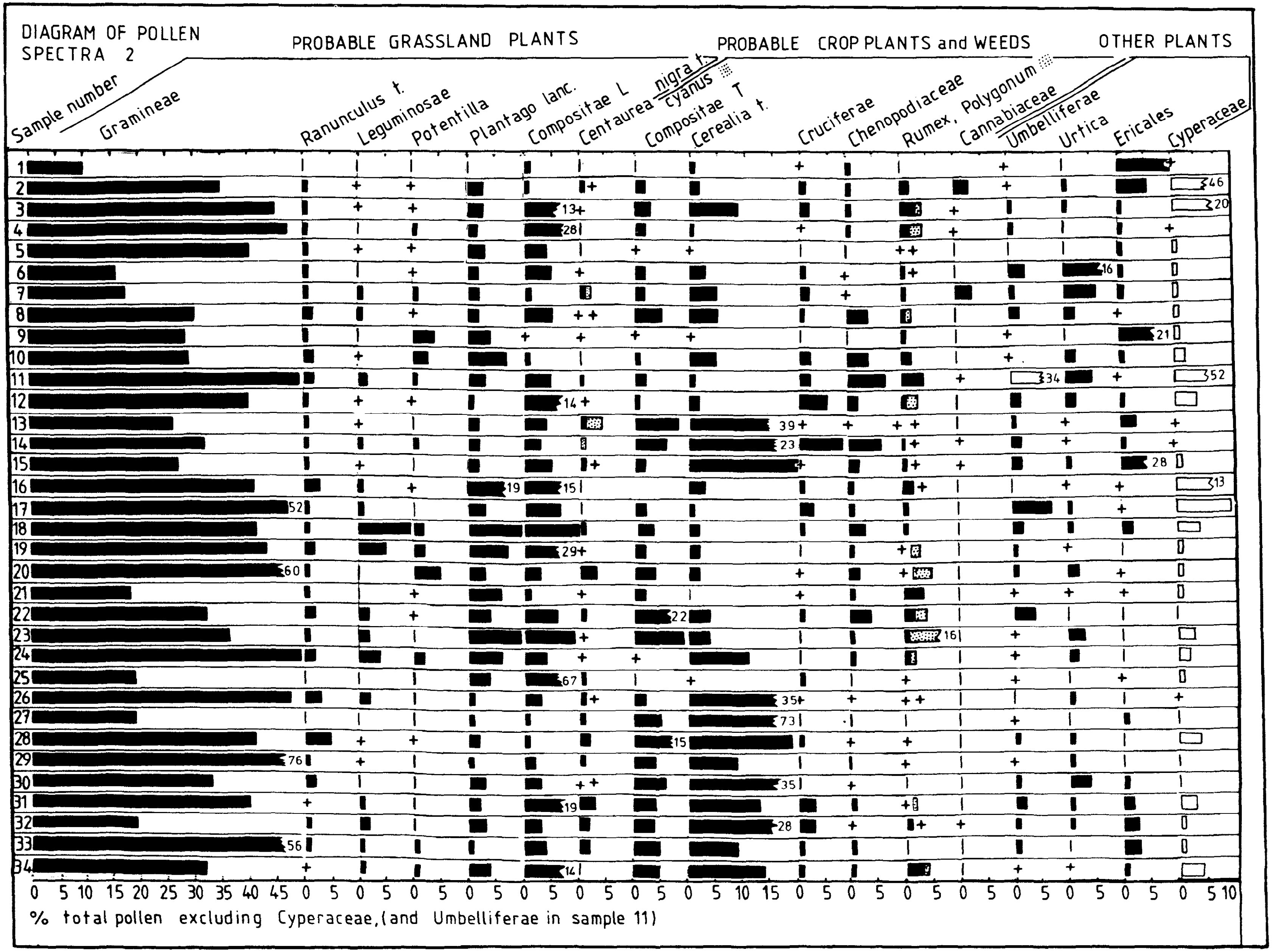

Fig 24 Details of pollen spectra examined. Pollen records of a range of less abundant taxa have been omitted, but are mentioned in the text. The taxa are arranged in three main groups: grasses and pollen records thought mainly to represent grassland plants; cereals and pollen records probably representing weeds of disturbed ground; and pollen records probably representing other habitats, such as heathland.

rural contexts. *Alnus* (alder), *Betula* (birch), and *Corylus* (hazel) are the most abundant types, and some spectra have especially large amounts, such as a buried soil with 30% *Alnus* (alder) pollen (5), which is discussed later. *Fraxinus* (ash) is occasionally abundant (6, 7), another of the trees and shrubs which are common in and around towns today as they evidently were also in the past. *Sambucus nigra* (elder) pollen is also sometimes relatively abundant, especially in some ditch deposits (6, 7, 10, 14). Elder grows best in nitrogen-rich ground, like a weed, and gives a strong record here even though its pollen is rare in conventional pollen diagrams, and it is insect-pollinated.

Some other pollen types which only appear in trace amounts, such as *Acer* (maple), *Cratuegus* type (eg hawthorn), *Prunus* type (eg sloe), and *Ilex* (holly), appear to be greatly under-represented in the pollen record because of low productivity and dispersal, for they are all insect-pollinated. Such trees and shrubs may, however, have been an important feature of the vegetation in certain places, for example in hedgerows (Groenman-van Waateringe 1978), and the pollen records are therefore much more important than they might at first appear to be. Modern pollen results on the representation of such plants are badly needed. The occasional records of *Juglans* (walnut) pollen are very interesting because little is so far known about the history of this introduced tree in Britain (Godwin 1975, 248). Finds of walnuts (eg Willcox 1977) could easily be from imported food, but the pollen probably represents trees growing in this country. The poor pollen representation of many trees and shrubs shows how incomplete a record may be preserved by pollen, and makes it very difficult to estimate how many trees grew near these sites.

Gramineae (grass) pollen is very abundant in most of these spectra, ranging from 10% - 70% of the pollen sum. Since grasses grow in such a wide range of habitats, only a limited interpretation can be based on abundance of their pollen alone, apart from the presence of grassy vegetation. The highest Gramineae values (> *c* 35%) come from buried soils (4, 5), pond and ditch deposits (3, 11, 12, 16 - 19), wells (20, 23, 24), and some occupation deposits (26, 28, 29, 31, 33), not all where signs of grasses would perhaps be expected.

Cerealia (cereal) pollen can usually be fairly clearly distinguished from the smaller grains of the other Gramineae (grasses) except when the pollen is very distorted. Although detailed studies of the morphology of Cerealia pollen have been made (Andersen & Bertelsen 1972), consistent separation to generic level (ie wheat, barley, oats and rye) has not proved possible-this was tried in the case of some of the material from the Lloyds Bank site, York.

Cereal pollen may occur in large amounts, and values of 11 - 79% were recorded in three groups of spectra from ditches and ponds (12 - 14) and all but two of the occupation deposits (26 - 28, 30 - 32, 34), the exceptions having very high Gramineae pollen values instead (29, 33). Such high cereal pollen values contrast with the much lower levels recorded from natural deposits like peat bogs (2, 3), and are a characteristic feature of many archaeological deposits, especially those from towns. Since it is very unlikely that cereal crops were ever grown inside towns, high Cerealia pollen values can usually be interpreted as the result of pollen dispersed by human agency (Fig 22, lower right), and this very significant feature of some archaeological deposits is discussed in much fuller detail later.

Cannabiaceae-type pollen appears sporadically in archaeological deposits, but it is very hard to identify it further, separating *Cannabis sativa* (hemp) from *Humulus lupulus* (hop). The separation can be made with more certainty when there is an accompanying macrofossil record, as at Askham Bog (2) (Hall *et al* 1979; Bradshaw *et al* 1981).

The pollen records (Fig 25) of *Artemisia* (mugwort), Caryophyllaceae (eg chickweed), Cruciferae (eg shepherd's purse), *Polygonum* (eg knotgrass), and *Urtica* (nettle) probably represent weeds of disturbed ground; so also do some of the Compositae pollen records discussed below. These plants are much more abundantly represented in pollen records from archaeological deposits than in those from more natural deposits, as might be expected. The variation between archaeological samples, however, does not seem to follow any pattern, so on present evidence it is not possible to tell whether there were, for example, more weeds growing near some sites than others.

The pollen records from *Rumex* (docks and sorrels), *Ranunculus* (buttercups), *Potentilla* (cinquefoils), Umbelliferae (umbellifers), and from other pollen types omitted from Fig 24—Campanulaceae (eg harebell), Dipsacaceae (scabiouses), Geraniaceae (eg cranesbill), Labiatae (eg mint), Linaceae (flaxes), Malvaceae (eg mallow), *Poterium* and *Sanguisorba* (burnets), Rubiaceae (bedstraws), Scrophulariaceae (eg speedwell), and Valerianaceae (valerians)—probably represent grassland plants. Once again, there seems to be no discernible pattern in pollen values of these plants, so interpretation of the results is difficult.

Compositae (Liguliflorae) pollen (a group which includes dandelions, hawkbits, and many others) has values which fluctuate from less than 1% to 67% of the pollen sum, and in this case there is a pattern: samples with abundant Compositae (L) pollen often also have abundant Gramineae pollen, and some other pollen records appear to correlate in the same way. One of these is Compositae (Tubuliflorae) pollen (a group which includes daisies, mayweeds, corn marigolds, and similar plants). This pattern is further discussed in connection with the plant macrofossil evidence, and in the interpretation.

Ericales pollen (from ling or heather, heaths etc) is present in small amounts in most of the pollen spectra, but larger amounts (21%, 28%) were found in two cases (9, 15), the significance of which is discussed later.

Leguminosae pollen records are normally very small in spectra from natural deposits, but relatively large amounts were found in some of the archaeological deposits, for instance 9% (18), and there were significant records (> 1%) in eight spectra (11, 18, 19, 22 - 24, 26, 32). Pollen resembling that of the cultivar *Vicia faba* (broad bean), a very important crop in the past (Bennett 1947; Krzywinski & Faegri 1979; Körber-Grohne 1967), is rarely found in British deposits.

Plantago lanceolata (ribwort plantain) pollen is ubiquitous in archaeological deposits, with occasional cases of abundance such as 19% (16), and 10% (18, 23). Similarly large amounts have also occasionally been recorded in spectra from natural deposits such as Bishop Middleham, Co Durham (Bartley *et al* 1976). The archaeological deposits which had the greatest *Plantago lanceolata* values were ponds and wells. Pollen of the other two plantains, *P. major* (greater plantain) and *P. media* (hoary plantain), is found only in small amounts, which is surprising, since the plants are such common weeds today; this is perhaps a case of poor representation.

Cyperaceae (sedges etc) pollen is very often found, occasionally in large amounts, and mainly in samples from moats and ponds (6, 11, 16, 17). These amounts are similar to those obtained from natural deposits where the sediments formed at least partly from the remains of sedge vegetation which grew there. These archaeological deposits may therefore also have had sedge vegetation growing at the margins. Pollen from other wetland plants occurs sparsely in archaeological samples.

Spores of *Pteridium* (bracken) and other ferns also occur in archaeological deposits, but in this study large amounts were only found in one sample (5), a buried soil. In this case, the spores may have come from bracken growing on the site, or have been brought with soil wash in floodwater (see Peck 1973, 57 - 8). Some samples (27 - 30) contained fragments of bracken frond but very few spores—in this case the bracken may have been gathered when it was young, before spore formation.

Ova (eggs) from parasitic intestinal worms have been found in a number of pollen preparations, for they are of a similar size to pollen and survive the pollen preparation process with their diagnostic outer shell layers intact. Two nematode taxa have so far been identified, *Trichuris* and *Ascaris* (Jones, this volume, 66- 70). The largest numbers of these were recovered from a latrine (26), which is not surprising. In other places, ova can provide evidence of the presence of faecal material, as in a pond (15) and an occupation layer (33), although it may not always be possible to distinguish human from animal waste.

In summary, it can be seen that some of the pollen spectra obtained from archaeological deposits (1, 4 - 10) are quite similar to those from natural sediments (2, 3). Some of the other pollen spectra are obviously different, with unusually large amounts of Gramineae, Cerealia, Compositae, *Plantago lanceolata,* or Leguminosae pollen, and the significance of these is discussed below.

Pollen and plant macrofossils

The results of pollen analysis alone provide only one part of the botanical information that can usually be obtained from suitable archaeological samples. Plant macrofossils can provide vital clues to the understanding of pollen data, and the converse is also true. Evidence from fruits and seeds is mainly considered here, but leaves, wood, bud scales, and whole plants (in the case of mosses and liverworts) can also supply useful information.

Records of many of the common weeds identified to species from macroscopic remains appear to correspond to pollen identified to family or genus level. Thus, weeds like *Stellaria media/neglecta* (chickweed), *Chenopodium* spp. (goosefoots), and *Raphanus raphanistrum* (wild radish), the seeds of which are commonly found, may be the source of the pollen records of Caryophyllaceae, Chenopodiaceae, and Cruciferae respectively. Likewise, seed and pollen records of *Polygonum* (eg knotgrass), *Rumex* (eg dock), *Urtica* (nettle), *Potentilla* (cinquefoil), *Ranunculus* (buttercup), members of the Umbelliferae (umbellifers), and, in some cases, Compositae (see Fig 25) appear to correspond to one another. These macrofossil records provide extra evidence of the plant communities represented by pollen. The amounts of pollen in such cases are often less than 5% total, but the seeds may comprise 20 - 30% of the total seed sum, probably because the weeds produce such an abundance of seeds.

Sometimes there are substantial pollen records from plant groups which are not recorded among the macrofossil results except in trace amounts. There are various explanations for this difference in representation; one is poor seed survival, for some seeds, like those of *Quercus* (oak), are not very resistant to decay. Similarly, most of the macrofossil records of *Ulmus* (elm) come from identifications of wood or charcoal (Godwin 1975, 243), again probably because of poor seed survival. Pollen of *Artemisia* (mugwort), *Plantago* (plantain), Leguminosae (legumes), and *Salix* (willow) is often found in archaeological material, but the seeds rarely, if ever, probably because they are not easily preservable. The scarcity of seed remains of Gramineae (grasses), Cerealia (cereals), and *Plantago* (plantain) may be the result of poor preservability and also of the difficulty in recognizing them, especially when fragmentary like cereal periderm or 'bran' (Dickson *et al* 1979). The fossil record of grasses, cereals, and the rare finds of legumes come mainly from material preserved by charring (see Hillman 1978, 109), circumstances in which pollen does not survive.

Another possible cause of sparse seed records compared with those from pollen is low seed production; not all plants produce seeds as abundantly as the common weeds, and some, like *Armoracia rusticana* (horseradish), hardly ever set seed. A further factor may be poor seed dispersal. Thus the heavy fruits of plants like *Tilia* (lime), *Ilex* (holly), and *Corylus* (hazel) fall near the parent tree and only there will large numbers of seeds be present, unless they are carried by water and concentrated in that way. Dispersal by birds and small mammals would result in a sparse scatter of seeds.

At other times, the converse of this disparity between pollen and macrofossil records is true, and little or no pollen may be found from plant groups known to have been present from macrofossil remains in the same deposit. Poor pollen survival may be the cause of this disparity in some cases (eg *Juncus* (rush), *Populus* (poplar)). Otherwise, low pollen production and poor dispersal, usually from insect-pollinated plants, is probably the reason why there are such insignificant pollen records from families like the Boraginaceae (forget-me-nots etc), Labiatae (mints etc), Papaveraceae (poppies etc), Scrophulariaceae (figworts, speedwells, etc) and Violaceae (violets etc), even though seeds from plants in those groups are often abundant.

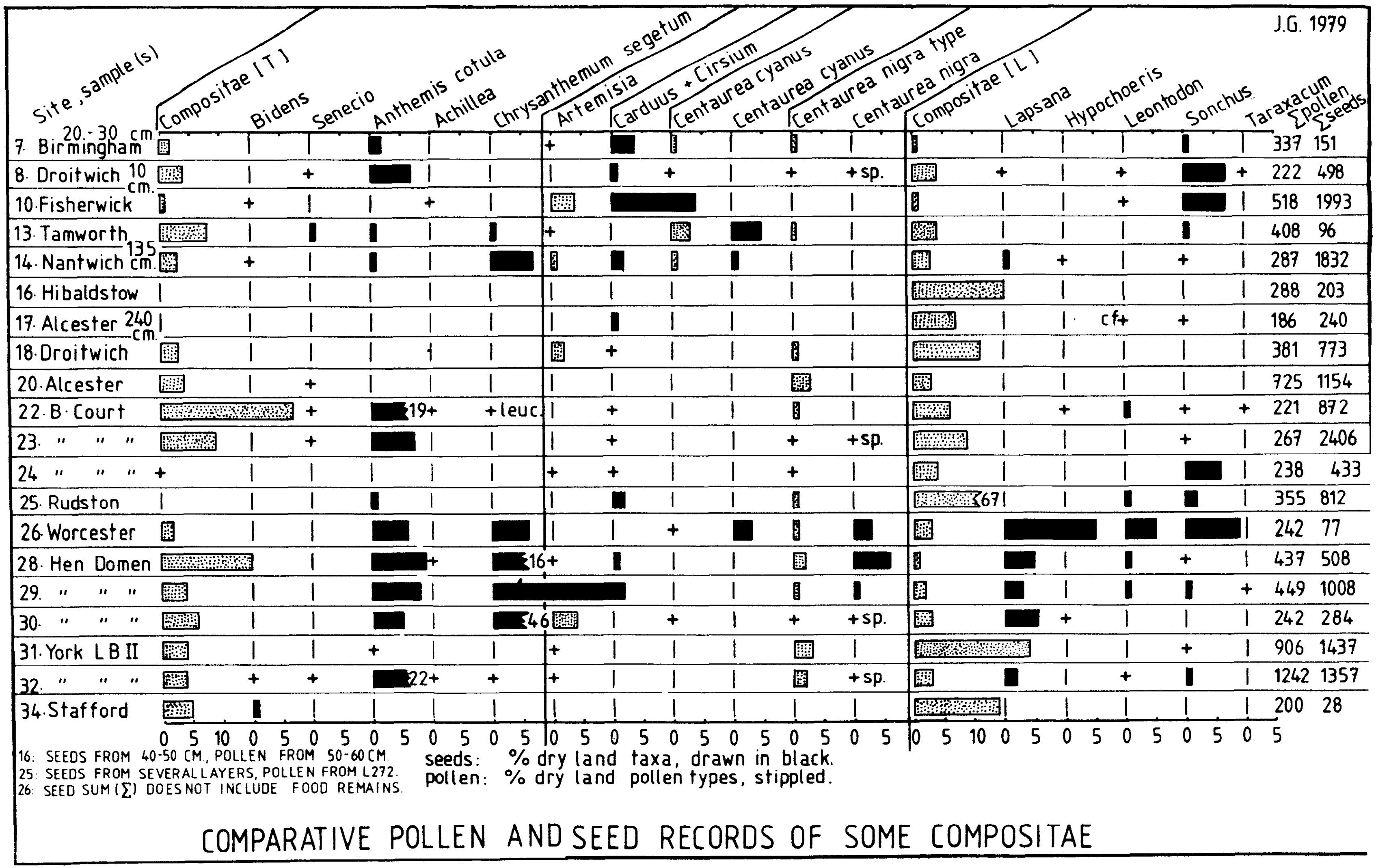

Fig 25 Compositae pollen and macrofossil results. Several pollen types (eg Bidens*-type and* Anthemis*-type) have been combined in Compositae (T).* Artemisia *macrofossils were not found, and the pollen of* Carduus *and* Cirsium *rarely, so the appropriate spaces have been omitted from the diagram.*

The relationship between pollen and macrofossil records of various Compositae groups has proved to be complex, and the results which are so far available have been presented in a histogram (Fig 25). This shows that the records of the various Compositae pollen types are matched by corresponding macrofossil records in some cases, but not in others. This is most evident in the Compositae (L) pollen and macrofossil records (Fig 25, right): samples 16, 17, 18, 20, and 25 contained pollen but few or no seeds from that group, while many of the other samples (eg 24, 26, 28, 29, 30, 32) contained both pollen and seeds in substantial amounts. This unusual pattern can also be detected in the records of some of the other composites, such as Tubuliflorae and the *Centaurea nigra* (knapweed) group. Other Compositae records do not show this pattern, either because there were no seed records *(Artemisia* (mugwort)), or because pollen was not found *(Arctium* (burdock), *Carduus* and *Cirsium* (thistles)), or because the records were too sporadic, like those of *Centaurea cyanus* (cornflower).

This unusual pattern, in which the Compositae pollen and seed records correspond in some cases but not in others, does not appear to have been noted before, perhaps because it does not become evident until a large number of samples has been examined.

The records of the distinctive pollen of *Centurea cyanus* (cornflower) are particularly interesting. This weed of cereal fields (especially rye) appears to have spread with the increase of rye cultivation (Behre 1976). This seems to date from the late Iron Age and early Roman period in Holland (van Zeist 1976), and palynological evidence from northern France shows that *C. cyanus* and *Secale* were probably present there in pre-Roman times (Beal *et al* in prep). The records of *Centaureu cyanus* from Britain, on the other hand, date from the 12th century AD (15) and later (7), and in Germany also macrofossil remains of cornflower are of medieval and later date (Knörzer 1976). The complexity of the study of the spread of cornflower and rye is shown by the absence of the former from some places where it would otherwise have been expected (Pals & van Geel 1976).

Pollen and insect remains

Insect remains (principally Coleoptera (beetles) and Diptera (flies)) are often preserved in deposits with pollen and other plant remains, so that a fauna and a flora may be extracted from the same sample. The evidence from insect remains can be very useful for the interpretation of pollen analyses, and these various lines of research should always be considered as integral parts of the complete biological analysis of a particular sediment. The remains of other insects are also found (eg bees, parasitic wasps, and ants) and other Arthropoda (eg spiders and mites-see, for example, Girling 1978; Denford 1979; 1980).

Archaeological beetle faunas vary greatly (see, for example, Osborne 1971; Girling 1977; Kenward 1978), and a summary from a palynologist's point of view cannot do justice to them. However, one kind of fauna which may add valuable information to that from pollen is one containing a large number of beetle species each represented by small numbers of individuals. Such beetle assemblages are generally considered to have formed slowly and in the open, and are often extracted from sediments from ditches (10), ponds (16), and wells (25). The water surface (or well opening) apparently trapped insects from many sources to give such a 'background fauna' (Kenward 1976), and the pollen is likely to have been deposited in a similar manner, from both regional and local sources. The pollen spectra from such sites are rich in Gramineae (grass) and *Plantago* (plantain), and may be rich in Compositae (L) pollen with few seeds. It may thus be possible to characterize such deposits in terms of fauna as well as flora, and the additional information can be very valuable in interpretation. The evidence from beetles can, for example, show from the abundance of certain dung-inhabiting species that cattle or other stock may have been kept in the vicinity, thus providing the palynologist with certain clues about land use. The presence of certain phytophages (plant feeders) can be secondary evidence of the appropriate food plants, although the botanical results do not always supply corresponding records, and may differ considerably.

Other faunas are species-poor, with some taxa represented by very large numbers of individuals (the 'superabundants' of Kenward 1978). In such cases, it can often be shown that the insects were associated with the deposit as it formed, because the remains of immature stages (such as fly puparia) are present (Buckland *et al* 1974). Such a deposit may provide a wealth of information about the ways in which it might have formed and of what it may have originally consisted. For example, fly maggots often require considerable warmth to develop, and their presence in a deposit may demonstrate the heat-generating 'compost heap' conditions that must have prevailed in order to create the right temperature. The pollen spectra from such deposits (26, 28, 29, 30, 32) are often rich in Cerealia (cereal) pollen, providing the basis for another characterization of the plant and insect remains.

Another example of entomological data of use to the palynologist comes from the distinction of 'outdoor' and 'indoor' faunas (Kenward 1978). Some occupation deposits contain faunas which are more characteristic of those found outdoors, and which may therefore have formed in the open (31); others, often in the same series of layers, have faunas of insects which are generally found inside buildings or deep within piles of rotting matter and which often would not survive in the open (32). This is a useful guide as to whether the pollen is likely to have come from regional and local sources (where there is an 'outdoor' fauna), or perhaps from elsewhere, when there is an 'indoor' fauna.

Modern pollen studies

Practical results from the study of modern pollen production, dispersal, and deposition are very important for the understanding of all fossil pollen spectra, which are necessarily biased and incomplete records of past vegetation. Although it is often difficult to demonstrate how certain fossil pollen spectra could have arisen by finding equivalent modern spectra, this is a vital part of pollen analysis (see, for example, Birks, 1973, 282-97). Preliminary results from some investigations into sources of some pollen spectra often found in archaeological material are reported here.

Large values of Cerealia (cereal) pollen often occur in

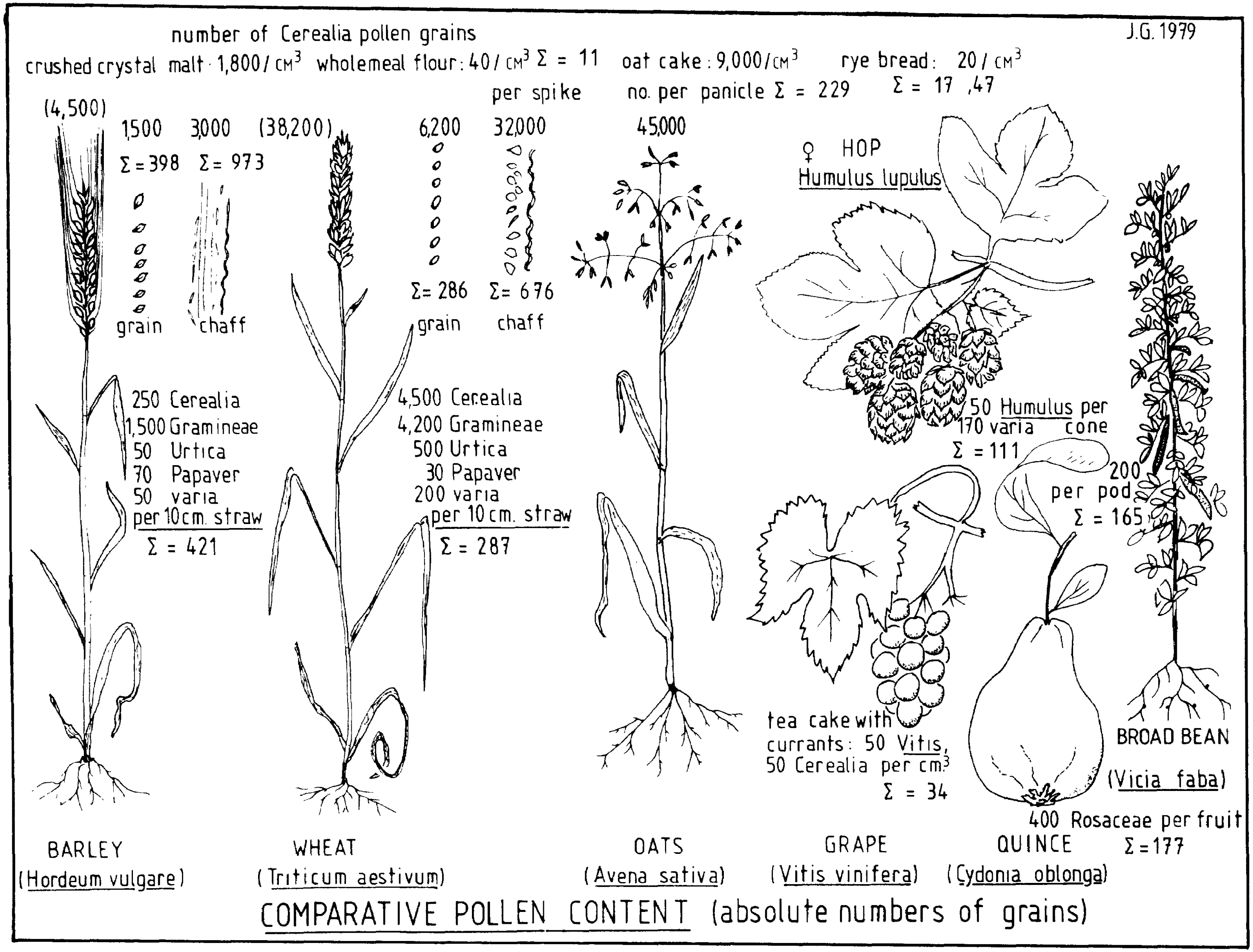

Fig 26 Preliminary results of analyses of the pollen content of some food materials and straw. Whole cereal plants were collected at harvest time from fields in Lincolnshire, and the grain and chaff were separated by hand from a single spike (wheat and barley) and analysed for pollen content. The results from straw are based on culm and leaf. Acid hydrolysis was found helpful in making some of the preparations from food.

archaeological material (eg 13, 26, 27). This, it was suspected (Buckland *et al* 1974), was pollen which had persisted on parts of cereal plants, and the retention of pollen on grains of barley was demonstrated by Robinson and Hubbard (1977). The pollen content of certain foods and its survival of the human digestive process were shown in the case of barley meal by Krzywinski (1979). To investigate pollen content and retention further, samples of cereal plants were tested. Following a suggestion that the pollen analysis of bread might be instructive (M A Robinson *in litt),* preparations were also made from malted grain, flour, oatcake, and some kinds of bread. Furthermore, the persistent flower remains from some ripe *Cydonia oblonga* (quince) fruits, a cone from seeded *Humulus lupulus* (hop), and a ripe pod of *Vicia faba* (broad bean) were prepared.

The results (Fig 26) show that the highest concentration of the persistent cereal pollen was found in chaff, which also contained some extraneous pollen from weeds. Chaff remains in archaeological deposits would therefore be likely to prove a rich source of cereal pollen, whose origin might be hard to detect if, for example, the chaff had been used as animal feed. Wheat and barley grain also retained substantial amounts of cereal pollen, but very little from other plants. Grain products such as wheat flour also retained cereal pollen, but much less than might have been expected in view of the results from analyses of whole grains. In rye bread, cereal pollen was outnumbered by that of Umbelliferae which could have come from *Carum carvi* (caraway) seeds. The tea cake preparation showed that cereal pollen survives in white flour even though the seed coat has been removed by milling, and the preparation from malted barley that it survives the sprouting and roasting process in an amount similar to that of fresh grain. It is evident, then, that cereal and other types of pollen in archaeological deposits could have come from a wide range of grain products used for human food and drink and animal food, especially where there is evidence of faeces. The results from the straw are very interesting because they show that a surprisingly large amount of cereal and other pollen may adhere to the vegetative parts of such plants. Straw, even without any chaff, could therefore be an important source of cereal pollen in archaeological deposits formed from its remains. It would also be the source of pollen of a range of cornfield weeds, as listed (Fig 26), and this local pollen component from cornfields could easily be transported by human activity. It is interesting to note that the pollen of *Papaver* (poppy) was found here, although the records from archaeological material are very sparse.

The other modern pollen results show cases of pollen persistence which may not yet have been detected in archaeological material, but which could easily occur. The results from quince suggest that the persistent remains of flowers in pomoid fruits such as apples and pears can retain significant amounts of Rosaceae and other pollen which could possibly be found in deposits of faeces. The results from hops show that even female flowers retain pollen, so that some Cannabiaceae pollen records could represent the remains of brewing waste, even if it had been used secondarily as animal feed. Other plants which were used in brewing in place of hops (until supplanted in *c* 1450 in Britain, Corran 1975) might also leave a pollen record; they include *Myrica gale* (sweet gale), fruits of which were found in quantity at Svendborg, Denmark (Jensen 1979, 71-3). The persistence of *Vicia faba* pollen on the pods of broad beans is interesting, for the pollen of this legume is poorly represented compared with that of, for example, the cereals. Beans do, however, appear to produce enough pollen for remains like bean straw to be detected by pollen records from archaeological deposits (Körber-Grohne 1967). Macrofossil evidence (Hillman 1978) and a lack of pollen records suggest that beans were not as widely grown in Britain as in other countries (eg Germany, Norway).

Pollen persists in some surprising materials, such as the tea cake preparation which contained an appreciable amount of *Vitis vinifere* (grape) pollen from the currants, showing that even fruit which has no persistent flower parts can still bear pollen. The remains of honey can also contain pollen, as shown by Dickson (1978).

Preparations from two samples of hay gave spectra almost entirely of Gramineae (grass) pollen, with small amounts of Compositae (L), *Plantago lanceolata,* and some other types. Ancient hay may have been richer in plant species than modern, however.

Interpretation

Natural deposits

The various lines of evidence, already discussed individually, can be brought together (Fig 27) to test various aspects of the model of pollen deposition (Fig 22). The results from 'natural deposits' should be useful in providing background information on the vegetational state of the countryside around a town. It can, however, be difficult to fulfil this aim: the upper, most recent, levels of places like lowland peat bogs, of the greatest value to the urban environmental archaeologist, may have had peat cutting, hemp retting, drainage ditching, or other disturbance. Thus the first conclusion about the study of 'natural deposits' is that it is very important to study the plant macrofossils and insect remains as well as the pollen in order to have sufficient information on the extent to which such deposits can really be said to be natural in origin. It is also wise to sample such deposits by coring in different places so that there is evidence from two or three profiles (as at Askham Bog) and disturbance is more likely to be detected from differences between the results from the profiles examined.

The amount of background information on the countryside which can be obtained from such pollen diagrams also depends upon the pollen sources: modern pollen results, for example those from the uppermost (modern) deposits in the moat at Cowick (Greig unpublished), show that a few trees, such as *Alnus* (alder), growing over a site like this, can deposit large amounts of pollen even though the surrounding countryside is largely treeless (for example, 10 cm from surface, *Almus* = 34% pollen sum). Such local pollen rain, coming from wet woodland, could be the source of much of the tree pollen in 'natural deposits' (such as 2, 3), or in the buried soil with large amounts of *Alnus* pollen (5) which could have come from local vegetation or from flood water. The regional pollen rain, with its evidence of the state of the countryside as a whole, may therefore be the less obvious aspect of such pollen diagrams. These effects of

Sample	Urban / Rural	Tree and shrub > 30%	Compositae [L] > 5%	Plantago lanc. > 3%	Leguminosae > 1%	Compositae pollen, not seeds	Diverse insect fauna	Gramineae > 35%	Compositae pollen and seeds	Cerealia > 10%	'Superabundant' fauna	parasite ova > 1% pollen sum	Ericales > 15%	main characteristics
1.	U	+												human-dispersed natural
2.	R	+												natural
3	R		+					+						natural: small catchment
4.	R		+					+						" " " " " "
5.	U	+						+						natural
6.	R	+												" "
7.	U	+							+					mixed: s-c + human
8	U	+							+					" " " " " "
9.	U	+		+			+						+	" " " " " "
10.	R	+		+			+		?					mainly natural: s/c
11	U				+			+						natural: small catchment
12.	U		+					+						" " " " " "
13.	U								+	+				human dispersed: Cerealia
14.	U								+	+				" " " " " "
15.	U									+		+	+	" " " " " "
16.	U		+	+		+	+	+						natural: Gramineae-local
17.	U		+			+		+						" " " " " "
18.	U		+	+	+	+		+						" " " " " "
19.	U		+	+	+			+						" " " " " "
20.	U					+		+						? natural: Gramineae-local
21.	R	+		+			+							mixed natural spectra
22.	R		+	+	+		+							natural: Gramineae-local
23.	R		+	+	+		+	+						" " " " " "
24	R			+	+		+	+	?	+				mixed: Gram.-loc. + Cer.-hu.
25.	R		+	+		+	+							natural: Gramineae-local
26.	U				+			+	+	+	+	+		human: Cerealia + hay
27.	R									+				human: Cerealia
28.	R							+	+	+	+			human: Cerealia + hay
29.	R							+	+		+			" " " " "
30	R								+	+				human dispersed: Cerealia
31.	U		+			+	+	+						natural: Gramineae-local
32.	U				+				+	+	+	+		human dispersed Cerealia
33.	U							+						indeterminate
34.	U		+	+		+				+				mixed: Gram.-loc + Cer-hu

NATURALLY-DISPERSED ← || → HUMAN-DISPERSED

Fig 27 A summary of the results: the main characteristics of the samples studied, and a brief interpretation of the pollen sources.

disturbance and local pollen rain probably dominate the results from such sites to so great an extent that it is very difficult to tell what the surrounding countryside would have been like, except in very general terms. Various types of disturbance are illustrated in Fig 22, lower left,

Semi-natural deposits

In the case of semi-natural deposits like ditches and ponds, where a man-made feature has filled with sediment which may have accumulated there by natural processes, the likelihood of disturbance is obvious from the archaeological context of the deposit. Here, too, evidence from plant macrofossils, insects, and other remains can be very useful in determining how a deposit formed and where the pollen might have come from, Some of the pollen spectra from these semi-natural deposits such as those from soils (5, 6), moats (6, 7), a ditch (10), and one from a pond (9) are similar to those from 'natural' deposits discussed above, consisting mainly of tree, shrub, and grass pollen. Similarly, the tree and shrub pollen can often be shown to be mostly of local origin when corresponding macrofossil remains are also found (eg 7). The vegetation of the landscape as a whole would probably be represented by the large amounts of—pollen from herbs such as grasses, composites, plantains, etc which might have come from a largely treeless countryside. Thus it may be possible to make a fairly precise interpretation of such pollen spectra—the signs of trees and shrubs in most of the examples mentioned above can be interpreted as the result of local rather than regional woodland or isolated trees. The faint signs of insect-pollinated trees and shrubs of hedgerows, although sometimes slightly amplified by macrofossil evidence, are hard to interpret in any detail at present.

Some of these spectra have unusually high values of Compositae (L) (3, 4, 12), *Plantago lanceolata (9,* 10), Leguminosae (11), or Gramineae (3, 4, 5, 11, 12) pollen compared with most conventional pollen diagrams. This is probably because such sites, which cover small areas (less than 100 m from sampling site to dry land) have less pollen from local bog surface vegetation than do more extensive sites. Conversely, the dry land vegetation is much closer, and is therefore better represented in the pollen rain there. Small natural sites with Compositae (L) rich spectra include peat bogs (Aberaeron, Taylor 1973) and buried soil (Greig & Keeley 1978). High *Plantago lanceolata* values have also been obtained from buried soils (Dimbleby 1973; Groenman-van Waateringe 1978) and from peat bogs such as Clarach (Taylor 1973) and Hallowell Moss (Donaldson & Turner 1977). This last site had large Leguminosae pollen values in the upper levels. Such 'small catchment' pollen spectra arc discussed more fully below.

The pollen spectra from the Roman sewer at York (1) seem to be exceptional because they contain more forest tree pollen (especially that of *Tilia* (lime)) than any other discussed here, even the 'natural' deposits (2, 3). The site is in the middle of Roman York, however, not a place where the signs of an apparently undisturbed lime forest might be expected. Two of the sewer spectra also contained large numbers of fern spores, which could be a sign that some pollen had been washed into a watercourse with soil (Peck 1973) and then transported into York, perhaps in the water supply channelled from a stream flowing through an area of forest some distance away (Greig 1976). Another possibility is that some of the pollen came from peat laid down at the time of the forest maximum *(c* 3000 BC) and brought into Roman York, for these spectra are similar to some obtained from Askham Bog (AB2/45: 18% *Tilia*). *Tilia*-rich pollen spectra have also been reported from material interpreted as the remains of honey (Dickson 1978).

Another example of a site with unusual pollen spectra is the well from which a sample of moss (21) contained far more tree and shrub pollen than that from the rest of the sediment (22). In this case the ecological affinities of the moss, *Hylocomium brevirostre* (Brid.) B., S. & G. (for woodland), add to the evidence from the pollen spectrum obtained from it, showing that the moss probably collected the local pollen rain in woodland where it would have grown, and was then gathered and brought to the site (the well)—a clear example of a human pollen component.

A final example of unusual pollen spectra from a semi-natural site comes from the sediments of a possible brine-pit (8) with very high values of *Ulmus* (elm) pollen. This pollen is not normally present in more than trace amounts in archaeological samples, so a series of spectra with 10-25% *Ulmus* is noteworthy. Elm trees might have grown over this particular site, or alternatively elm may have been collected for some purpose.

Spectra from archaeological deposits

High Gramineae etc

These spectra are characterized by an abundance of Gramineae (grass) pollen (>*c* 35%), Compositae (L) (>*c* 5%), *Plantago lanceolata* (ribwort plantain) (>*c* 3%), and sometimes Leguminosae (>*c* 1%). The results from plant macrofossils (Fig 25) show that deposits with this pollen spectrum type often have very few seed remains to correspond to the abundant pollen record of Compositae (L). This is also true, but to a lesser extent, of the Compositae (T) pollen and seed records. Deposits with this type of pollen and plant macrofossil assemblage can also be characterized by results from the study of insect remains, for they often have the species-rich 'background' type of fauna. The results with most of these features are summarized in Fig 27 (16, 17, 18, 19, 22, 23, 24, 25, 31, 34). The archaeological features from which these samples came are ponds, wells and ditches, and a few occupation deposits.

This type of assemblage does not appear to have been noted before, because there are so few cases where the results from pollen, seeds, and insects from the same deposits have been studied together. Such results from individual sites might have been regarded as exceptional, but when they appear from such a range of different sites they add up to a significant pattern. Individual features (such as high Compositae (L) values) have already been mentioned as features of 'small catchment' sites.

The simplest explanation for the origin of this type of flora and fauna is that the pollen, seeds, and insects all arrived in the forming deposits by the same means. The similarities between the pollen spectra and some of the features of 'small catchment' natural sites suggest natural deposition, and this view is supported by interpretations made of 'background faunas', which are confirmed by the results obtained by trapping modern death assemblages in places like roof gutters and drains. These demonstrate the 'background fauna' available to deposits as they form (Kenward 1975; 1976; 1978). Similar studies of modern pollen rain in towns are greatly needed, but without such confirmation it would appear that the pollen in such deposits comes mainly from rather local sources on dry land, in contrast to the mixed dry land and wetland pollen spectra from the semi-natural and natural deposits. It therefore seems appropriate to refer to this pollen spectrum type as 'Gramineae/local'.

There are other possible sources of at least some of the pollen in this 'Gramineae/local' spectrum. The palynology of hay and herbivore dung is to be studied although it is probably more important in connection with the next spectrum type (see below). Pollen could also have been carried by insects, for it has been suggested that bees could be responsible from abundant Compositae (L) pollen in some archaeological deposits (Bottema 1975), but in the mostly waterlogged spectra considered here bee nests are not a likely source of this pollen. Pollen could also have been carried by insects such as bees and pollen-eating beetles like *Meligethes,* which could have dropped into the deposits with their pollen loads. This would be difficult to test for particular cases, but insect pollen loads might be expected to provide highly local pollen concentrations in deposits. One spectrum (not presented here) contained 45% *Sambucus nigra* (elder) polleq and might possibly have arisen in this way; however, this appears to be an exceptional case.

The reason for the divergent pollen and macrofossil records of the Compositae is not yet clear; one explanation for the abundant pollen but scarce seeds might be that the deposit was formed early in the year, or contained material gathered then, when the plants had flowered but not yet set seed. A more likely hypothesis is that the pollen came from composites like *Hypochoeris* (cat's ear), *Leontodon* (hawkbit), and *Taraxacum* (dandelion), which have a very efficient seed dispersal mechanism (the 'dandelion clock') which disperses the seeds so widely that they are not concentrated in any one place. This may explain why seeds of these plants are usually found in such small numbers compared with those without a 'clock'. Larger concentrations of these seeds would only occur in deposits formed from the remains of plants which had been gathered up with other vegetation, as in hay or straw, so that natural seed dispersal could not occur.

Such apparently natural 'Gramineae/local' assemblages would appear to come from vegetation with grass, composites, plantains, and legumes (perhaps clovers). These plants are typical of the vegetation of short grassland such as would be found on grassy banks in and around towns today. It remains to be seen whether modern pollen studies can confirm and amplify this interpretation.

High Cerealia etc

This second distinctive spectrum type is mainly characterized by abundance of Cerealia (cereal) pollen *(>c* 10%). Further evidence comes from the moderate values of Compositae pollen with a corresponding seed record (especially in the case of Compositae (T)) (see Fig 25). Deposits from which such plant assemblages are obtained often also have a characteristic insect fauna consisting of few taxa, some of which are present in very large numbers of individuals ('superabundants'). The presence of immature insects shows that they were actually living in the deposit as it formed, as does the fauna of a compost heap today, rather than having fallen into it. Such 'indoor' faunas often come from organic occupation deposits. These characteristics are summarized in Fig 27, showing that samples 13, 14, 15, 30, and 32 are typical examples. This kind of spectrum is so distinctive that it was noticed when results from the study of pollen, seeds, and beetles from such a site became available (Buckland *et al* 1974). It is clear that much of the pollen has probably been dispersed by human agency, so this spectrum type may be termed 'Cerealia/human'.

One interpretation of this spectrum type is that it represents a deposit formed from the remains or straw or chaff. The great retention of pollen by cereals shows that this is possible (Fig 26), and further evidence comes from the macrofossil record (Fig 25) which shows the abundant seed remains of plants which were troublesome cornfield weeds in the past, such as *Arthemis cotula* (stinking mayweed), *Chrysanthemum segetum* (corn marigold), species of *Sonchus* (sow thistle), and *Centaurea cyanus* (cornflower) (this last only in medieval and later deposits). Straw was probably used (and reused) for a number of purposes, such as for flooring, roofing, animal bedding etc and much work remains to be done to try to tell more than merely that it was present.

Another source of the large amounts of cereal pollen in such deposits is from the remains of cereal foods. The retention of cereal pollen in grain and food has been shown (Fig 26), as has its survival of passage through the human gut (Krzywinski 1979), so faeces containing the remains of grain products could also be the source of some of the cereal pollen in such deposits. This likelihood is demonstrated if there are also parasite ova in the pollen preparations, and high power microscopy of fragments of periderm can show which cereals were present (Körber-Grohne 1964). Animal faeces could also contain pollen if stock had been fed grain or straw, or perhaps brewing waste, and work is needed on the palynology of various kinds of dung to investigate the possibility of identifying such materials.

Gramineae/Cerealia

This spectrum type has, as its main characteristic, a large amount of Gramineae pollen, together with other signs that most of the pollen was human-dispersed (26, 28, 29; Fig 27), in contrast to the other spectra with high Gramineae pollen values discussed above. It can be interpreted as representing the remains of grassy material such as hay, and the lack of present knowledge about what hay might have consisted of in the past makes it an interesting subject for further study.

The composition of hay, and thus its pollen content, might be expected to be variable, according to the type of meadow from which it came and the system of management in operation, Some meadows which are maintained by an ancient system of management are floristically interesting, such as Pixey Mead, Oxon (Tansley 1939, 568), and it is possible that future work on archaeological remains might demonstrate the presence of hay crops from such places. A further problem in the study of the remains of hay is that it contains a range of plants, most of which are wild, and remains of which could have come from local vegetation as well as from hay.

Another complication is that very little is known about the palynology of animal dung and the amount of pollen from meadow plants which could be transported in this way. Insect remains often supply good evidence whether dung was present.

Ericales

Ericales pollen (including ling, heather, heaths, etc) represents a group of plants which are unlikely to have grown in towns, yet high pollen values (20-30%) are sometimes obtained from urban deposits and there is often a macrofossil record to show that the pollen came from whole plant parts rather than from the atmosphere (9). It appears that heather was brought into towns for a variety of uses such as for flooring or roofing material, another example of a human-dispersed pollen component (Fig 22, upper left).

Discussion

The characterization of natural, semi-natural, and some archaeological pollen spectra and associated plant macrofossil and insect assemblages serves to provide an outline to show what potential there is for urban pollen analysis. These spectra, however, only account for a few of the many obtained in this work, and the others may prove much harder to characterize and to interpret. Furthermore, some important aspects of archaeological deposits may prove hard to detect from pollen records. These are discussed below.

Weeds

Although some kinds of man-made deposits seem to give clear palynological clues as to what they contained, other plant materials are harder to trace. The pollen records which probably represent a range of weeds and grassland plants (eg Chenopodiaceae (goosefoots), Cruciferae (eg shepherd's purse), Polygonaceae (eg knotgrass), *Ranunculus* (buttercups), Umbelliferae (eg hemlock), and *Urtica* (nettles)) seem to have no discernible pattern and neither do the corresponding macrofossil records. Such weeds are likely to have been present in plant material brought in from fields (eg straw, hay) as well as in weed communities growing in the towns themselves. The lack of pattern in the records may be a reflection on the many different sources of the pollen and seeds of such plants, and so the interpretation of weed records is so far proving to be very difficult.

Wetland vegetation

The pollen records from archaeological deposits do not often have strong signs of the presence of wetland vegetation such as sedges, yet the evidence for this from plant macrofossils and insect faunas may be abundant. Pollen retention on some plants, like the Cyperaceae, seems to be much lower than in the case of the Gramineae, for high Cyperaceae pollen values only seem to occur in deposits, such as in ponds (11, 17), which were wet enough for the plants to grow there. Floor deposits seem to have much lower Cyperaceae values, like some of the layers at the site at 6-8 Pavement, York. The pollen records of other aquatic taxa such as *Ranunculus trichophyllus* type (water crowfoots) are also very low, even when abundant macrofossils are recovered, so it is difficult to detect wetland vegetation by pollen analysis alone.

Mixed deposits

Archaeological deposits are, by their very nature, liable to have been disturbed or made up of a mixture of different materials, and this heterogeneity makes interpretation very difficult. Even if the remains of fairly pure plant products, like thatch, straw, hay, or faeces, were found, they would present enough difficulties in interpretation; when a deposit might represent a mixture of such substances with a contribution from local plant communities, and even the remains from industrial processes, formed indoors and then dumped outside, the problem becomes extreme. The difficulties of work on such deposits (often organic occupation material) serves to emphasize the point that pollen results should not be considered in isolation, and neither should those from plant macrofossils or insects; the integrated approach is the only way of assembling enough evidence upon which to base an accurate and detailed interpretation, so far as it is possible. A latrine deposit (26), for example, which contained the expected evidence of faeces and the remains of cereal food, had an insect fauna which was not associated with this aspect of it. It showed that the plant matter in the latrine had probably been indoors, perhaps as floor covering, for the insects could not have lived in the faeces. The plant macrofossils showed that hay and straw had been present as well as a range of fruit stones of food plants which would not have been swallowed but rather spat out on to a floor. The results from this deposit therefore show something of the fields and orchards in that area, the domestic floors, and finally the faecal deposit itself and its content of parasite remains.

Urban and rural sites

The results from this work can be examined in relation to the archaeology of the sites from which the samples were obtained: some sites which are rural on archaeological grounds, such as the Roman farmsteads at Barton Court and at Rudston, had wells from which were obtained 'Gramineae/local' pollen spectra (22, 23, 25), as did some archaeologically 'urban' sites like Hibaldstow, Droitwich, and Worcester (16, 18, 19). Pollen spectra of the 'Cerealia/human' type were also obtained at both rural sites like the motte and bailey castle at Hen Domen (27, 28) and urban sites such as at York (31, 32). Conversely, pollen spectra with large tree pollen values, which occur most often in material from rural sites, also come from urban material such as a buried soil (5) or in a pond (9). It therefore seems that there is no palynological (or indeed biological) distinction between the results obtained from sites which would be considered, on archaeological grounds, to be either urban or rural.

Roman and medieval sites

More significant, perhaps, are the differences between the results from Roman and medieval sites; the 'Gramineae/local' type of spectrum came mainly from Roman deposits

(16, 17, 18, 19, 22, 23, 25), while the 'Cerealia/human' spectrum was obtained from medieval sites only. One site, with deposits which seem to span the whole period, has pollen spectra first of one type, then of the other: the lower layers of the Ebor deep trench, considered Roman (King 1975), have some of the 'Gramineae/local' pollen characteristics (12), while the upper layers which seem to be medieval have some of the 'Cerealia/human' pollen characters (15).

This seems to agree with documentary records which may relate to the same site '. . . James Birkeby enjoined to cleanse the common sewer in his garden and to sett a suffysent grait at his garthyng door at Saint Ellyng Lane end', in 1580 (York City Archives). The 'Cerealia/human' type of pollen spectrum is also to be obtained from faecal deposits from latrines, which are a typically medieval type of structure (Atkin & Smith 1979).

The striking differences between pollen spectra from Roman and medieval deposits seem to confirm the traditional view that rubbish accumulation was a major problem in medieval settlements (Keene, this volume, 26-30). Roman sites were apparently clean, perhaps because there was much less use made of organic materials in Roman times, for the use of brick, tile, and pottery then gave way to the medieval practices of building with wattle and daub walls and thatch roofs, strewing floors with herbs, and making many wood and leather containers in place of pottery. Even so, the presence of domestic animals in Roman times would still have led to the need for fodder and bedding, and a corresponding requirement for the disposal of dung. Perhaps animals were not so extensively kept in towns as they were later. The archaeological evidence from Roman towns shows that rubbish disposal was highly organized, so that water supply and drainage systems provided a means for the disposal of liquid waste, such as the Roman sewer system at York (Whitwell 1976). Solid waste seems to have been taken outside the towns for disposal. as at Cirencester where quarry nits were used (Esmonde Cleary 1979). Thus the palynological information seems to agree with that from archaeology in this instance, but the reason why so many Roman sites seem to have been surrounded by short grassland is still a mystery.

Methodology and future work

The treatment of pollen by components, although the divisions must remain largely theoretical, is probably logical, because the source of the different pollen types is so important in interpretation. The results show that the scheme of pollen dispersal (Fig 22) appears to be justified.

The intensive approach provides a very useful method of obtaining enough data for a full interpretation, but it is also extremely time-consuming. If it had been relied upon too heavily, results could only have been considered from a few sites, and some of the pollen spectrum types identified and discussed here might have been dismissed as rare exceptional occurrences or have been missed altogether. On the other hand, over-emphasis of the extensive approach would have resulted in a great range of pollen spectra without the vital evidence from seeds and insects to confirm and help interpret such data. The extensive approach has proved valuable in showing important differences between parts of otherwise rather uniform profiles (9 and 16; 12 and 15) which can in turn demonstrate the need for more intensive study. Both approaches need to be applied with caution, to make sure that they are cost-effective; pollen analysis could be useful in testing a series of samples from a particular site in the minimum time in order to show the potential for more intensive work. Series of samples from moats and ponds seem most likely to be uniform in content and therefore to need a selective approach (7, 8, 14).

This study has posed more new questions than it has answered existing ones, but that is only to be expected in a fairly new line of study. More results are urgently needed from extensive and intensive archaeological pollen studies, work on modern pollen deposition, and, above all, integrated studies of pollen and other fossil remains to show whether these preliminary results demonstrate the general pattern of pollen spectra from archaeological material. Then, the ideas put forward here can be further tested and perhaps amplified, and more plant materials in archaeological deposits identified by their pollen spectra.

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Records from archaeological sites of the remains of parasites infecting man are reviewed. The value and limitations of the fossil record are discussed and problems of identification outlined. It is concluded that further morphological studies of parasites, particularly of egg size in trichurids, and of material clearly associated with human corpses are required.

Introduction

There are few lines of research available to archaeologists and biologists which will illuminate the medical and nutritional status of past populations, fields which are very difficult to investigate and will probably remain so. Some information is available from historical and documentary sources, though these are very incomplete and tend to concentrate on the unusual, overlooking common diseases and ailments. Most early documents were compiled by people from the upper strata of society who were generally not much concerned with the common people. Nevertheless, two groups of documents, the medical treatises and recipe books, are particularly enlightening, for information concerning a wide range of diseases, including parasitic infestations, can be gleaned from them. This aspect of medical history has been carefully studied by Hoeppli (1959), although further documentary research will doubtless bring to light other fascinating insights into parasitism in early societies.

Although the meticulous study of the palaeopathology of human skeletal remains produces useful results, many common diseases leave no trace on bones. Furthermore, few skeletons are excavated and subjected to detailed pathological investigation. As will become apparent, some evidence of certain parasites is likely to be found while the skeleton is being excavated. Thus, there is a great danger that excavators will overlook valuable parasitological data. Unfortunately, processes of cleaning well preserved articulated skeletons to the standards required for site recording are such that it is difficult to ensure that this information is not lost. Where excavators are trained to recognize, or sample for, parasite remains, large numbers are recovered.

A further possible line of research which may produce evidence of diseases is the recovery of remains of pathogenic micro-organisms—viruses, bacteria, etc—from archaeological deposits. This approach is unlikely to be very productive; even if isolated, their remains would be very difficult to identify using morphological criteria. Furthermore, it would be hard to be certain that such remains were contemporaneous with the deposits in which they were found and not later contaminants.

On the other hand, ova of trematodes (flukes) and nematodes (roundworms) and cysts and ova of cestodes (tapeworms) are a promising source of information concerning the history of the diseases for which these animals are responsible. They have been recorded from a number of sites; the records can be split into three groups on the basis of their archaeological context. Here, only evidence from the British Isles and mainland Europe is considered. Archaeological records of parasitic diseases of animals have recently been discussed elsewhere (Baker & Brothwell 1980).

It is clear, from those records where specific mention of soil conditions is made, that nematode ova are most commonly preserved where deposits remain moist. However, ova have been found in a Roman gypsum burial at Poundbury, Dorset, and concreted Viking age faecal material from a number of sites in York (Jones in prep a). Waterlogging is not necessary for the persistence of hydatid cysts in the soil.

Review

Remains from corpses

The first group of records is of parasite remains found in preserved human bodies. These records are the most valuable source of information, as any remains found are harboured by a host whose age, sex, and possibly social status may be known.

Gut parasites have been found in preserved bodies excavated from bogs, in both Poland (Szidat 1944) and Denmark (Helbaek 1958). In 1944, the intestines of two very well preserved bodies, the 'Drobnitz Girl' and the 'Karwinden Man', excavated from peat in East Prussia, were examined for parasites. Eggs identified as of the roundworms *Ascaris lumbricoides* (L.) (maw worm) and *Trichuris trichiura* (L.) (whipworm) were found in both bodies. In addition, the man's intestines contained structures which resembled the eggs of the fish tapeworm *Bothriocephalus latus* (now usually known as *Diphyllobothrium latum* (L.)). The numbers of the eggs of the two worm species recovered from the girl were found to correspond to the proportions of eggs in faeces from a rural population in Prussia in 1939 (Szidat 1944). The 'Grauballe Man' and 'Tollund Man', recovered from peat deposits in Jutland, were both found to contain large numbers of *Trichuris trichiura* eggs (Helbaek 1958). These records are most informative but, unfortunately, well preserved bodies are rarely, if ever, found during urban excavations. Archaeologists excavating churches and inhumation cemeteries should be alert to the possibility that parasitological investigations might be profitable where conditions of preservation are good. It should be noted, however, that plant-infesting and free-living nematode remains have been recorded from some bodies (Szidat 1944), these having invaded the body after burial. Thus a sound knowledge of both parasitic and free-living soil biota is essential.

In addition to parasite remains preserved in waterlogged conditions, one group of parasitic organisms has been reported several times from burials on dry sites. These are hydatid cysts (calcified resting stages of certain tapeworms), which have been recorded from Orton Longueville, Cambs (Wells & Dallas 1976), Winchester, Hants (Price 1975), Orkney (Brothwell 1978), and from a Danish inhumation (Weiss & Møller-Christensen 1971). Most of these finds were made during the course of systematic archaeological excavation of cemeteries. The known distribution of fossil hydatid cysts almost certainly does not reflect their true distribution, however. Archaeologists, whether volunteers or site directors, should be sure to look out for such cysts.

Coprolites

The second major source of parasite remains is coprolites. These curious objects are readily recognized as individual stools from their shape, and are not to be confused with deposits of 'cessy material' commonly encountered on urban excavations. A number of workers on the European mainland have devoted time to coprolites. In the 1950s and 1960s Grzywinski investigated nearly 200 coprolites from archaeological excavations of a domestic Slavic settlement of the 1lth-13th centuries (Grzywinski 1955; 1959 - 60; 1962), a site located on an island in the River Odra in Poland. Using a sedimentation and flotation technique he recovered eggs of *Fasciola hepatica* (L.), the common liver-fluke, from a small number of samples. Coprolites dated to *c* AD 160 from a cave near the Dead Sea in Israel (Witenburg 1961) proved to contain protozoan cysts and eggs identified as *Trichuris trichiura,* the common whipworm of man. Jansen & Over (1962) reported a range of parasitic species from faecal material thought to be of human origin, from terp material dated 100 BC to AD 500 in north-west Germany; ova of the large roundworm *Ascaris lumbricoides,* whipworms *Trichuris trichiura* and *T, ovis* (Abildg.)/ *globulosu* (Linst.), the liver fluke *Fasciola hepatica,* and the tapeworms *Diphyllobothrium latum* and *Taenia solium* (L.)/ *saginata* (Goeze) were recognized. In addition, ova of *Toxocara canis* (Werner) (a parasite principally of dogs, but which can infest humans causing blindness), and the nematode *Oxyuris equi* (Schrank) were found in what were assumed to have been domestic animal faeces.

Samples of human excreta from prehistoric salt mines at Hallstatt and Hallein, Austria, were examined by Aspöck *et al* (1973). Ten of thirteen samples examined produced ova of *Trichuris trichiura,* while a further sample contained ova of both *T. trichiura* and *Ascaris lumbricoides.*

Only one instance of coprolites with parasite ova has been reported from deposits excavated in the British Isles. In an excavation report of a site at Ivinghoe Beacon, Bucks, C R Lethbridge recognized eggs of a nematode of the genera *Trichuris* or *Capillaria* from what is thought to have been a dog coprolite (Dimbleby 1968). Similar investigations of bone-filled (presumably canine) coprolites from York and North Elmham, Norfolk (Jones unpublished) have, so far, failed to produce recognizable parasite ova.

As a source of parasitological information, coprolites are less useful than preserved bodies; however, much can be learned from their study. Both the form of the stool and the assemblage of parasite ova recovered may indicate the host species. The danger of circular argument should not be ignored, however. Thus, because a sample of coprolites is suspected from their form to comprise, for instance, horse-apples (turds), any parasite ova recovered are more likely to be identified to a species associated with horses. This leads to circularity when the conclusions that the deposit is horse droppings is subsequently 'confirmed' by the identi fication of the parasite remains.

Any parasite ova isolated from coprolite samples are almost certainly from one individual of a particular host species, although post-depositional contamination may occur. To judge from the large quantities of bone present in coprolites from British urban sites, dog faeces appear to be the only kind that are commonly encountered. This is not, perhaps, surprising as the presence of bones no doubt contributes to the preservation of coprolites by mineralization.

Cess deposits

Latrine-, rubbish-, and cess-pits are a third group of archaeological features which has repeatedly produced parasite ova. These features are commonly excavated on urban sites and several workers have independently reported ancient parasite remains.

Europe

Parasite ova have been recorded from cess from a number of sites in north-west Europe. Thus, for example, Specht (1964) reported an interesting soil sample from a cess-pit at the Roman fort of Kunzing, at Vilshofen, Germany. Eggs of *Trichuris trichiura* were present in these deposits, dated to AD 140 - 250. From 1st century Roman deposits from Valkenburg-on-Rhine in the Netherlands, ova of *Oxyuris equi* were recorded, while samples dated to AD 750 - 1400 from the same site proved to contain eggs of *Trichuris trichiura* and *T. ovis/globulosa* (Jansen & Over 1966).

By contrast, deposits from a 'refuge mound' in north-west Germany (Over & Jansen 1962), dated to 100 BC - AD 500, produced ova of *Fasciola hepatica,* as well as shells of the gastropod *Lymnaea truncatula* (Müller) (reported as *Galba truncatula),* the intermediate host of the liver fluke.

A 14th/15th century latrine pit from Olofskapel Gatehouse, Amsterdam, examined by Jansen & Boersma (1972), yielded both *Trichuris trichiura* and *Ascaris lumbricoides* ova as well as other ova of species of other genera of the families Trichuridae and Capillaridae.

Nansen and Jørgensen (1977) have demonstrated the presence of *Fasciola hepatica, Ascaris* sp., *Taenia* sp., and *Trichuris* sp. in material from excavations in Ribe (AD 750- 800). Recent excavations in Oslo (Schia 1979) have produced ova of *Trichuris* sp., *Ascaris* sp., and operculate eggs with a size range corresponding to that of *Diphyllobothrium latum* (Jones 1979) in a 15th century cess-pit.

Pollen preparations on material from cess-pit deposits from medieval Bergen have been shown to contain both trichurid and ascarid ova (K Krzywinski, pers comm).

British Isles

The first record of parasite ova from archaeological deposits in the British Isles was made on material from a pit at Winchester, dated to *c* AD 1100 (Taylor 1955). This pit contained eggs .of *Ascaris lumbricoides* and *Trichuris trichiura* in addition to *Dicrocoelium dendriticum* (Rudolphi), a liver fluke of sheep, deer, and, rarely, man. Pike and Biddle (1966) and Pike (1967), working on similar material, again from Winchester, confirmed the presence of these three kinds of eggs, but reported the finds as *Trichuris* sp., *Ascaris* sp., and *D. dendriticum*. The same author examined Roman material from Owlesbury, near Winchester, recording ascarid, trichurid, and capillarid ova (Pike 1968). An early medieval pit in Southampton produced *Ascaris* sp. and *Trichuris* sp. ova (Pike 1975), while another pit from Southampton, examined by R A Wilson, contained exceptionally well preserved eggs of *Trichuris* spp. and *Ascaris lumbricoides* group (Buckland *et al* 1976).

Wilson and Rackham (1976) reported structures resembling the ova of *Trichuris* sp. and *Ascaris* sp. from samples from a Roman sewer system in York. However, it should be noted that some of the fills of this sewer may be contaminated by material of post-Roman date. More recent excavations of Roman, Viking, and medieval deposits in York have produced samples containing ova of *Trichuris* sp. and *Ascaris* sp., sometimes in very large numbers. These genera have also been recognized in medieval material from Hull (Jones in prep b), while pits from London (P Boyd, pers comm) and Droitwich and Worcester (J Greig, pers comm and this volume) have all produced trichurid and ascarid ova. Recently, Dickson *et al* (1979) have described deposits from Scotland which appear to be composed largely of faecal material and, while processing samples for microscopic and macroscopic plant remains, also identified trichurid and ascarid ova.

The value and limitations of the fossil record

It is clear from the published literature that two kinds of egg occur most frequently in archaeological deposits *(Trichuris, Ascaris),* while other taxa which might be expected to occur are rarely or never recorded. It may be contended that the absence of some species from the archaeological record may be as much a function of their biology as of the ability of their eggs to resist decay. There are several classical and other early records which bear witness to the presence of common parasites which are not found in archaeological deposits. For example, *Trichinella spiralis* (Owen), a nematode which encysts in muscle and is transmitted in inadequately cooked pork, has never been recorded from archaeological layers. Undoubtedly, this is because the worm does not produce resistant eggs. A further example is the pinworm, *Enterobius vermicularis* (L.) which, in temperate regions today, is among the commonest of parasites of children (and also occasionally of adults), but which is absent from the European fossil record. This species lives in the rectum and, unlike most intestinal worms, does not release its eggs into the gut lumen but at night crawls out of the infected person and lays its eggs around the anus, secreting an irritant which causes the medical condition 'pruritus anis'. The result is that about 2% of an infected population pass stools containing eggs.

Returning to the archaeological records, it may be profitable to consider some of the problems and limitations of fossil parasite material. Various authors have been at pains to point out that the evidence from parasites may not, of itself, permit far-reaching archaeological conclusions to be drawn. Perhaps as a consequence of this, archaeological parasite records have often been presented as little more than novelties.

Some authors have been cautious in their identifications, tentatively publishing only generic names, while others have published specific names. In some cases both metrical and density data have been published with the identifications (see, for example, Taylor 1955 and Pike 1967), while elsewhere identifications alone are given (for example, Jansen & Over 1962).

Although the estimated density of eggs in the deposits examined has ranged from as low as 200 eggs per gram (Pike 1967) to as high as 30,000 eggs per gram (Jones unpublished), it is unlikely that much information relating to the degree of infestation, either of individuals or of populations, can be extracted from these data. Factors such as the fluctuating egg production of worms, the dilution of cess by other domestic refuse and by soil, and the degree of biodegradation of organic material in a deposit will all influence the concentration of eggs in archaeological deposits.

Similarly, the methods used to extract eggs have varied, some workers preferring flotation techniques while others use dilution methods.

In the former technique, once a sample is disaggregated, ova are concentrated by the addition of a dense salt (eg zinc sulphate) solution. Any ova observed in the float are counted and the number multiplied by a factor calculated from a scan of the non-floating residue; this gives a value for the concentration of eggs in the deposit. Dilution techniques also require samples to be disaggregated, but here small aliquots of the resulting suspension are examinated microscopically. Depending on the degree of dilution, the number of eggs per gram can be calculated.

A number of workers have recognized eggs in material treated with acids and alkalis for pollen analysis. Records of certain parasite ova in pollen preparations point to their extreme robustness as they clearly withstand the rigours of acetolysis.

Problems of identification

A very large number of both free-living and parasitic animals and plants produce spores, cysts and ova which act as dispersive, reproductive, or resting stages in their life-cycle. The resting stages are usually resistant to biological decomposition, being made for instance of chitin, and they may under suitable conditions be preserved in archaeological deposits. There is thus a plethora of microscopic remains that could be encountered but, with experience, parasite remains can be differentiated from fungal spores and pollen grains.

While certain parasite ova possess distinctive characters, many are preserved in such a state that specific identification is impossible. Problems of identification are particularly acute when considering groups of parasitic organisms that are taxonomically closely related. The trichurids provide a good example for further discussion. Members of this family are found in the alimentary canal of man, pigs, dogs, mice, rats, sheep, and a range of other mammals. The ova of all the trichurid species possess the same characters, being

Table 7 Dimensions of the ova of *T. trichiura* and T. *suis* (data taken from Beer 1976)

Species	*Reference*	*No of eggs examined*	*Width*		*Length*	
			mean	*range*	*mean*	*range*
Trichuris trichiura	Dinnik 1938	100	26.8	22.5-30.0	57.8	50.0-65.0
	Sondak 1948	100	25.6	24.0-29.0	56.7	54.0-60.0
	Hohner & Müller 1965	60	2	23.1-29.7	56.3	49.5-62.7
	Catár & Hynie 1967 - 8		—	25.0-28.0	—	51.0-57.0
	Beer 1976	100	25.5	23.1-28.7	54.8	49.9 - 61.1
Trichuris suis	Dinnik 1938	100	29.6	25.0-37.5	62.0	57.5-67.5
	Sondak 1948	100	27.8	25.0-30.0	61.0	57.0-68.0
	Hohner & Müller 1965	60	28.8	26.4-31.4	64.3	56.1-69.3
	C atár & Hynie 1967-8	?	—	26.0-28.0	—	59.0-65.0
	Beer 1976	100	30.1	26.8-34.5	62.1	46.6-71.2

barrel-shaped with two 'polar plugs'. However, there are differences in overall size between the species. According to Soulsby (1965), *Trichuris vulpis* (Froel.), the whipworm of dog, produces eggs which measure 70 - 89 microns by 37 - 41 microns while *T. suis* (Schrank), the whipworm of pigs, has ova which measure 60 - 68 microns by 28 - 31 microns. Thus, there should be little difficulty in distinguishing between ova of these species. Unfortunately, many species of whipworm produce eggs with size ranges which overlap those of closely related species. Two species of whipworm of medical and economic importance that have been well studied are *T. trichiura* (in man) and *T. suis* (in pigs). Beer (1976) has reviewed the literature dealing with the differences between those two species. While Schneider (1866) suggested that they were from two separate species, as late as the 1920s Schwartz (1926) maintained that the trichurids of man and pigs were a single species. There are at least five accounts of the differences between *T. suis* and *T. trichiura* giving detailed measurements of eggs. While these authorities arrived at the same conclusion, their data are far from identical (see Table 7). It thus becomes apparent that the identification of very closely related parasite ova depends on accurate measurement of many eggs and the application of statistical tests, as well as further biological research into taxa of small economic importance.

A further interesting aspect of Beer's (1976) work are experiments in which humans were infected with *T. suis* and pigs with *T. trichiura.* He concludes that some human whipworm infestations may be caused by pig whipworms, *T. suis.* It should be noted, however, that several workers, including Shtrom and Sondak (1938), failed to infect pigs with *T. trichiura.* Thus archaeological samples from human faecal material may prove to contain ova of both *T. trichiura* and *T. suis.*

Before palaeoparasitologists start to measure hundreds or thousands of eggs with a view to identifying them, two major problems must be borne in mind. These are, firstly, that detailed statistics for modern egg dimensions are not yet available and, secondly, that it is unknown whether egg dimensions have changed with time, through evolutionary changes, the circumstances of burial and preservation, or the treatment used during disaggregation and preparation prior to counting.

Preliminary work in York (Hall *et al* forthcoming) shows that the treatment parasite ova receive in standard pollen analysis dramatically distorts their shape. Investigating changes in egg shape during burial is rather more difficult. The most obvious starting point is to obtain samples of parasite ova from well preserved bodies, for here it is certain that ova of a restricted range of worm species, or even a single species, are being examined. The author is currently searching for samples from the gut region of ancient human burials which might produce trichurid ova. To date, samples from a burial in waterlogged soil from excavations at 16 - 22 Coppergate, York (a site with exceptional organic preservation including parasite ova from cess pits) and a group of samples from burials at Bordesley Abbey, Worcestershire (where wooden coffin fragments survived) have all failed to produce parasite ova. Perhaps the most likely source of irrefutably human parasite ova will be ancient bodies, which have only partly decomposed, in lead coffins. Such inhumations are often remarkably well preserved, with hair, skin, and occasionally flesh surviving.

Only when well preserved remains from human burials have been thoroughly investigated will it be possible to determine whether trichurid ova may be specifically identified and so to evaluate the information that is undoubtedly present in the cess-pits so frequently excavated on archaeological sites. Nevertheless, the parasitologist can be of great assistance to archaeologists and biologists by recognizing the presence of parasite ova, for these are good indicators of faecal material.

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