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Circaea

Association for Environmental Archaeology

Circaea is the Journal (formerly Bulletin) of the Association for Environmental Archaeology (AEA) and—as from Volume 4—it is published twice a year. It contains short articles and reviews as well as more substantial papers and notices of forthcoming publications.

Editorial policy for *Circaea* is to include material of a controversial nature where important issues are involved. Although a high standard will be required in scientific contributions, the Editors will be happy to consider material the importance or relevance of which might not be apparent to the editors of scientific and archaeological journals—for example, papers which consider in detail methodological problems such as the identification of difficult bioarchaeological remains.

Notes for contributors may be found on the inside back page of this issue.

Circaea is edited and assembled by Allan Hall and Harry Kenward at the University of York, England. It is distributed free to members of the AEA. Requests for information concerning purchase of back issues should be sent to Allan Hall (EAU, University of York, Heslington, York YO1 5DD, U.K.).

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The *Newsletter* of the Association, produced four times a year, carries news about conferences and the business of the Association. It is edited by Vanessa Straker (Department of Geography, University of Bristol, Bristol BS8 1SS, U.K.) and Gill Campbell (University Museum, Parks Road, Oxford OX1 3PW, U.K.), to whom copy should be sent.

Front cover: Some elements of Environmental Archaeology; based on sketches for Figures 20 and 21 in this issue, with apologies to E. H. Shepard (and Mike Hill!).

Editorial

At least one observant reader has noticed that, in the caption to Figure 8 in *Circaea* 9(1) (p. 14) the teasel heads were wrongly named: the left-hand specimen should, of course, have been labelled *Dipsacus fullonum* and the right-hand one *D. sativus*. We hope this didn't spoil your enjoyment of Mike Hill's excellent drawings!

The fault lies with giving the job of pasting up to an entomologist with pretensions to a classical education—quite obviously (he thought), the fullers' teasel must be *D. fullonum*... But no, life is never that easy.

The originator of this tricky nomenclatural point must be Linnaeus, who gave the first authoritative binomial to wild teasel—perhaps like so many he wasn't aware that the common wild plant was not the one used in commerce. He was, after all, at least 50% a zoologist!

We draw a veil over the botanist who failed to spot the error when carrying out a final proof check...

A further error we should report—this time one of omission-is forgetting to thank Becky Nicholson for co-ordinating the contributions to the taphonomy workshop, a second portion of which appears in this issue.

The Editors have long been promising themselves a little therapeutic comment on common problems encountered in incoming articles for *Circaea*. Authors are sometimes annoyed or mystified by changes to their text that we have made. Changes fall into two main categories. The first are those that are editorial niceties, some of which, perhaps, reflect a rather conservative and old-fashioned (dare we say pedantic?) approach to writing English–for example, the correct use of *due to* (which should not be used to mean *as a result of*), and an avoidance of words like *partial* (which, because it can be used to mean both *biased* and *incomplete* is sometimes ambiguous). On the question of the number implied by the word *data*, we are steadfastly holding out against the world! *Data* are (not is) made up of individual items, each of which is a *datum*. Points of this kind can, we admit, become the objects of obsession, but while we believe language must adapt in the face of need, we cannot see any justification for sloppiness. If you disregard the details of language and allow a kind of uncontrolled drift of usage, what we write now may be unintelligible, or at least of unclear meaning, within decades. There is also the matter of comprehensibility to readers whose first language is not English. We should use words simply and clearly, and in ways which are defined as common usage in current dictionaries.

Very much more important than these changes of detail are editorial attempts to clarify obscurely expressed passages in texts. If the Editors do not immediately take the meaning of a piece of writing, there is every chance that a good proportion of other readers will not. Many of our authors write good, clear, flowing English, and their texts are a pleasure to work with (and can be published much more quickly and painlessly). We do occasionally receive material which appears never to have been read by its author, or at least not read sufficiently long after completion for quite obvious failings to be noticed. We share with other authors the feeling of relief at completing a draft and the desire to be rid of it as quickly as possible, but there is much to be said for waiting for, say, a month before making final revisions.

We often suggest changes to the wording of papers to improve clarity. Generally, authors appear to find this helpful, or at least accept it with resignation. There are occasions, however, when these suggested changes are met with resentment–ironically, the author's ire often being in inverse proportion to the clarity of expression of the original manuscript! Sometimes the changes reveal ambiguity in the original text, since the intended meaning is lost. If this happens, it will almost always be the result of poor expression, although of course harassed editors can (and do) make mistakes.

Of course, no author likes to receive a text covered in marks from editors or referees, but (wearing our authors' rather than editors' hats) we find that a large proportion of such comments are justified and that our own papers are very much improved by taking heed of them.

The Editors do not always agree between themselves, it must be said. Something which is unclear to one of us may be perfectly comprehensible to the other, not least because we are familiar with different usages of words, having different 'specialist' backgrounds. In such cases, we endeavour to rephrase so that the passage is comprehensible

to a reader who is not necessarily *au fait* with the jargon of a particular field.

We are all too aware that we probably make as many mistakes as other authors and, indeed, sometimes suffer profound embarrassment on reading our work once it is published. A trivial—and ironic—example of this was the misspelling of idiosyncrasies in the phrase 'idiosyncrasies of spelling' in the *Notes for Contributors* on the inside back cover of *Circaea* (compare 7(1) and 7(2)!). On a larger scale, one of us suffers remorse over his using the present tense in describing fossil material from archaeological deposits, rather than a more appropriate past tense 'reporting' style. This aping of tabloid newspaper copy may have made some reports more 'lively' but it produced absurdities such as 'this layer is rich in insects' when the deposit ceased to exist during excavation many years before the report was written.

We shall abuse our editorial privilege further in subsequent issues of *Circaea* to make brief mention of a few of the common faults which authors can easily avoid with a little thought. How many of us would use phrases such as 'human, bird and animal bone' or 'flowers and plants' if we considered exact meaning of what we had written?

Conference Reports

Ancient Woodlands their archaeology and ecology: a coincidence of interest

A conference organised by the Landscape Conservation Forum, held at the Moat House Hotel, Sheffield, 25–26th April 1992.

The Landscape Conservation Forum is a body based in the Sheffield/Peak District area which aims to integrate different elements of 'heritage conservation' in this region. Speakers at this conference, however, discussed various aspects of the history and ecology of ancient woodlands throughout England.

To open the meeting, Dr Donald Pigott read a paper in which he presented pollen diagrams from small waterlogged sites within woodland in the Lake District. These provided evidence that over most of the area, now covered by oak-dominated woods, the entire tree cover had been cleared within the historical period. However, small stands of lime (*Tilia cordata*) on steep rocky slopes beside streams appear to be true primary woodland. Indeed, since the shortest sequences studied only covered the past 800 years, there is the possibility that the same individual trees are represented throughout these sequences. Some herbaceous species, including *Festuca altissima* and *Sanicula europaea*, appear to be associated with the primary woodland stands in the Coniston Basin. But the reasons for such restricted distribution may be varied; whereas some species, such as *Tilia* itself, may be true relicts, their distribution being limited by poor powers of colonisation, transplantation experiments have shown that it is grazing by sheep that restricts *Festuca altissima* to the rocky slopes which also harbour primary woods.

Dr Petra Day also cast doubt on the use of herbaceous species as 'primary woodland indicators' in her paper, 'The Origins of Ancient Woodland'. Pollen spectra from sites within woodland are rare, but she presented some from Sidlings Copse in Oxfordshire, which has a rich flora containing many taxa suggested as potential indicators of primary woodland sites. The pollen record shows that, although ancient, the site has not been continually wooded (it is not true primary woodland), as Roman clearance of the area was extensive.

Other papers presented on the first day of the conference concentrated on the ancient woodlands in the Sheffield and Derbyshire region. Melvyn Jones gave a synopsis of the sources of historical evidence available to those researching woodland history, and used these to illustrate the history of woodlands in South Yorkshire. Many ancient sites still exist in this industrial landscape; most seem to have existed as wood-pasture until the 15th century, when coppicing (later to be the common form of management in 90% of woods in the district) was introduced. Other woods were managed for the production of holly foliage as a winter feed for stock.

Clive Hart described a study of the archaeology of Eccleshall Woods, Sheffield. On this ancient site, human activity has been intense, with the earliest evidence of human presence being neolithic flints. Later, the area appears to have been wood-pasture, with at least two medieval hunting parks. More recent activities include coppicing, the removal of stone and soil, and the production of white coal (kiln-dried wood) and charcoal.

The theme of white coal and charcoal production in the North Derbyshire and Sheffield areas was continued in the paper presented by David Crossley. The two forms of fuel were major woodland products of the 17th and 18th centuries, white coal being used by the lead smelting industry, charcoal in the production of iron. Both have left archaeological evidence: pits known as 'Q-holes' appear to be the bases of white coal kilns, whilst charcoal burning sites take the form of shallow depressions with blackened soil. Since the soil from around the charcoal stack was removed to cover it, effects on local ecology must have been substantial. This paper also raised the probability that there was competition between the iron and lead smelters for fuel; white coal is best made from older wood, whereas young coppice wood made the most effective charcoal. Since the two smelting areas overlapped, the economics of fuel production for these industries must have affected the management of woods (for example, length of coppice cycle) in the region.

In a paper entitled 'Ancient woodlands in Sheffield and the Eastern Peak District—their importance to critically endangered wildlife species related to history and management', Dr Ian Rotherham described the local Red Data lists for Sheffield, particularly the high proportion of taxa on these lists which can be classified as woodland species.

Derek Whiteley returned to the theme of the use of indicator species in a paper in which he suggested that insects, particularly saproxylic (dead wood dwelling) hoverflies and beetles, could be used as indicators of ancient woodlands in the Sheffield area. Although not perfect, using the presence of assemblages of these species as markers of ancient woodland is now a workable tool for site assessment.

Evening presentations by delegates covered the ecology of dormice, pollarding and management of old trees in Britain and on the continent, and archaeology in ancient woodlands (the latter talk given by Tim Darnell, archaeologist at the Forestry Commission).

On Sunday 26th, a field trip to Eccleshall Woods in Sheffield was arranged. Documentary and archaeological evidence relating to this ancient site is good, and we were able to see Q-pits and charcoal-burning sites on the ground. However, although some of the herbs associated with ancient woodland, such as bluebells (*Hyacinthoides non-scripta*), wood anemones (*Anemone nemorosa*), and dog's mercury (*Mercurialis perennis*), were present in parts of the wood, evidence of its coppice structure was sparse. Only one or two of the participants claimed to have seen possible former coppice stools, and hazel appears to be absent. Today, the wood has been effectively converted to high forest of oak, sweet chestnut (*Castanea sativa*), and beech (*Fagus sylvatica*), with invading sycamore (*Acer pseudoplatanus*). Recent neglect has left an uneven age structure with few middle-aged trees to replace the giant old beeches that are reaching the end of their lives and becoming unsafe for an area open to the public.

The conference's concluding address was given by Professor Chris Baines, who stressed the need for communication between experts (each with their own narrow sphere of interest) and the general public, in order to conserve ancient sites. This could be achieved, he suggested, in a network of protected areas that were not necessarily of prime importance ecologically or archaeologically but, more importantly, were close to the urban areas in which most people live. Only by encouraging the public to be involved in their landscape can there be any hope for the conservation of ancient woodlands in the years to come.

Overall, the conference seemed to be biased towards the ecology, rather than archaeology, of woods, and many of the delegates appeared to be concerned with the management of woods, particularly reserves. However, there was a wide range of delegates, from members of local wildlife groups to representatives of national bodies such as the Forestry Commission.

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Ninth Symposium of the International Work Group for Palaeoethnobotany, Kiel, Germany, 18–23 May 1992

The IWGP held its first meeting in Czechoslovakia in 1968; since then, the locations of the triennial meetings have been more-or-less equally divided between eastern and western Europe. At earlier meetings, most of the papers concerned central and eastern European waterlogged or charred plant

remains. It is probably fair to say that the IWGP really came of age at the meeting in Groningen in 1983, when a truly pan-European group of archaeobotanists attended, a really substantial book of proceedings came out within a year and, most importantly, many papers went beyond tables of data to look at issues such as taphonomy, sampling and ethnoarchaeology.

This year's meeting in Kiel, a port and university town on Germany's Baltic coast, was blessed by highly efficient organization (by Helmut Kroll of the Institute of Archaeology, Kiel University, with a host of colleagues and students assisting), gorgeous sunny weather, and a good programme of speakers. As is usual today, accommodation was split, with hotels for those with funding and, for those without, the Falckenstein youth camp on the shores of the Kieler Förde. About half the conference participants stayed in the youth camp (soon labelled 'Frankenstein') which proved unexpectedly comfortable, was very cheap, and was the ideal venue for conversation and cold beer in the evenings.

The five days of talks gave the opportunity to hear the full spectrum of approaches to archaeobotany as practised in Europe. Some speakers took the traditional approach of presenting a list of species, with a picture of each seed type, and a final, brief, strictly phytosociological interpretation of the weed ecology. I found two aspects of this work worrying: the tendency to lump all the results from a site together for ecological and economic interpretation, rather than considering them sample by sample ('taphonomy' was a rarely heard word at this meeting) and, secondly, there was little discussion of what the archaeobotanical results actually meant in terms of human behaviour: what was the archaeological relevance of the work?

The talks on the first day were at the opposite extreme from this approach. On the subject of ethnographic and ecological models, Glynis Jones (Sheffield, U.K.) used her studies of traditionally irrigated fields in northern Spain to look at how we can recognise irrigation from archaeobotanical weed floras. In an elegant demonstration of multivariate statistics, shade tolerance was shown to be a key characteristic of weed species of irrigated fields (rather than water needs)—and this is a character we could use to identify such weed species in other areas.

R. Pasternak (Kiel) talked about traditional agriculture in Jordan, with modern examples of how cross-contamination of cereal and pulse harvests occurs on the threshing floor. Mark Nesbitt (Cambridge, U.K.) looked at why emmer and einkorn wheat are still grown in northern Turkey, and why they have disappeared elsewhere. Mordechai Kislev (Ramat-Gan, Israel) discussed medieval finds of *Cordia myxa* from Ashkelon, using documentary sources and his own ethnographic work in Cyprus to show how they are used for making bird-lime. Both modern Cyprus and ancient Ashkelon lie on important migration routes for birds.

The increasing amount of archaeobotanical data available is stimulating interest in use of databases. The most elaborate was described by Philippa Tomlinson (York, U.K.). This major project is well into storing all the seed (and some pollen and charcoal) records for the many hundreds of archaeobotanical reports available for Britain. G. Paskevic (Kiev, Ukraine) showed results for a similar database for the Ukraine, and Martin Dick (Basel, Switzerland) showed how results from one site could be handled. These talks excited a lot of interest, and Philippa Tomlinson proposed a newsletter on archaeobotanical databases. One question concerns the reliability of results: there is a risk that as soon as unreliable identifications enter a database they will be treated uncritically by users.

Statistics did not feature largely in the conference, but one particularly clearly presented example of their use was given by Otto Brinkkemper (Leiden, Netherlands), grouping samples according to similarities in species composition. Sampling and recovery was another rare subject: Ursula Thanheiser (Vienna, Austria) gave a preview of a cunning electrostatic device that removes organic materials (seeds, bones, etc.) from a loose matrix. This is ideally suited for sorting flotation heavy residues, and for material in a sandy matrix.

The use of chemical analysis is a rapidly developing field of archaeobotany. On the Tuesday morning Francis McLaren (London, U.K.) used infra-red spectrometry to compare spectra from palaeolithic fruit stones from Doura cave in Syria with modern species of plums. This technique, which has already given excellent results with ancient rye and wheat remains, obviously has great potential for other classes of plant remains. In this

session (designated as 'varia' in the programme), we also heard of early agriculture at the aceramic neolithic site of Nevali Cori, Turkey (R. Pasternak, Kiel) and admired wonderful colour photos of waterlogged seeds from Samos, Greece (D. Kučan, Wilhelmshaven, Germany).

The highlight of this morning was the presentation of early neolithic seeds (*c.* 8000 bp) from Nabta-Playa, in the Egyptian desert. Careful identification by K. Wasylikowa (Krakow, Poland) and Lucyna Kubiak-Mertens (Poznan, Poland) has shown a wide range of wild seeds present, including wild millets and sorghum. There is no evidence for crop-husbandry and, contrary to other reports, no barley or wheat has been found.

In the afternoon a milling crowd of enthusiastic archaeobotanists took over a laboratory to show each other their odd and/or unidentifiable seeds. I was particularly interested to find that the same unidentified crop (or gathered plant) I have from eastern Turkey has also turned up in Greece and Yugoslavia (but it's still unidentified!). Mordechai Kislev demonstrated his computerised key to grass caryopses; based on length, breadth and thickness measurements for species occurring in the Levant this is a very useful tool for narrowing down the field, but must be used in conjunction with a reference collection.

On Wednesday and Thursday two particularly interesting (and well-presented) talks dealt with non-seed materials. Werner Schoch (Adliswil, Switzerland) demonstrated the use of simple, cheap chromatography to identify ancient resins and pitch, and then discussed results from ancient Swiss artefacts with regard to ethnographic records of tree-tapping of resin or manufacture of pitch (from *Pinus*, *Picea* and *Betula*) and experimental archaeology. Klaus Oeggl (Innsbruck, Austria) described the identification of artefacts (arrowheads, knife, axe-shaft), clothes, charcoal and food remains (wheat spikelets, sloe fruits) discovered near the ice-body found recently in the Austrian Alps. The stomach contents still await analysis.

The IWGP has a good record for attracting speakers from what was once behind the 'Iron curtain': this year, G. Paskevic (Kiev) spoke about medieval plant remains from the Ukraine, and G. Levkovskaya (St Petersburg, Russia) looked at the (late, *c.* 2000 bc) arrival of agriculture in the Baltic zone of Russia. Ksenija Borojevic (Novi Sad, Yugoslavia) covered Iron Age agriculture from Bosut Tell in Yugoslavia, while from Poland Romuald Kosina (Wrocław) compared medieval wood finds in Wrocław to surrounding vegetation, and Marek Polcyn (Poznan) analysed an intriguing mixture of rye and common millet from a medieval jar, from the beautiful island site of Ostrow Lednicki. Cvetana Popova (Sofia, Bulgaria) presented Early Bronze Age plant remains from Bulgaria. As much of this work is otherwise only published in Cyrillic language journals of limited circulation, the IWGP proceedings are a valuable outlet.

The last two days of the conference were devoted to the special theme of the Middle Ages. I missed the final talks (and the archaeological excursion on Saturday), but those I did hear contained all too few references to the documentary evidence, which can complement archaeobotany so well. A rare exception was a stimulating talk by Hansjörg Küster (Munich, Germany), in which changing finds from medieval Constanz were related to documentary evidence for land-ownership around the city. One conclusion was that 11th century documentation could not be used for 13th century plant remains.

There were too many talks concerning European and medieval archaeobotany to be listed individually, but the strong contingent from Scandinavia, working at the other climatic extreme to the Near Eastern specialists, gave a good geographical balance.

One especially impressive project was a survey of crop cultivation in Switzerland, integrating evidence from the large number of sites being worked on by Stephanie Jacomet and her students at Basel University. From further afield, Mukund Kajale (Deccan College, India) looked at the history of garlic, in the light of a new discovery in India dating to 150 BC-AD 250.

One encouraging trend is the consolidation in more countries of archaeobotany as an integral part of archaeology, and I particularly enjoyed meeting archaeobotanists from Greece, Italy and Spain. The matter of language was raised a number of times: many of the talks given in German proved difficult for archaeobotanists from the Mediterranean and eastern European countries (not just to the notoriously monolingual British). Perhaps the time has come to encourage the use of English as the

main language of the conference, or at least to make the abstracts and overhead projections bilingual?

I returned to England greatly inspired, if rather overwhelmed at seeing 105 archaeobotanists (usually a rare breed) in such a short time. This was one of the best conferences I've been to, and I would strongly recommend the next one to anyone interested.

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[Editors' note: Those interested in receiving or contributing to an archaeobotanical database newsletter should contact Philippa Tomlinson at: Environmental Archaeology Unit, University of York, Heslington, York Y01 5DD, U.K.]

Papers from the bone taphonomy workshop at York, September 1991

Taphonomic factors in a human skeletal assemblage

Introduction

Most human burials excavated from British archaeological sites were (barring cases of mutilation through disease, injury or surgery) originally interred as complete individuals. Thus the numbers of each skeletal element originally present in an assemblage can be taken as known. Patterns of deficits in skeletal elements are thus usually explicable in terms of post-depositional factors, including losses during recovery. This is in contrast to most archaeological animal bone assemblages: their original composition with respect to skeletal elements is rarely known and hence patterns of loss through taphonomic factors are difficult to assess directly.

The present work comprises a study of the relative representation of various skeletal elements in a collection of human burials from Ipswich, Suffolk, U.K., and an attempt is made to distinguish patterns of loss resulting from differential destruction of skeletal elements in the soil from those brought about by differential recovery during excavation.

The assemblage

Bones from 250 burials were recovered during excavations at the site of the Blackfriars' Friary, Ipswich, by Suffolk Archaeological Unit in 1983–5. Of these, 226 were adults (Mays 1991) and form the basis of the present study. The burials were of medieval date and were of friars and lay benefactors interred in the friary between its foundation in AD 1263 and its suppression in AD 1538. Interments were almost invariably in the supine position. The bones were carefully hand-recovered; no sieving for small bones was carried out.

Methods

A skeletal element was recorded as present if it was represented by a complete or incomplete bone. The representation of each element in the whole assemblage of 226 adult skeletons (Rep_T) was calculated by expressing the total number of an element present (T_o) as a percentage of that expected (T_e) if all burials were represented by complete skeletons:

$$Rep_T = T_o/T_e$$

Probably the three most important factors reducing skeletal completeness at the Ipswich Blackfriars site were:

(i) damage to burials by the cutting of later features (principally further burials);

(ii) recovery factors during excavation;

(iii) preservation factors—destruction of bone in the soil.

Burials showed similar patterns of *relative* representation of skeletal elements whether or not they had been cut by later features (although, as expected, skeletons in graves which had been cut by later features tended to be less complete). This indicates that damage to burials by later features did not influence the composition of the assemblage with respect to the various skeletal elements. On this basis, the remainder of this paper focuses on preservation and recovery factors.

The overall state of preservation of each skeleton was classified as 'good', 'moderate' or 'poor' on the basis of visual assessment of the degree of erosion of the external surfaces of the bones (an assessment of whole-bone

preservation as opposed to histological preservation (Hanson and Buikstra 1987) of the skeletons). Scoring of burials into these preservation categories was found to be reproducible by the author. Preservation varied markedly between individuals, with burials at the site ranging from soil silhouettes with only a few fragments of bone present, to almost complete, intact skeletons. There was no correlation between preservation and age, sex, or location of the burials, or with whether or not a burial was cut by a later feature, but there was a significant correlation between preservation and skeletal completeness, the poorly preserved burials also tending to be less complete. This implies that poor survival of bone in soil played a part in reducing skeletal completeness.

In an attempt to distinguish the effects of differential recovery from those of preservation factors on the composition of the assemblage, the representation of each skeletal element was calculated separately for those burials classified as being of 'good' preservation (N = 51) and those classed as 'poorly preserved' (N = 55), giving Rep_G and Rep_P respectively. A measure of the relative deficit of a skeletal element in poorly preserved burials, compared with well preserved ones, ($Rep_{P/G}$), is given by:

$$Rep_{P/G} = \frac{Rep_P}{Rep_G} \times 100$$

Results

Figure 18 shows Rep_T and $Rep_{P/G}$ for each skeletal element.

It could be argued that excavators tend to be less careful when excavation a skeleton which appears poorly preserved than one which is apparently in a good state of preservation; had this been the case at Ipswich then this differential recovery would clearly have been a source of differences in the relative representation of the various skeletal elements in well and poorly preserved burials. At the Ipswich Blackfriars site, permanent teeth were little affected by preservation factors, generally being whole, even in poorly preserved individuals: thus it was thought that any differences in the numbers of permanent teeth present from poorly preserved and well preserved burials might help show up any differences in the care with which the inhumations were excavated. However, similar numbers of teeth were recovered from poorly and well preserved skeletons, suggesting no important differences in the care with which they were excavated.

The data for $Rep_{P/G}$ in Fig. 18 are listed in sequence, with the bones with the lowest values at the top and those with the highest at the bottom. Thus, the further up the diagram an element is placed, the greater its deficit in poorly preserved compared with well preserved burials and, by implication, the greater its vulnerability to destruction in the soil. On this basis, the bones most vulnerable to destruction seem to be those having a high proportion of cancellous bone, for example the sternum, vertebrae and ribs. Among the vertebrae, the lumbar are the least and the cervical the most affected by soil erosion, as expected given the relative strength and robusticity suggested by their gross morphology. Also showing a relatively large deficit in poorly preserved compared with well preserved skeletons are the hyoid and the smaller bones of the hands and feet. This implies that preservational factors were implicated in their destruction in the soil, or at least damaged them sufficiently to render them unidentifiable, and hence were an important cause of their fairly low numbers in the assemblage as a whole. Conversely, as might be anticipated, elements with a high proportion of cortical bone—the skull, mandible and the larger bones of the appendicular skeleton—seem to be relatively less affected by preservational factors (that is, they show smaller differences in numbers between the poorly preserved and well preserved burials).

The pattern of relative representation of different skeletal elements in the assemblage as a whole (Rep_T) may be considered a result of a combination of preservation and recovery factors (assuming minimal losses of elements during post-excavation processing). If preservation factors alone influenced the relative representation of elements in the assemblage as a whole, we might expect elements to follow the same rank order for Rep_T as they do for $Rep_{P/G}$. Figure 18 shows that the rank order for Rep_T is fairly similar to that for $Rep_{P/G}$, suggesting that preservation factors are a major influence on the composition of the assemblage as whole. However, several anomalies are apparent. The carpals and hand phalanges were present in rather lower numbers than might be expected

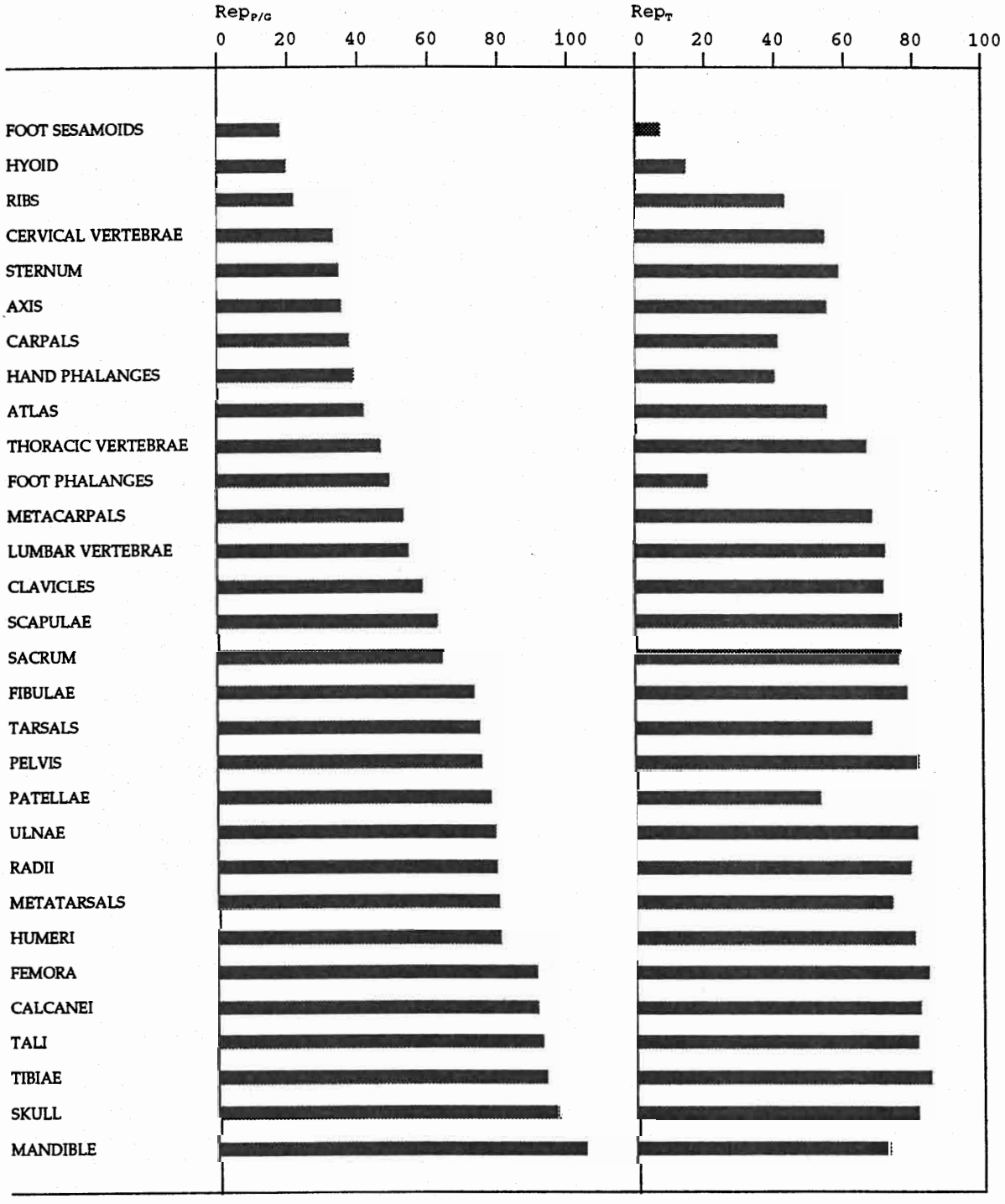

Figure 18. Rep$_T$ and Rep$_{P/G}$ (for explanation, see text) for each skeletal element in the assemblage of human remains from Blackfriars Friary, Ipswich

from their positions in the ranking in the diagram of $Rep_{P/G}$. This implies that recovery factors, in addition to their destruction in the soil, played a part in reducing their numbers overall. $Rep_{P/G}$ was greater for foot phalanges than for hand phalanges, suggesting that the former had a greater resistance to destruction in the soil. Despite this, foot phalanges were present in lower numbers in the assemblage as a whole, suggesting differential recovery—more of the (generally smaller) foot phalanges than hand phalanges were missed during excavation.

Patellae were present in only slightly smaller numbers in poorly as opposed to well preserved burials, but nevertheless are under-represented in the assemblage as a whole compared with bones of similar size and cancellous:cortical bone ratio (for example tali and calcanei). This would seem to imply poorer recovery of patellae during excavation—surprising given their fairly large size and in view of other indications that the Ipswich bones were, in general, fairly carefully recovered (for example, fragments of ossified throat cartilages and pleural and other soft tissue calcifications were recovered, and recovery of sesamoid bones was surprisingly good with 13.2% of the expected number of foot sesamoids present in the assemblage). It may be that patellae appear rather undistinctive to excavators and, if dislodged from their anatomical positions during cleaning of the skeleton or the removal of the grave fill, may not be recognised as bones, particularly if the soil is rather light coloured and/or stony.

Discussion

Analysis of a medieval human bone assemblage excavated from the site of the Ipswich Blackfriars suggests that destruction of bone in the soil was an important factor in reducing skeletal completeness. As might be anticipated, those elements of the skeleton which tended to survive least well in the soil were the fragile bones such as the hyoid or those with high proportions of trabecular bone such as the ribs, vertebrae and sternum. Least affected were those with a high cortical bone content, such as the skull, mandible and the long bones of the appendicular skeleton.

Losses of the small bones of the hands and feet were attributable to preservation and recovery factors and there are indications that loss of patellae may largely reflect recovery.

Although some post-depositional movement of bones in articulated skeletons frequently occurs (discussions in Reynolds 1976; Boddington 1987; Brothwell 1987), the location of the various bones in the skeleton can, to a great extent, be anticipated during excavation. This would be expected to reduce losses of small bones in articulated skeletons compared with disarticulated material, where the positions of bones cannot be anticipated.

Although the overall composition of the Ipswich assemblage with respect to skeletal elements is broadly similar to that observed at other cemetery sites (e.g. Ancaster, Cox 1989; Ipswich School Street Anglo-Saxon cemetery, Mays 1989; West Tenter Street, London, Waldron 1987), the results clearly cannot be extrapolated uncritically to other sites, since preservation and recovery of bone must vary with soil chemistry, the anatomical knowledge of the excavators, and the recovery methods used.

Acknowledgment

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Short contribution

A quick, semi-quantitative method for recording nematode gut parasite eggs from archaeological deposits

Summary

The current quantitative approach to parasite remains is discussed and found to be overcomplicated in relation to the results produced and in view of the increasing need for rapid recording techniques in environmental archaeology. The simpler, semi-quantitative method presented here has been tested and found to produce adequate results in a short time, using uncomplicated equipment.

Introduction

The aim of this contribution is to examine the quantitative approach to the preparation of soil samples for parasite egg analysis employed by Jones and co-workers, and to suggest a simpler method. The efficacy of the latter is supported by the results of analyses of samples from excavations in Carlisle and York.

As has been suggested elsewhere (e.g. Kenward 1992) it is becoming increasingly necessary to develop rapid recording techniques for biological remains from archaeological sites as funding diminishes in relation to volume of work, particularly as the trend continues towards intensive surveys of sites (as opposed to investigation of a few, possibly atypical, contexts). Such techniques for recording insect and plant remains are now well established (Hall and Kenward 1990; Kenward *op. cit.*). Parasite egg analysis remains a somewhat laborious task which to date has largely been carried out using relatively specialised techniques and equipment. This is unfortunate in view of the fact that results are rarely precise, often just indicating the likely presence or absence of faeces in a deposit, sometimes indicating a particular host species, generally *Homo sapiens*. It is increasingly necessary to develop a more rapid technique in the light of work discussed by Jones *et al.* (1988, 275–6), which highlights the fact that parasite eggs can be preserved in a much wider range of archaeological deposits than previously expected, including sediments containing little trace of other organic materials.

Currently, results from parasite egg analysis are presented in number of eggs per gram of sample. These counts are obtained using either a dilution method, such as the modified Stoll technique (Jones and Hutchinson 1991; Hall and Kenward 1990, 297) or a salt solution flotation method (Hall and Kenward (*ibid.*), where a saturated magnesium sulphate solution was used). Both techniques stem from methods used by parasitologists to detect worm eggs or larvae in the fresh faeces of humans (Davey 1966, 110–12) and other mammals (MAFF 1971, 1–16).

A wide assortment of both dilution and flotation methods suitable for the concentration of eggs of various or particular species have been brought together by the Ministry of Agriculture, Fisheries and Food (MAFF 1971, 1–16) for use by veterinarians, and these methods have been adopted, with very little modification, by environmental archaeologists studying parasite eggs in samples of ancient deposits. Hence, we have also adopted the clinical parasitologist's practice of estimating numbers of eggs per gram of deposit (originally eggs per gram of *fresh* faeces), a value designed to be one of 'a series of counts or comparison of counts in animals of *known* history' (my emphasis) or to be 'of some help in the diagnosis of helminthiasis provided they [the counts] are interpreted with caution' (MAFF 1971, 1). In the context of veterinary parasitology we are warned that 'the assumption that the size of worm burdens may be accurately deduced from faecal egg counts has not proved

justified'; there is a diurnal variation in the number of eggs released in faeces, eggs are often not evenly distributed throughout the faeces, and the moisture content is variable, thus affecting its density (*ibid.*). Furthermore, in infections where the worms are close together and the parasitized mucosa is badly damaged, egg production can be expected to be reduced (Faust *et al.* 1962, 232). These facts alone render the use of 'egg count per gram' fairly meaningless unless strict control is put on the time of day of faeces collection and on moisture content.

In addition to these unknowns, the variations in egg counts from archaeological contexts will clearly be greatly affected by unknown factors such as dilution by other waste and backfill deposits, biodegradation of organic material (Jones 1982, 68) and the incidence of parasitism in the contributing population.

Considering all these variables, there seems little justification in attempting to estimate egg concentration in archaeological deposits to anything more than a rather crude level. It may be argued that nobody has previously attempted to assess the worm burden of an individual or the proportion of an infected population on the basis of the analysis of archaeological sediments, yet a measurement has been adopted which has little purpose other than to be used in this way. It may enable a comparison between samples to be made, or indicate the presence of faeces, but as a quantitative measurement it has spurious accuracy, is generally unnecessary, and may be misleading.

The alternative method proposed in this paper still provides an indication of the presence of ancient faeces in a deposit, but is more rapidly employed and requires less specialised equipment and procedures, and is thus more suited to current needs. Quite simply, it involves using 'squashes' of raw sediment.

The method given below was used for the present experiments. It may be desirable to change the scanning magnification (Kenward *et al.* (1986, 246), for example, used x120). The magnification used here was adopted because of the equipment available, rather than for good theoretical reasons. Clearly if *measurement* of eggs is to be attempted, a higher magnification should be used (Kenward *et al.* (*op. cit.*) suggest x400).

Methods

In the 'squash' technique small lumps of raw sediment (approximately 3 mm diameter) were taken from three separate points within the sample (to take account of heterogeneity) and homogenised in a little water by shaking. After allowing coarse particles to settle for a few moments, a drop of the supernatant was removed using a Pasteur pipette and placed on a 76 x 22 mm glass microscope slide and covered with a 22 x 50 mm cover slip (an approximately 1 cm diameter drop on the slide being sufficient). With a little practice it became fairly easy to ensure that the mixture was not too flooded with water or so thick that large particles were incorporated in the 'squash'. The whole mount was then scanned rapidly using a magnification of x60 and the abundance of eggs was recorded semi-quantitatively on a six-point scale: one; 'trace' (estimated as 2–5); 'few' (6–10); 'some' (11–20); 'many' (21–100) and very many (probably more than 100).

This method was first carried out on 70 samples, mostly from Roman deposits, from excavations at Old Grapes Lane A (OGLA), Carlisle, Cumbria, U.K., provided by the Carlisle Archaeological Unit for insect and parasite analysis (results are presented by Allison *et al.*, forthcoming).

In order to check the reliability of the results obtained, it was decided to test a number of samples using the modified Stoll technique (MAFF 1971, 3–4), in the form used by Jones and Hutchinson (1991, 68–9). Eighteen samples were checked: six for which no eggs had been found in the squashes, six for which small numbers had been noted, and six for which they had been recorded as numerous.

Briefly, a subsample of 6 g was taken from each sample and placed in 42 ml of sodium pyrophosphate ($Na_4P_2O_7$) solution, in which it was disaggregated by shaking. Each subsample was left for 2 days before pouring it through a freshly flamed 250 µm sieve to remove coarse particles and adding a further 42 ml of water. A 0.15 ml aliquot of the resulting suspension was then placed on a 76 x 25 mm microscope slide and covered with a 22 x 50 mm cover slip. The mount was then scanned under a transmission microscope at a magnification of x60, and all the eggs seen were identified and counted.

Following the modified Stoll method it would then have been a simple matter to convert the number of eggs counted into an estimate of eggs per gram by multiplying by 100 (Jones and Hutchinson 1991, 70; Jones 1985, 109). This has not been done here for two reasons: firstly, in order to facilitate comparison with the 'squash' technique results and, secondly (and more importantly), because this 'multiplying up' exaggerates the errors inherent in the counting technique. It would not be difficult to believe that a lump of deposit with an actual concentration of, say, 300 eggs per gram might give an estimate of between 0 and 1000 or more.

Table 2 shows the results of this comparison for the 18 samples from OGLA.

It was immediately clear from the results that only samples with a low concentration had been tested and it was deemed necessary to test some samples with a known, higher, concentration.

Seven samples from Anglo-Scandinavian deposits from excavations at 16–22 Coppergate, York, previously examined using the modified Stoll technique by A. K. G. Jones (Kenward and Hall, forthcoming) were re-examined using the squash technique. Two counts had originally been made on some of the samples and both have been given.

Unfortunately the unused portions of the parasite subsamples chosen had become desiccated, so it was first necessary to rehydrate a small portion of each. Again, three small lumps were taken from different areas of each sample. These were then soaked in a little water for 3 days. At this stage it was still not possible to disaggregate the samples by shaking, so it was decided to boil each for a few minutes. All but one of the samples then broke down fairly well, but an initial examination of sample 3000 showed that it had not fully disaggregated. A further subsample of it was therefore soaked in a little sodium pyrophosphate solution for 2 days before re-examination.

The scanning procedure was carried out in the same way as for the OGLA 'squash' samples. The eggs were, however, recorded both semi-

Sample	Stoll		Squash	
	Trichuris	*Ascaris*	*Trichuris*	*Ascaris*
3	15	1	few	trace
7	0	0	trace	0
14	3	0	one	0
15	5	0	one	0
17	0	0	0	0
24	1	1	0	0
26	0	4	trace	few
35	0	0	0	0
39	0	1	0	0
42	0	0	one	0
48	1	1	trace	trace
50	0	4	0	0
59	0	0	0	trace
64	1	0	0	one
67	0	2	0	0
76	0	0	few	one
77	0	0	one	0
85	0	0	0	one

Table 2. Parasite eggs from 18 samples from the Old Grapes Lane A site, Carlisle, recorded using the modified Stoll technique (quantitative) and the squash technique (semi-quantitative).

quantitatively and as number of eggs per slide (the latter in order to test the ratio of *Trichuris* to *Ascaris* eggs in the sample and to compare this with the same ratios from Jones' results). The counts are recorded in Table 3, and Table 4 compares the *Trichuris*/*Ascaris* ratios.

Results and discussion

In examining the results obtained from the OGLA samples, it is firstly important to note that in all cases the concentrations of eggs were quite low, the highest apparently being that from sample 3, where 15 *Trichuris* eggs were counted using the modified Stoll technique. Given the method suggested by Jones (1985, 109) this would indicate a concentration of 1500 eggs per gram, which Jones tentatively suggests is indicative of a layer 'probably containing a substantial amount of faeces; (Jones 1985, 112). The squash technique showed a 'few' *Trichuris* eggs. The techniques were thus in broad agreement. Sample 76, on the other hand, also gave a 'few' *Trichuris* eggs but the subsample examined by the modified Stoll technique was apparently barren. Presumably this was the result of sample heterogeneity.

In all other cases, it appears the results from the squash and modified Stoll methods are similar where egg concentrations are low. Low numbers of eggs may be missed by either technique, but the archaeological significance of low concentrations is doubtful. As suggested by Allison *et al.* (forthcoming) these variations are not really surprising considering the likely patchy distribution of eggs in any archaeological deposit.

The results obtained from the Coppergate samples using both techniques (see Table 3) clearly indicate higher concentrations of eggs and thus provide a further proof of the effectiveness of the squash technique. In cases where a substantial number of eggs had been revealed by the Stoll technique, the squash method invariably indicated a similar high concentration. In fact, in most cases the results were remarkably close, considering the lack of precision involved in the squash preparations. There are some inconsistencies in the data, however, such as the number of *Ascaris* eggs recorded from sample 1913, though this hardly detracts from the validity of the squash technique. The results for sample 3000 are at first sight less consistent in that, whilst considerable numbers of both *Trichuris* and *Ascaris* were apparent in the squash, these values were still significantly lower than those obtained using the Stoll method. There are two possible explanations for this. Firstly, an examination of the written record for worm

Sample	Stoll		Squash	
	Trichuris	*Ascaris*	*Trichuris*	*Ascaris*
1353	25	4	24 (many)	5 (trace)
—	20	5		
1732	19	15	28 (many)	19 (some)
1907	132	43	105 (v. many)	28 (many)
—	131	48		
1911	142	28	270 (v. many)	41 (many)
—	149	21		
1913	37	0	72 (many)	10 (few)
2135	469	10	282 (v. many)	16 (some)
—	157	12		
3000	117	81	51^{x} (many)	42^{x} (many)
			49^{y} (many)	42^{y} (many)

Table 3. Parasite eggs from 7 samples from the 16-22 Coppergate, York, site recorded using the modified Stoll technique (quantitative) and the squash technique (quantitative and semi-quantitative). x/y: before/after treatment with sodium pyrophosphate solution.

egg analyses held in the Environmental Archaeology Unit suggested that this sample may have received non-standard treatment because of its proportionally high *Ascaris* content. A second possibility is that the squash subsample was not sufficiently disaggregated even using sodium pyrophosphate (the two results obtained with and without pyrophosphate use are very similar), which may indicate the need for a more effective disaggregating agent. When the sample was originally examined it was described as 'moist to wet', so disaggregation may have been more easily accomplished than for the dehydrated material used here.

A further important question answered by the Coppergate data is whether or not the squash method is equally effective for different parasite species. Table 4 shows a comparison of the ratios of *Trichuris* to *Ascaris* eggs in all seven samples. It is clear that in all cases the two methods have given a similar ratio.

Sample	Stoll	Squash
1353	6.25 4.0	4.8
1732	1.27	1.47
1907	3.07 2.73	3.75
1911	4.89 7.09	6.59
1913	—	7.2
2135	46.9 13.08	17.6
3000	1.44	1.21[x] 1.17[y]

Table 4. Ratio of Trichuris *to* Ascaris *eggs in samples from 16-22 Coppergate tested using the modified Stoll and 'squash' methods. x/y = before/after treatment with pyrophosphate; No* Ascaris *eggs were recorded from sample 1913 by the Stoll method so no ratio can be given.*

The squash technique has clearly been vindicated by these results for use on archaeological deposits suspected of containing parasite eggs. It will certainly provide an adequate and rapid check, where a large number of samples are being examined, in order to isolate those samples where significant numbers of parasite eggs are present. In addition it also appears suitable for more thorough and systematic examination, where measurements of individual eggs are required. If necessary, subsamples could be disaggregated using chemical means and even sieved prior to measurement. However it is the view of the author that it would have been possible to measure the eggs in the samples discussed here without further processing, which is useful in view of both the cost of specially made sieves and the time involved in the preparation of Stoll samples.

Further, by recording semi-quantitatively, the results obtained are explicitly seen to be estimates, perfectly adequate for establishing the presence or absence of significant amounts of faecal material. The recording scale used is open to discussion and it may be thought necessary to revise it. It should be borne in mind, however, that an accurate measurement of faecal concentration is never likely to be obtained using parasite eggs for the reasons discussed in the introduction. From the data obtained by Jones (1985, 112–13) it could, very cautiously, be suggested that 'trace' amounts probably represent the background level for many urban occupation deposits in the British Isles. 'Few' possibly indicates some faecal contamination in a deposit, 'some' may indicate a substantial amount of faeces, 'many' a probable faecal layer and 'very many' a deposit consisting primarily of faeces.

It is hoped that this technique will aid the future study of parasites, especially in areas where analysis has been dismissed previously as too complicated, time-consuming or expensive. The squash method is fairly easily adapted to surroundings, requiring little specialised equipment (except a transmission microscope), and could probably even be attempted in a site hut during excavation. This study will also have been of some use if it provokes the examination of methods used in other archaeological disciplines, especially where they have been borrowed from related fields and perhaps applied indiscriminately.

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The author would like to thank Harry Kenward, Allan Hall, Annie Milles, Keith Dobney, John Carrott and Colin Nicholson for their time and advice in both my initiation into work on parasites and in the preparation of this contribution. This note is based on a project carried out in the Environmental Archaeology Unit, University of York, during a period of undergraduate work experience.

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Book notices

These two books both have something to offer the palaeo(ethno)botanist and may well be of interest to all environmental archaeologists.

de Rougemont, G. M. (1989). *A field guide to the crops of Britain and Europe*. London: Collins. 367 pp., numerous colour pls., line drawings, maps. ISBN 0 00 219713 8. £14.95

Although published in 1989, this useful addition to Collins' generally excellent *Field*

Guide series has only recently come my way (at, it must be said, very much less than the recommended retail price, via the shelves of a National Trust shop). Comparisons will inevitably be made with *The Oxford book of foodplants* (Oxford University Press, 1969), now rather hard to obtain. However, the *Field Guide* aims to cover only Britain and Europe (presumably Britain was not part of Europe in 1989!), whilst the *Oxford book* includes foodplants from all parts of the world; the *Field Guide* deals with all kinds of crops (from fibres to drugs), whilst the *Oxford book* restricts itself to edible plants. Moreover, the *Oxford book* was evidently largely a vehicle for Barbara Nicholson's extraordinarily good colour illustrations (the accompanying text being somewhat skimpy), whereas the text of the *Field Guide* is more comprehensive and is supported by excellent colour plates (by Elizabeth Rice and Elisabeth Dowle).

Entries in the *Field Guide* are dealt with alphabetically by family (beginning, somewhat surprisingly, with Annonaceae, the custard apple family—these plants from tropical S. America are grown on a small scale in S. Spain, at least). For each species there is a description of the plant, a list of vernacular names in the main European languages (Russian names being transliterated), a discussion of the plant's uses and of its origins, distribution and cultivation. Lastly, mention is made of similar plants, principally those with which the crop plant in question might be confused in the field. One cannot help but think that this handy tome would be essential reading for the checkout staff at supermarkets whose training appears not have reached to the accurate identification of the bulk of the fresh fruit and vegetables they are handling!

Cardon, D. (1990). *Guide des teintures naturelles*. Lausanne: Delachaux et Niestlé. 399 pp., 49 colour pls. (by Gaëtan du Chatenet), numerous chemical formulae. ISBN 2-603-00732-7. Apparently not available in Britain. My copy (which cost £30) was ordered by a bookshop, probably from the publisher, Delachaux et Niestlé, Service Promotion, 79 route d'Oron, CH-1000 Lausanne 21, Switzerland.

Another 'field guide' and certainly much more like Collins' Field Guides of a decade or two ago in its overall appearance. The scope of this book is remarkable. As well as the plants one would expect (and the coverage is worldwide, so the familiar woad, madder and greenweed of N. W. Europe are complemented by a bewildering range of tropical dyewoods, for example), there are lichens, fungi, molluscs and insects, the last group including the kermes and cochineal insects of which Mme Cardon has made a special study.

The 'taxonomic order' for this book, by contrast with the last, is (bio)chemical, at least for the plants. Thus the first section in the body of the book deals with all those plants giving red dyes—the basis for the colour lies with the presence of quinones (such as alizarin in madder), so there is more sense to this approach than a strictly family-by-family scheme. Descriptions of the plants are followed at the end of each section with a brief survey of the organic chemistry. Here can be found such delights as hamamelitannin (digalloylhamamelose) and paeonidol, not to mention curcumins I, II and III!

Besides descriptions of the organisms furnishing dyes or tannins, and some brief recipes for obtaining the colours, the entries give a history of the extraction and use of the colouring matter, sometimes with delightful asides. One such is the comment under the entry for dog whelk (*Nucella lapillus*, a source of a sort of poor-man's Tyrian purple), with the heading 'gastronomie' (the author is, after all, French!). I translate: In England in the 19th century it was sold, boiled, on the market in Hastings under the rather engaging name of *man-suckers*...

The book carries a very useful bibliography of references (including the source of the aside about dog whelks), rather more detailed than one is perhaps used to find in a 'field guide', which make this a very important work for anyone interested in the history of dyeing and in particular in the use of plants, fungi, lichens and animals. There is no doubt in my mind that the book (which is, of course, entirely in French) would find a considerable market in the U.K.; the publishers, I understand, have no intention to commission an English translation, however. *Ainsi soit-il!* I shall struggle on with my rudimentary French, so much is there to glean from this excellent *Guide*.

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The biochemistry and microbiology of buried human bone, in relation to dietary reconstruction

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Summary

This paper presents a survey of the background to the biochemical and microbiological study of human bone, reviews previous and current applications of this work, and discusses the implications for the reconstruction of past human diets. Information has been drawn from a range of published sources, not all of them easily accessible to the archaeological community. It is intended that this paper should provide a summary and reference point for students and researchers with an interest in palaeodietary studies, but without a specialist biochemical background or time to undertake a literature search themselves.

Introduction: bone chemistry and diet

Attempts have been made to reconstruct the diets of prehistoric communities from a study of their skeletal tissue using two approaches: the study of stable isotope ratios (mostly either carbon or nitrogen) in the organic matrix and the analysis of trace elements in the inorganic bone mineral.

The isotopic method is based on two observations: (i) bone collagen isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) reflect the corresponding isotopic ratios in the animal's diet (DeNiro and Epstein 1978; 1981); and (ii) different foods have characteristically different isotopic ratios depending on the base of the food web (Van der Merwe 1982; Schoeninger and DeNiro 1984). Stable carbon and nitrogen isotope ratios have therefore been used to distinguish between a reliance on terrestrial and marine food sources in the diet of prehistoric humans. Carbon isotope ratios have also been used to distinguish between the consumption of C_3 and C_4 plants (defined below; see also DeNiro and Epstein 1978; Van der Merwe 1982). Nitrogen isotope ratios can also reflect the differential utilisation of nitrogen-fixing organisms (legumes and N_2-fixing cyanobacteria) and non-nitrogen fixing plants (DeNiro and Epstein 1981).

The inorganic fraction of bone contains a range of trace elements, some with presumed dietary significance. The first element to be so identified was strontium (Sr), which is still the most important element in palaeodietary reconstruction. Other potential indicators are zinc (Zn), magnesium (Mg) and barium (Ba), although the behaviour of these elements in the body is not well understood. There are also other elements which may be deposited in bone, such as lead (Pb) and copper (Cu), the analysis of which may provide information about the general health of the individual.

This paper seeks to summarise the biology and chemistry which underlie palaeodietary studies, and to draw together and critically review recent developments in the field.

Background: the structure of bone (Figure 19)

Bone is a structural tissue: in a living 70 kg adult human, the skeleton will weigh approximately 10 kg (Snyder *et al.* 1976). In

life, it performs a number of functions: (i) it provides support for soft tissue; (ii) it protects delicate organs such as the brain; (iii) it allows movement by providing points of attachment for muscular tissue; (iv) it acts as a reservoir for the storage of essential elements, and, to some extent, acts as a repository for unwanted elements (Armelagos *et al.* 1989, 230).

It is a highly specialised composite material, which exhibits as principal characteristics rigidity and strength, while retaining a degree of elasticity. These properties derive from bone's structure: a complex mineral substance (containing chiefly calcium, phosphate, hydroxyl, citrate and carbonate ions) deposited within a soft organic matrix, composed largely of the protein collagen. Although the composition is variable, the average composition of dry compact bone is 70% (by weight) insoluble inorganic matter, 20% organic matter and 10% water (i.e. that lost below 105°C).

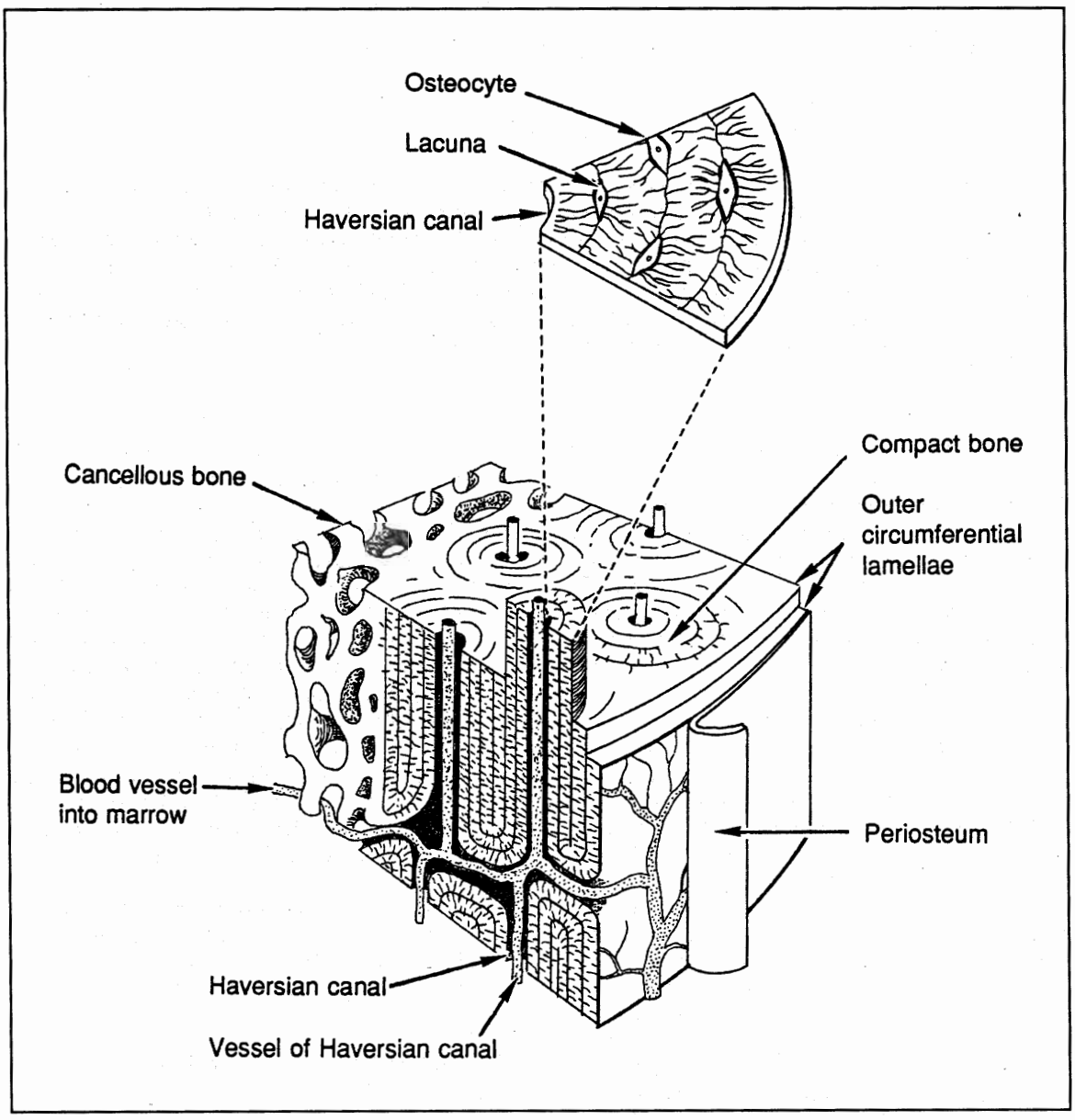
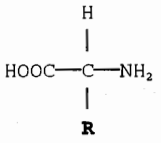


Figure 19. The microscopic structure of bone (based on Anthony and Thibodeau 1984).

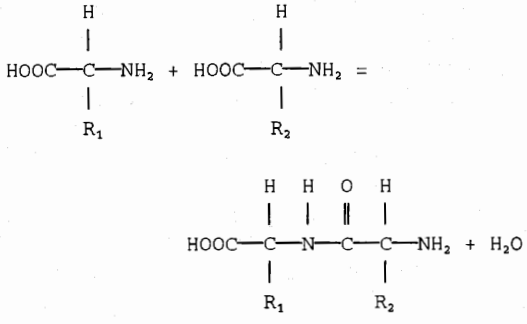
The organic matrix

Approximately 90% (by weight) of the organic fraction is made up of a fibrous structural protein of the collagen family. Collagens are widely distributed throughout the connective tissue of the body, and are largely responsible for the strength and elasticity of such tissues.

Proteins are biopolymers consisting of interconnected chains of amino acids, linked by peptide bonds. Amino acids have the general formula:



where R is one of a number of organic radicals—the simplest being H, giving glycine (*gly*), the simplest member of the amino acid family. The peptide bond is formed when the amine ($-NH_2$) radical of one amino acid links to the acid radical of the next, with the elimination of a water molecule:



This elimination reaction can continue until a protein chain has been formed containing many thousands of amino acid residues. The protein is characterised by the sequence of amino acids, labelling from the nitrogen-containing radical end of the chain. There are 23 'natural' amino acids found in protein, but collagens typically only contain about 17 of these. The dominant sequence of collagens is the repeated unit: glycine (*gly*) — proline (*pro*) — hydroxyproline (*hypro*), resulting in an average composition of 33–35% *gly*, 6-13% *pro* and 9-17% *hypro* in most kinds of collagen, with the other amino acids together making up less than half of the total residues. *Hypro* is an unusual constituent in that, of all the proteins, it only appears to be a significant component of collagen.

Collagen is made up of a rope-like structure consisting of three polypeptide chains, twisted together in a right-hand helix (polypeptides are chains of amino acids linked by peptide bonds). Each individual chain is twisted to the left, one turn per three residues (thus aligning the glycine molecules at every third residue), with ten turns of each chain per turn of the triple helix. The relatively small size of the glycine molecule makes for a tightly twisted chain, and the strength of the triple helix derives from hydrogen bonding between the amide nitrogen of glycine in one chain and a non-glycine carbonyl oxygen in the adjacent chain. There are seven or eight common sequences of amino acid chains in collagens, most simply described as types 'a' to 'g' (McGilvery and Goldstein 1983, 164) and collagens in different tissues are made up of different combinations. The most common collagen (referred to as Type I) makes up approximately 90% of body collagen, and occurs in bone, tendon, cornea, soft tissue, and scar tissue. It is made up of two chains of type 'a' plus one of type 'b', and is therefore described as a_2b. The majority of the rest are made up of three identical chains, such as Type III (d_3), occurring in blood vessel walls.

Bone collagen fibrils have an average molecular weight of 300,000 Daltons (a Dalton is the mass of one atomic unit), with a length of 260 nm and a diameter of 1.4–2.0 nm. In collagen fibres, the fibrils are aligned head to tail, with a gap of 40 nm between fibrils, and a stagger of 65 nm (one quarter of the length of the molecule) between adjacent rows. This gives rise to the characteristic 65 nm banding that is visible in electron micrographs of collagen. Mature collagen is insoluble in water because of the covalent cross-links between adjacent polypeptides in the helix. Solubility increases, however, as the protein is denatured (i.e. as the overall molecular weight is reduced), as when bones are boiled for soup!

The other organic components of bone (approximately 10 weight percent) are often grouped together as non-collagenous proteins (ncp). Carbohydrates include proteoglycans (predominantly glycosaminoglycans), consisting of protein combined with acidic carbohydrates. Common in dentine (a major constituent of teeth), but not in bone, are phosphoproteins, with an unusual amino acid composition of 50% serine and 40% aspartic

acid, and a total phosphorus content of 26 weight percent. Other proteins include osteocalcin, in which the glutamic acid side chain has been carboxylated. These so-called 'gla' proteins are the major component of the ncp fraction in bone. The lipid component in dentine and defatted bone makes up only about 0.1 weight percent of the tissue: in bone, by contrast, three-quarters of this is triglyceride, the rest predominantly cholesterol (Williams and Elliott 1989, 366).

The mineral phase

The principal components of the inorganic phase are calcium and phosphate ions. It is poorly mineralised (i.e. having much amorphous material and small crystals), but is normally described as calcium hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). Apatites have the general formula $Ca_{10}(PO_4)_6X_2$, where X is commonly either OH^- or F^-. Fluorapatite is a relatively common mineral, but hydroxyapatite is rare outside the animal kingdom. Apatites are ionic crystals (apart from the covalent phosphate ion), with the phosphate ions forming hexagonal close-packed sheets, with sheets stacked in the 'aba' system (i.e. the third layer ions are directly over those in the first layer). This kind of structure has two types of spaces (interstitial vacancies) within it, labelled A and B. The A position (the octahedral vacancies) gives rise to channels running all through the structure: in hydroxyapatite, two out of three of these channels are occupied by Ca^{2+} and the other by OH^-. The same channels are lined with the remaining Ca^{2+} ions, leaving, in a perfect crystal, the B position (the tetrahedral sites) unfilled. This structure is therefore very porous, so that dead bone easily takes up ions from the groundwater.

Pure hydroxyapatite is difficult to synthesise, and in biomineralisation a number of substitutions are common, which distort the hexagonal structure. Any ions may be involved, providing they are of closely similar size and, less importantly, charge. Thus, AsO_4^{3-} will substitute freely for PO_4^{3-}; HPO_4^{2-} and CO_3^{2-} will substitute in a limited way. Sr^{2+}, Ba^{2+} and Pb^{2+} will substitute freely for Ca^{2+}, Na^+, H_2O (and ion vacancies) in a limited way, and K^+ and Mg^{2+} in a restricted fashion. Hydroxyl ions are freely substituted by halide ions (fluoride, F^-, chloride, Cl^-, bromide, Br^-, and iodide, I^-), but only in a limited way by H_2O and vacant sites. Double substitutions can also occur—for example, two hydroxyl ions can be replaced by CO_3^{2-} or O_2^{2-}.

Synthetic hydroxyapatite crystals can be made with sizes in the millimetre region, but commonly they only have dimensions of a few microns, particularly if they are non-stoichiometric (i.e. the ratio of ions does not conform to the formula for the mineral), as is common in biosynthesis. In bone, the typical crystal has a needle shape, of length 15–79 nm and diameter 5 nm (Sillen 1989, 213). This has a number of important consequences in life: it has been calculated that 1 gram of mineral has a surface area in excess of 100 m^2 (McLean and Urist 1968, 61), so a 70 kg human will have a total surface bone crystal area of approximately 0.5 km^2! This implies that this vast mineral surface is bathed by only a few litres of body fluid, and thus that most metabolic processes must be the result of surface phenomena.

The calcium minerals in bone are poorly crystalline *in vivo*, as well as being small in size: in mature rat femur, the crystallinity has been estimated as 65% (McLean and Urist 1968, 65). Other phases may be present, including whitlockite ($Ca_3(PO_4)_2$), monetite ($CaHPO_4$), brushite ($CaHPO_4.2H_2O$), octacalcium phosphate ($Ca_8(HPO_4)_2(PO_4)_4.5H_2O$) and amorphous calcium phosphate, which may contain the structural unit $Ca_9(PO_4)_6$ (Williams and Elliott 1989, 323). In addition, substitution may occur, especially of the hydroxyl in hydroxyapatite by fluoride ions, to yield fluorapatite, which is the most stable of the apatites. Bone also contains significant quantities of carbonate (3-5% by weight) and citrate anions ($C_6H_5O_7^{3-}$; 1%), either as substituted carbonate-containing apatite ($Ca_{10}(PO_4)_6.CO_3$), or, more likely, as surface-adsorbed species on the apatite mineral (especially in the case of citrate, which is too large to substitute).

Bone metabolism

At the highest level, two major types of bone are recognised in most vertebrate groups: (a) cancellous, trabecular or spongy bone and (b) compact or cortical bone. Cancellous bone is characterised by a porous structure, consisting of a network of trabeculae (struts). The distribution of cortical and cancellous bone throughout the skeleton is governed largely by biomechanical considerations. In general, cancellous bone is found beneath cortical bone, surrounding the blood-rich marrow

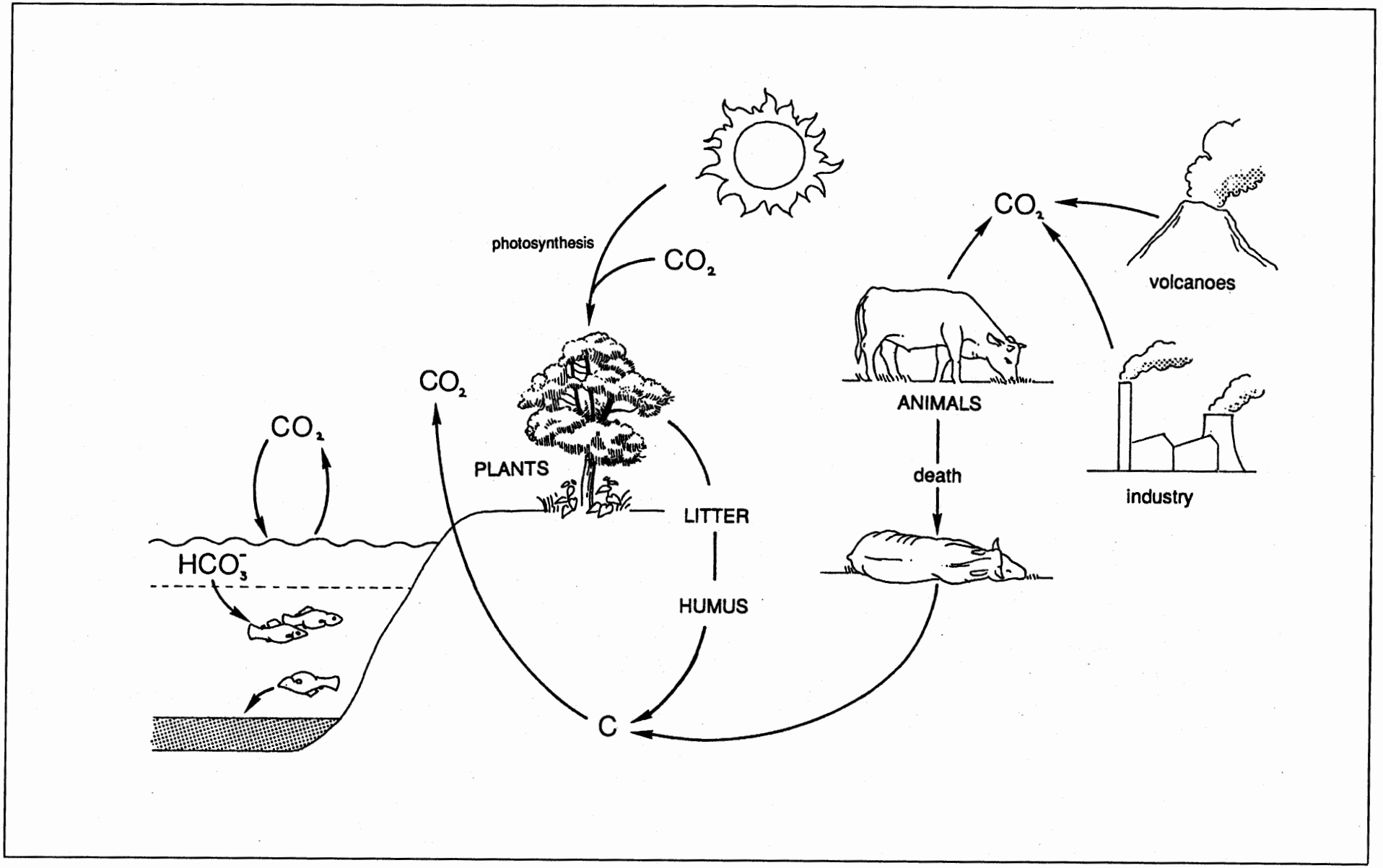


Figure 20. The carbon cycle.

at the epiphysial ends of long bones. Cancellous bone is supplied with blood by a network of arteries entering from all sides and branching into the bone marrow. For the external, cortical bone, four major types have been recognised: woven bone, lamellar bone, haversian bone and fibrolamellar (plexiform or laminar) bone (Currey 1984). In adult humans, haversian bone predominates, in which blood vessels and nerves, housed in vascular canals, are surrounded by a cement sheath and concentric layers of bone (the lamellae). Except in certain locations, living bone is covered by connective tissue—externally, by the periosteum, on internal spaces (e.g. bone marrow channels, cancellous trabeculae and haversian canals) by the endosteum. Growth involves deposition on the outer (periosteal) surfaces, as well as at the epiphyses (ends of bone), and resorption takes place from the internal (endosteal) surfaces.

When a living tissue, bone contains a number of specialised cells carrying out a variety of functions. Biomineralisation takes place through the activity of osteoblasts, which occur on the surface of growing or developing bone, in a continuous layer in active bone. Bone production proceeds by the deposition of bone mineral onto collagen fibrils. Mineralisation of hydroxyapatite from the extracellular fluid probably proceeds via an amorphous calcium phosphate precursor, with the Ca/P molar ratio rising from 1.5 to 1.67 in the fully mineralised hydroxyapatite. As the osteoblast becomes surrounded by calcified tissue, it becomes an osteocyte, which probably regulates the release of bone mineral into the bloodstream. The structural organisation of human bone (after the first year of life) results in new bone being laid down in lamellae, arranged in a cylindrical pattern around the haversian canal system, in units called osteons, which are usually orientated along the long axis of the bone. The collagen fibrils of each lamella run spirally along the axis of the canal. In a human femur, these osteon bundles are approximately 0.25 mm in diameter. The outer surface of compact bone is surrounded by a circumferential layer of osteons under the periosteum and the endosteum.

Osteoclasts are giant multinuclear cells which usually occur on the surface of the bone, associated with areas of bone resorption. They usually lie in lacunae, which are thought to result from erosion by the osteoclasts themselves. Resorption is the result of removal of both the mineral fraction (by acidic action, or the result of a chelating agent) and the organic matrix (as a result of the action of a collagenase enzyme, which breaks down and renders soluble the collagen). In a normal adult, approximately 3-5% of the skeleton is remodelled at any one time, with turnover being more rapid in cancellous bone (Armelagos *et al.* 1989, 235). The cycle of resorption and remineralisation can take from three months to a year, according to skeletal component, age and health.

In vivo, bone is bathed by the blood plasma and the intercellular fluid which, combined, make up 20% of the body weight. This serves to transport oxygen and carbon dioxide around the cells, and also to exchange minerals between the bone and the fluid. The intercellular fluid contains, in a 70 kg individual, approximately 500-700 mg of calcium ions, compared with 1.2 kg in the skeleton. Adult body plasma contains approximately 10 mg per 100 ml calcium (half as ions, half as protein complexes) and 3 mg per 100 ml total phosphorus (mostly in the form of HPO_4^{2-} ions). The recommended adult daily intake of calcium is 0.8 g, although as little as 20% of the dietary content may be utilized—the rest being eliminated in the faeces. The daily requirement of phosphorus is approximately 1 g (McLean and Urist 1968, Ch. XI).

Bone is therefore a reservoir for both calcium and phosphorus, allowing mobilisation via osteoclastic resorption when needed. Various other chemical elements, many with no known physiological function, reside in the skeleton, although sodium and magnesium may be accessed when needed by other tissues. Nearly half of all body sodium is stored in skeletal mineral, but potassium is not a bone-seeking element. Other ingested elements, especially strontium and lead, are stored in the skeleton. Fluoride ions have a high affinity for bone mineral, converting hydroxyapatite to fluorapatite.

Biochemical background

Carbon dioxide fixation pathways in plants (Figure 20)

Photosynthetic plants trap carbon dioxide and assimilate it by one of the following mechanisms, or occasionally by a combination of two:

1. Calvin-Benson cycle (C_3 photosynthesis)

The first step is the carboxylation (i.e. the addition of CO_2 to an existing organic molecule) of the 5-carbon sugar ribulose 1,5-biphosphate (RuBP). This forms an unstable 6-carbon compound, which hydrolyses spontaneously to form two molecules of 3-phosphoglyceric acid (3-PGA). The 3-PGA thus produced is further phosphorylated by the enzyme phosphoglyceryl kinase to yield 1,3-diphosphoglyceric acid (1,3-dPGA), the phosphate being donated by adenosine triphosphate (ATP). The dPGA so produced is reduced by nicotinamide adenine dinucleotide phosphate ($NADP^+$) to give 3-phosphoglyceraldehyde (3-PGAL). A fraction of this PGAL is further converted by triose phosphate isomerase to dihydroxyacetone phosphate (DHAP). Fructose 1,6-biphosphate (F 1,6-BP) is synthesised from the remaining PGAL and the synthesised DHAP, and glucose is produced from this by a sequence of enzymatically-catalysed reactions. Algae, autotrophic bacteria, and most terrestrial and aquatic higher plants assimilate CO_2 using this mechanism.

2. Hatch and Slack cycle (C_4 photosynthesis)

In this mechanism, there is a preliminary carboxylation in the mesophyll cells of the leaf. Carbon dioxide is trapped during the day and carboxylates the three-carbon organic acid phosphoenol pyruvic acid (PEP), giving a four-carbon acid, malic acid. This is transferred to the cells surrounding the vascular bundle (the bundle sheath cells), where it is decarboxylated to release CO_2. This is then assimilated by the Calvin-Benson cycle described above. The C_4 cycle is found mainly in tropical grasses and is an adaptation to exploit higher light levels and temperatures and to counter limited water availability.

3. Crassulacean acid metabolism (CAM)

A third pathway, mainly found in succulents, and important only in certain tropical ecosystems, involves the synthesis of malic acid by carboxylation at night, and the subsequent daytime breakdown of the malic acid to liberate CO_2 for photosynthesis. In darkness, stored carbohydrates are broken down by glycolysis to PEP, which is carboxylated to malic acid, which is stored in the vacuole. In the daytime, the malic acid is decarboxylated to yield pyruvic acid and CO_2, which is then used in the normal Calvin-Benson cycle.

Carbon isotopic fractionation

Variations in the isotopic composition of natural carbon are due to two fractionation mechanisms:

(i) a kinetic effect, resulting in the depletion of the heavier ^{13}C isotope during the assimilation of CO_2 by photosynthetic plants;

(ii) an enrichment of ^{13}C in marine bicarbonates, and eventually in limestone, when compared with atmospheric CO_2.

The main features of the observed variations in the $^{13}C/^{12}C$ ratio in plant material can therefore be explained by systematic differences between marine plants, C_3 terrestrial plants, C_4 tropical plants, and CAM plants (Van der Merwe 1982). Since the ratio of $^{13}C/^{12}C$ is small, it is normal to discuss variations in this ratio using the δ notation, where $\delta^{13}C$ is defined as follows:

$$\delta^{13}C = \left[\frac{(^{13}C/^{12}C)\ sample}{(^{13}C/^{12}C)\ standard} - 1 \right] * 1000\ per\ mil$$

where the reference standard is the ratio of $^{13}C/^{12}C$ in a particular carbonate rock (Pee Dee Belemnite, PDB). A similar expression is used to define $\delta^{15}N$, with the ratio $^{15}N/^{14}N$ replacing the carbon ratio. For nitrogen the reference standard is taken to be the ratio of $^{15}N/^{14}N$ in atmospheric nitrogen. Using this notation, increasingly positive δ values imply an enrichment of the heavier isotope, and *vice versa*.

Dietary implications

Because of the discrimination against the heavier isotopes of carbon in terrestrial C_3 plants, the $\delta^{13}C$ values for these plants are more negative than those found in atmospheric carbon dioxide. Thus $\delta^{13}C$ in atmospheric carbon dioxide is -6 to -8 per mil, whereas in terrestrial C_3 plants it is between -22 and -34 per mil (Tauber 1981; DeNiro and Epstein 1978). Animals feeding on these plants should show similar values, although observations by Van der Merwe (1989) have shown a difference of +5 per mil in animals feeding on C_3 plants, and +6 per mil for C_4

consumption. This difference (fractionation) probably results from isotopic variation in the dietary components: in the same organism, protein and carbohydrates are found to have the same isotopic value, but lipids are isotopically lighter. Normally, lipids are not used in the manufacture of bodily protein (in this case, collagen), but care must be taken to ensure that the correct fractions are being compared (Chisholm 1989).

In a marine environment, the absorption of CO_2 and the subsequent production of hydrogen carbonates and eventually carbonates is governed by kinetic factors which enrich the carbonate in the heavier isotope, giving marine carbonates a $\delta^{13}C$ value of around 0 per mil (i.e. more positive than atmospheric CO_2). When marine organisms assimilate these carbonates (and hydrogen carbonates) by photosynthesis, there is discrimination against the heavier isotope, giving a δ value of around -10 to -18 per mil in marine plants, again becoming less negative as the carbon is passed up the food chain.

There should therefore be a simple distinction between the $\delta^{13}C$ values of animals whose food chain is based on either C_3 or C_4 terrestrial plants or on marine plants, and it is this distinction which has been exploited in the carbon isotopic characterisation of the diets of ancient communities. Chisholm (1989) has suggested the use of collagen $\delta^{13}C$ end-point values of -20, -7 and -13 per mil respectively for C_3, C_4 and marine communities, allowing the approximate calculation of the relative importance of each food source in cases where one variable may be eliminated, or the contribution calculated from other information.

Further refinement in this analysis may be possible, since a number of amino acids are considered to be essential, i.e. they are required for protein formation, but cannot be synthesized by the body. These essential amino acids are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine (McGilvery and Goldstein 1983, 818). These must be obtained directly from dietary intake of protein and therefore comparison of the isotopic composition of one or more of these amino acids with that of the 'non-essential' components may yield further detail (Sillen *et al.* 1989).

Nitrogen isotope systematics (Figure 21)

Based on their nitrogen assimilation mechanism, living organisms can be divided into three categories:

(i) Atmospheric N_2-fixing organisms (legumes and cyanobacteria)

Since atmospheric nitrogen is the defined standard for the isotopic ratio, and little fractionation occurs during nitrogen fixing, $\delta^{15}N$ is approximately 0 for these organisms. This should be true irrespective of whether the plants are terrestrial or marine—published δ values for terrestrial nitrogen-fixing plants show a mean of +1 to +2 per mil, whilst that for marine nitrogen-fixing plants is between 0 and +3 per mil (Schoeninger and DeNiro 1984). N_2-fixing cyanobacteria and the zooplankton which feed upon them have lower $\delta^{15}N$ values than the phytoplankton which do not directly fix nitrogen, and the corresponding zooplankton which feed upon them (Wada 1980). Fish feeding on coral reefs, areas noted for large concentrations of cyanobacteria, have $\delta^{15}N$ values much lower than fish of equivalent trophic position in the open ocean (Schoeninger and DeNiro 1984).

(ii) Terrestrial organisms (other than those subsumed in (i))

The second group contains the majority of terrestrial plants (and consequently the animals which feed directly or indirectly on them). The major sources of nitrogen for terrestrial plants are inorganic nitrates and ammonium ions. Nitrogen uptake by plants involves very little fractionation, and most non-nitrogen fixing plants have δ values between 0 and +6 per mil (DeNiro and Epstein 1978).

(iii) Marine organisms

The third group contains all the marine organisms, excluding cyanobacteria. In deep ocean, denitrification (reduction of nitrates and nitrites to nitrogen) occurs, with relatively large fractionation. The remaining nitrates are thus enriched in ^{15}N, and therefore the nitrate utilised by plankton at the base of the marine food chain is richer in the heavier isotope than that used by terrestrial plants. This enrichment is carried up the food chain, causing marine phytoplankton, zooplankton and fish to have $\delta^{15}N$ values more positive than those of terrestrial organisms (Sweeney *et al.* 1978).

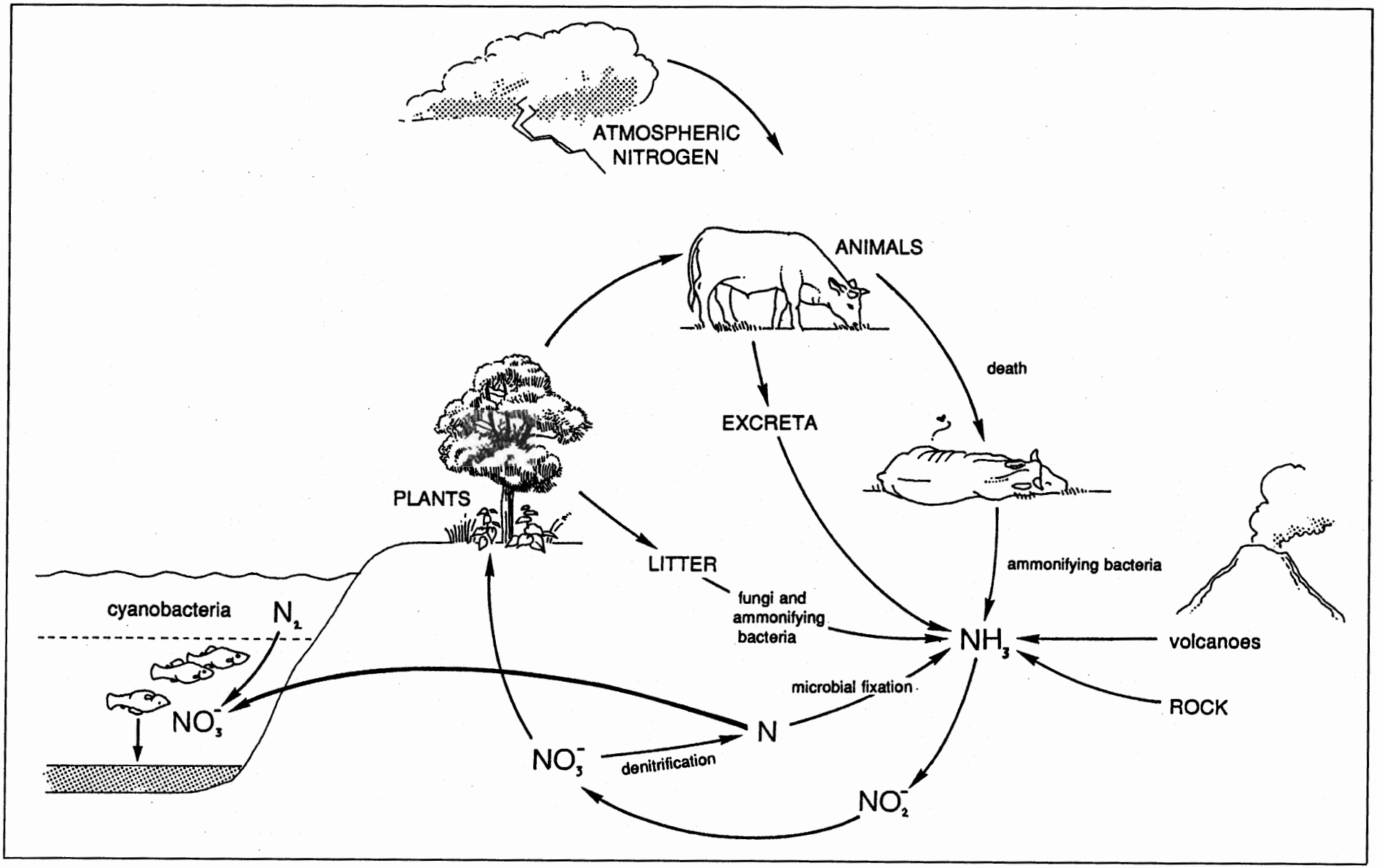


Figure 21. The nitrogen cycle.

Dietary implications

This suggests that the stable nitrogen isotopic ratio in bone collagen can be used to distinguish between three potential food sources: nitrogen-fixing plants, terrestrial plants (non nitrogen-fixing) and marine plants (non nitrogen-fixing). The biochemical mechanisms of nitrogen assimilation are, however, much less well understood than those relating to carbon assimilation, although the position is potentially simpler in view of the fact that nitrogen only occurs in dietary protein. In a study of both prehistoric and historic human bones, Schoeninger *et al.* (1983) showed that historic Eskimo populations with a primarily marine food intake had collagen $\delta^{15}N$ values ranging from +17 to +20 per mil, whilst those in historic European and Mesoamerican agriculturalists ranged from +6 to +12 per mil.

Diet and trace elements in bone

In addition to the major elements required to support life (calcium, magnesium, phorphorus, sodium, potassium and chlorine), fifteen trace elements are now regarded as essential: chromium, cobalt, copper, fluorine, iodine, iron, manganese, molybdenum, selenium, zinc, arsenic, lithium, nickel, silicon and vanadium (Armelagos *et al.* 1989, 240). These elements often take part in enzymic catalysis, and deficiencies can result in various abnormalities, although excesses can also be deleterious. Other elements absorbed from the diet can be regarded as extraneous (e.g. strontium), or disadvantageous (e.g. lead and cadmium), and are either excreted or deposited in the skeleton.

More than 99% of the strontium in vertebrate animal tissue is found in the mineral component of the bone (Schroeder *et al.* 1972). In animals, strontium is discriminated against (by renal excretion) in favour of calcium for the synthesis of bone tissue (Comar *et al.* 1957). Price *et al.* (1985) reported that the ratio of strontium to calcium in the bone of a herbivore is approximately five times lower than that ratio in plants consumed by the animal. Carnivores further discriminate against strontium, so that their bones exhibit a lower ratio still. Omnivores exhibit strontium levels intermediate between those of herbivores and carnivores, in proportion to the relative importance of plants and meat in their diet; this should be the case with human strontium levels. The situation is somewhat different in the marine environment, where higher strontium is found in organisms as a result of the element's relative abundance in oceanic waters (Rosenthal 1963). Palaeodietary studies of coastal populations from Alaska have suggested that strontium concentrations can be used to distinguish between the importance of marine and terrestrial organisms in subsistence (Connor and Slaughter 1984).

Zinc is also potentially a useful palaeodietary indicator. Hatch and Geidel (1985) suggest that high zinc levels in bone arise from a larger dietary contribution from animal sources (since blood and flesh are rich in zinc). Gilbert (1977), however, reported that both strontium and zinc can reach extremely high levels in certain nuts and shellfish, as can other elements such as vanadium, copper and manganese. In addition, humans subsisting wholly or largely on a marine diet might ultimately be expected to have higher zinc levels than those subsisting on a terrestrial diet, through the concentrating effect of sea-water as noted above. Magnesium, being another alkaline earth metal, has also been suggested as a possible dietary indicator (Lambert *et al.* 1979). Lambert *et al.* (1982) suggested that the elements most closely connected with diet are strontium, zinc and magnesium, and they noted that similar correlated levels of all three were found in both the ribs and femora of the same individual.

Applications of palaeodietary reconstruction

There is an extremely large and rapidly-growing body of literature on palaeodietary reconstruction, best summarised in Price (1989). Trace element studies have been carried out on European populations (Antoine *et al.* 1988a; Runia 1987; Tauber 1981), North America (Hatch and Geidel 1985; Lambert *et al.* 1979; 1982; Schoeninger 1979; and others), and in the Middle East (Schoeninger 1981; 1982). Stable isotope analysis of bone collagen has been widely used since its introduction by Vogel and Van der Merwe (1977) to reconstruct the diets of prehistoric humans and animals—e.g. Ambrose and DeNiro 1986; Antoine *et al.* 1988a; 1988b; Burleigh and Brothwell 1978; Chisholm *et al.* 1982; 1983; Sealey and Van der

Merwe 1985; Van der Merwe and Vogel 1978; and other papers in Price (1989).

Bone diagenesis

It has become increasingly clear in all this work, and has occasionally been forcefully pointed out (e.g. by Hancock *et al.* 1989), that buried bone may be subject to considerable alteration, and many authors have doubted that the dietary signal is retained in these cases. Considerable effort has been expended on the detection and elimination of diagenetic effects. Several strategies have been recommended, but none has been proposed as uniformly applicable.

The simplest case appears to be that of collagen. It has been known for many years that collagen gradually disappears from buried bone—in fact, the gradual removal of protein (monitored by the decrease in nitrogen content) has been used as a method for the relative dating of bone (Lynch and Jefferies 1982). It has generally been accepted that the isotopic ratios $\delta^{13}C$ and $\delta^{15}N$ of bone collagen are free of diagenetic effects (Chisholm 1989). Ambrose (1990) has demonstrated that the C:N ratio in bone 'collagen' remains at modern levels (2.9–3.5, expressed as an atomic ratio) providing a significant quantity (greater than 2% of the total bone weight) of 'collagen' remains in the bone. He uses the term 'collagen' to refer to the whole of the gelatinized residue from bone, which may be derived from other proteins in addition to collagen. It is possible that the 2% cut-off for the stability of the C:N ratio implies that at this stage only non- collageneous protein is left. This work suggests that, providing structurally-intact collagen is obtainable from the bone, the isotopic ratios are likely to be unchanged from the same ratios *in vivo*, as required for palaeodietary research.

The situation with the trace elements in bone is considerably more complicated, and the dietary significance of measurements on excavated bone is still the subject of debate. Several authors have studied variation in trace element composition as a function of skeletal component (e.g., ribs versus femora, Lambert *et al.* 1982), and variations in trace element distribution in bone cross-section (Lambert *et al.* 1984). These latter authors found iron, aluminium, potassium, manganese and magnesium to become concentrated along the outer margins of the bone, indicating that these were post-depositional contaminants, but concluded that the uniform distribution of zinc, strontium, lead, sodium and calcium confirmed that these elements are not enriched *post mortem*. Analysis of associated soil, however, showed increased levels of calcium and magnesium around the bone, indicative of leaching.

Lambert and others have asserted that careful cleaning and removal of the outer layer of bone yields material which can be safely analysed and interpreted from a dietary viewpoint. Measurement of the stable isotope ratios of strontium ($^{87}Sr/^{86}Sr$) in modern and prehistoric marine and terrestrial animals has, however, yielded evidence for the *post-mortem* contamination of buried bone by strontium from ground waters (Nelson *et al.* 1986). They studied the strontium content in the bones of modern seals and reindeer, and found the seal bone to be richer in strontium (about 1000 ppm, compared with less than 200), in accordance with the model of the transmission of strontium through trophic levels outlined above. In excavated bone, however, there was no difference in strontium content between seal and reindeer—both had of the order of 900–1000 ppm. The strontium isotopic ratio was also different in modern terrestrial and marine mammals, but uniform in excavated bone. This is interpreted as being the result of the interaction of the buried bone with a common source of strontium, probably groundwater.

Several studies have concentrated on the mineralogy of excavated bone. In view of the poor crystallinity and large surface area of living bone, it is not surprising mineralogical changes take place *post mortem*, which will affect the trace element composition (Pollard *et al.* 1991). Hancock *et al.* (1989) and others have stated that deviations from the figure of 2 for the Ca/P weight ratio in fired archaeological bone signifies diagenesis, and Sillen (1989) suggests that an increase in Ca/P may result from recrystallisation of the hydroxyapatite to other calcium phosphates of differing solubilities, and the deposition of calcite crystals into the bone. It is not clear what effect these processes will have on the dietary indicators—strontium, zinc, magnesium, and so on, but it is likely that recrystallisation will reduce the trace element concentrations in hydroxyapatite (since recrystallisation is a standard purification technique in chemical synthesis), although external contamination might subsequently

increase them, depending on the composition and pH of the groundwater. Tuross *et al.* (1989) have shown that bone strontium levels and hydroxyapatite crystal size both increase with time for animal skeletons exposed on the surface for ten years.

It has become common to analyse soil from the burial context in an effort to assess the elemental exchange between soil and bone. Pate and Hutton (1988) have emphasised the need to take soil chemistry into account in this process, considering the availability of exchangeable ions rather than the total soil composition. This requires an understanding of the physics and chemistry of soil, including factors such as the soil pH and temperature, the presence or absence of organic matter, as well as the geochemistry of the ionic species present and local groundwater movement.

The microbiology of buried bone

Clearly, the diagenesis of excavated bone is still an area requiring considerable research effort. A particularly important aspect which has so far received very little attention is the effect of microbial and fungal attack on buried bone. Very few chemical studies have taken into account the implications of such microbiological decay: the results of such attack are often recognised, but cannot be included in the assessment of diagenesis because of the lack of detailed microbiological information (e.g. DeNiro 1985; Price *et al.* 1985; Pate and Hutton 1988). Saprophytic soil fungi (including *Mucor* and *Fusarium* species) have been reported as being associated with microscopic focal destruction (tunnelling) in archaeological bone (Marchiafava *et al.* 1974; Hackett 1981; Piepenbrink 1986; Grupe and Piepenbrink 1988), but no model has been put forward for the mechanism involved.

Tunnelling is probably the result of a process similar to osteoclastic resorption, and the bone mineral is probably dissolved by organic acids produced by microorganisms as a by-product of metabolism. If the microorganisms are utilising the bone protein as their only source of both organic nitrogen and organic carbon, as seems likely, then those microorganisms capable of producing collagenase enzymes (i.e. enzymes which cleave the collagen helix) are most likely to produce tunnelling, since this will provide a means of attacking the collagen and breaking it down for utilisation. The number of bacteria and fungi known to be capable of producing collagenase is slowly increasing, but detailed work on bacterial attack is only just beginning (Child and Pollard 1991). Recent work (Child, in preparation) has isolated several micro-organisms from soil, human faeces and extracted human teeth, which are capable of producing collagenases at 10°C (taken to be a representative burial temperature in temperate regions). One of these (*Pseudomonas fluorescens* from soil) which produces a very active collagenase, inoculated onto sterile pig carpals has caused considerable degradation within nine weeks.

The implications of this and related work for those investigating extracted archaeological protein could be significant. The work on bacterial attack was initiated as a result of an unexpected scatter in the determination of age at death using the racemisation of aspartic acid in dental collagen (Gillard *et al.* 1991). Blind tests on modern individuals gave good results, but identical measurements on exhumations of known age from a church crypt (Christchurch, Spitalfields, London; time elapsed since death approximately 200 years) occasionally gave deviant ages, even in multiple determinations from the same individual. Since deviation was observed in both directions, microbiological activity was suspected, even in this relatively uncomplicated burial environment. Amino acid sequencing of the extracted collagen showed no apparent change, and consequently microbiological racemase activity was considered; this work is progressing in parallel with the detection of collagenase production.

It is known that microbiological attack on protein can take one or more forms, including cleavage into large fractions, gradual reduction of chain length (both resulting in increased solubility), removal and modification of specific amino acids and peptide sequences, and racemisation. It seems likely that work of this nature will be necessary to study many aspects of archaeological protein chemistry, including radiocarbon dating and stable isotope palaeodietary reconstruction. Little work has yet been attempted on the trace element implications of microbiological colonisation, although the possibility of introduction of contaminants has been considered in connexion with the spread of fungal hyphae through the bone.

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Rapid recording of archaeological insect remains—a reconsideration

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Summary

Methods for recording insect assemblages which have been employed in the Environmental Archaeology Unit (EAU) are outlined, with particular reference to those used for work on material from the 16-22 Coppergate, York, site. Rapid recording techniques have been adopted in order to examine sufficient samples to provide adequate representation of complex sites within available funding and realistic time-scales. The effectiveness and reliability of these methods are discussed; it is stressed that they require considerable experience and are not appropriate to the novice. Various semi-philosophical points concerning extensive and intensive studies of bioarchaeological remains are made in the hope of stimulating debate in this sensitive area.

Introduction

In 1986 the EAU entomological team contributed to *Circaea* on the subject of the evolution of the rapid recording techniques adopted in the unit in response to the need to cope very quickly with large numbers of assemblages of insect fossils (Kenward *et al.* 1986). The first large site recorded using methods of this kind has now been published: the General Accident site, 24-30 Tanner Row, York (Hall and Kenward 1990), from which about 300 insect assemblages were recorded. For this site it was concluded that the recording method which was applied to most of the samples ('scan' recording, outlined below) was very satisfactory. The methods were developed, however, during work on material from 16-22 Coppergate, York. This huge corpus (well over 600 insect groups have been recorded by one method or another) has now been prepared for publication in *The Archaeology of York* (Kenward and Hall, forthcoming).

Coppergate was a typical 'waterlogged' urban site, with deep, very complicated stratigraphy covering a long time-span (Roman to medieval). Most phases presented a variety of feature types requiring insect analyses, and—for the Anglo-Scandinavian ('Viking') period—there were four tenements which needed to be considered separately. In order to obtain useful representation of this plethora of features, it was necessary to collect and process large numbers of samples; it was clearly essential to examine several pit fills per tenement per phase and to see a series of representatives of the front and back of each tenement, for example. The numerous samples examined for insects just about provide an adequate cover of most of the excavated part of the site, although inevitably there were too few from certain phase/feature type combinations and unnecessary duplications from others.

During the final stages of practical work on the material from Coppergate, the majority of those insect assemblages which had initially been recorded using various rapid (but at the time not formalised) techniques were re-examined in order to search for some remains, such as fleas, lice, scale insects and beetle larvae, which had been poorly or erratically recorded on first inspection, and also to check and improve upon the recording of assemblages of which only a 'rough scan' (see below) had been made earlier. At about the same time a classification of recording methods was erected for use in the technical report (Hall and Kenward, forthcoming). This classification and definition of methods was obviously also desirable to ensure greater standardisation in future.

The EAU is increasingly being required to carry out 'evaluation' work on samples from preliminary excavations of sites threatened by development, and this necessitates even faster recording if it is to be completed sufficiently quickly to meet the very short contractual deadlines typically imposed, quite apart from the limited funding available. There is also a need to employ extremely rapid assessment methods in the early stages of post-excavation

work. It is thus timely to present a more systematic account of the range of recording methods employed in the EAU and to evaluate them, in terms of (a) accuracy of species lists and of the interpretations resulting from them, and of (b) relevance to work carried out within the stringent financial and time limits of the early 1990s.

This discussion is primarily intended to place the methods on record, together with my observations on their strengths and weaknesses. It cannot be an objective report on their precision, since project funds do not allow for large-scale methodological investigations. I hope to be able to consider some aspects of the accuracy of quantification and of calculated statistics elsewhere. I suspect that this discussion will have increasing relevance to the recording of archaeological plant and animal remains in general as more bioarchaeologists are obliged to some extent to forgo precision in favour of speed in their work. Publishing these methods may also prompt other workers to challenge their validity, but if such procedures—or something like them—are *not* considered appropriate and a return to immensely slow ones is advocated, then either some new source of funding must be found or the greater part of the material exposed during archaeological excavations will have to be left completely unexamined.

In judging any method of recording bioarchaeological remains it is necessary to consider the nature of the material and of the 'sample' being studied. Chance phenomena play a major part throughout the formation of short-lived insect communities and hence of the resulting death assemblages, in their recovery through archaeological excavation, and in their examination in the laboratory. In living communities of insects, there is great spatial variation on a small scale. Whether or not insects living at any depositional locus are preserved depends on luck, a large proportion of them probably emigrating and being lost to the record. Sample location is largely a matter of chance, as is the subsequent removal of the particular subsample of material analysed in the laboratory. The 'sample' is a single lump of deposit which is assumed to be representative of a layer, not a series of collections such as that upon which a field ecologist would expect to base quantitative observations. Remains, many identifiable, capable of passing through a 300 µm mesh, are likely to be lost during sieving. Extraction by paraffin flotation from the sieved material is probably at least 95% efficient in MNI (minimum number of individuals) terms in most cases. A small proportion of the fossils are inevitably overlooked during sorting unless and inordinate amount of time is devoted to the task. It may be argued, therefore, that to place great significance on minor variations in recovered assemblages is foolhardy, and that strongly characteristic or consistently reproducible assemblages are required before archaeological information may be deduced. Against such a background, is it important to record the exact identity of every single fragment (as was averred by the author early in his career) when *many* more assemblages can be recorded by using cruder methods? Ten assemblages recorded tolerably well will give a better picture of the consistency or variability of past conditions than one recorded to what is probably a spurious level of accuracy, surely?

The recording methods

The range of quick recording methods currently employed for insect remains in the EAU evolved slowly and erratically from very rapid recording (here termed *rough scanning*) of 'test' subsamples (Table 5). This was designed to provide only enough information for a decision to be made as to whether to process a sample for what was then the conventional recording method (now termed *detailed recording*, see below). In rough scanning, recording was restricted to noting the approximate abundance of the taxa seen during a quick inspection of the flot (*sensu* Kenward *et al.* 1980), and writing down a general impression of the nature of the material and its potential for interpretation. Rough scanning was very crude, rather subjective, but it was never intended to be any more thorough and was wholly successful in achieving its intended purpose.

It has been shown by re-examination of a large number of assemblages that, as anticipated, many remains were missed during rough scanning, and that quantification was occasionally very poor. Indeed, as few as half the taxa present were noted during the rough scanning of some of the samples. This method has proved generally reliable in capturing the ecological 'flavour' of assemblages. Although not used any more *as such*, it has survived in a modified and more explicitly subjective form as *assessment recording* (see below); *rapid scanning* (fully or

semi-quantitative) may often be more appropriate, however, providing as it does a more complete record and permitting the calculation of assemblage statistics, albeit only approximate.

The advantages and limitations of the crude early 'scanning' lead to the adoption of *scan recording*, employed as the standard method at present, and *semi-quantitative scan recording*, still found useful when time is short or material is of low priority.

The recording methods employed at some stage of the Coppergate project are outlined below (a description of assessment recording is added, since it is frequently employed in current work). These techniques apply to those insect groups upon which the 'main statistics' used for interpreting sample assemblages are based, namely adults of beetles and the majority of bugs (for the time being, those which in about 1987 it was feasible to quantify); other groups are mostly recorded semi-quantitatively. The methods are discussed in approximately descending order of precision, and are summarised in Table 5. It is not intended to imply that all the material from any one site should be recorded by any one of these methods; they need to be applied according to the nature and importance of particular phases or feature types, for example. Thus all the first priority samples might be scan recorded, but the remainder assessment recorded to ensure that no significant assemblages were overlooked; subsequently a few of the samples might be re-examined by detailed recording of subsamples fully processed (in the way described by Kenward *et al.* 1980) to address particular problems.

It must be re-emphasised that these methods, other than the traditional 'detailed' recording (the spirit of which was absorbed while working in the Coope-Osborne school in the Department of Geology, University of Birmingham) and assessment recording, arose in an informal way during work on the Coppergate site. All were formalised and named at a late stage of the project. Material recorded earlier formed a strongly noded continuum and most of the lists could be fitted fairly confidently into the classification, doubtful cases being assigned to the lower level of recording. For those methods where remains were recorded in alcohol (IMS), squared or lined paper was stuck to the underside of the Petri dish in which the flot was examined to facilitate systematic inspection.

Detailed recording: Normally applied only to 'fully processed' material, extracted using the methods outlined by Kenward *et al.* (1980, 8–14), and not by the abbreviated paraffin flotation method discussed by Kenward *et al.* (1986). An attempt is made to identify as far as possible every sclerite (of adult Coleoptera and Hemiptera, at least) retained by a sieve of 300 µm mesh aperture. This method can be very time consuming, taking one to several weeks for a single assemblage in some cases (Kenward *et al.* 1986, table 9); to set the perspective, a single sclerite (a head, for example), or set of genitalia, might sometimes take half a working day or more to identify, involving the preparation or dissection of reference material, obtaining literature, or a museum visit. Chasing the identity of more obscure material (beetle larvae, lice, aliens of any group) may involve weeks of work, gaining access to reference material, liaising with specialists and becoming familiar with the group concerned. Enjoyable and educational as such work is, it is now quite obviously generally impracticable to use detailed recording in projects which are funded by developers or by English Heritage; I feel it is, in any case, inappropriate to the aims of much of our work.

(Fully quantitative) scan recording: Normally applied to flots extracted using 'test' processing, with one paraffining stage (Kenward *et al.* 1986). An attempt is made to record every individual but identifications are carried only as far as is compatible with rapid working; rare or difficult specimens are not identified *unless they appear to be of importance in archaeological interpretation* (the contradiction seemingly implied by this last statement is recognised; the point is discussed below). Scan recording can be carried out either on successive aliquots of the flot in alcohol in a Petri dish, when all sclerites must be recorded, or on assemblages which have been picked out on to damp filter paper and arranged roughly into taxonomic groups (typically by a technician), and which can then be quantified using a minimum number (MNI) estimation, when there is, of course, no need to record sclerites. The first method is considerably faster overall, but remains are more likely to be overlooked and the whole task requires a high skill level; the second method requires a greater total time, but fewer fossils will be missed and the recording stage (demanding

Name	Method	Comment
Detailed	Attempt to identify every sclerite as far as possible and to calculate precise MNI	Very time consuming, applicable only to some research work; essential in training
Scan	Record MNI by noting sclerites in IMS or by quick count on damp filter paper	Standard method in EAU; can be almost as accurate as detailed recording. Fast. Statistics very reliable
Semi-quantitative scan	As scan, but using a five-point scale of abundance	Useful for many applications. Fast. Statistics can be used with some confidence
Rapid-scan	Recording in IMS, making best approximation feasible without recording individual sclerites	Very fast. Sometimes appropriate. Many remains may be missed. Statistics may be used, but with care
Semi-quantitative rapid-scan	As rapid scan, but using a five-point scale of abundance	As rapid scan, but even more care needed in use of statistics
Rough-scan	Very rapid inspection of flot, recording subjective impression and approximate abundance of observed species	Results variable, useful for choosing samples for further work, but now redundant. Statistics to be treated with great care
Non-quantitative scan	No attempt to make a full species list. Primarily for incorporation of notable records in databases when only (subjective) general nature of assemblage otherwise recorded	Sometimes useful for noting important taxa in other unrecorded assemblages but superseded by assessment recording for other purposes
Assessment	Flot examined in IMS, major or significant taxa and abundance of ecological groups noted subjectively	Very useful for ensuring that there is a record of material from evaluations and assessments. Limited interpretation is possible. Danger of excessive subjectivity.

Table 5. Summary of recording methods used for insect remains during the 16–22 Coppergate project. Assessment recording—adopted subsequently—is included for completeness. The 'pilot' samples of Kenward et al. *(1986, table 9) are subsumed in 'rough scans' (now replaced by assessment recording), while the term 'test', used in that paper, is now reserved for a processing rather than recording method.*

specialist skills) is much faster (the specialist must scan the flot quickly, however, as a check and to record fossils which cannot reasonably be picked out). Quantification is normally absolute, but numbers of very abundant taxa (with, say, 30 or more individuals) may occasionally be estimated approximately to save time.

Semi-quantitative scan recording: The methodology is essentially as for scan recording, except that quantification is on a five-point scale of abundance: 1, 2 or 3 individuals, or 'several' (estimated 4–9) or 'many' (estimated 10 or more). The last two are converted to 6 and 15 respectively for the calculation of statistics (see below for a discussion of this apparently dubious process). In practice, a mixture of scanning and semi-quantitative scanning has often been applied, with absolute counts or approximate estimates being made where practicable, and 'several' or 'many' estimates being used where quantification is more difficult or it is necessary to finish recording a sample quickly for some reason. There is obviously little point in using semi-quantitative recording when assemblages have been picked out on to filter paper, since (at least fairly accurate) MNI estimation is then easy. For certain kinds of material, especially large urban decomposer-dominated groups, semi-quantitative scanning, with approximation of very large numbers, is perhaps often the most appropriate response to the stringencies of poorly funded projects.

Rapid-scan recording: Applied where lack of time or low priority of the material means that

more accurate recording cannot be justified, rapid-scan recording is an improved direct successor to the original rough scanning. The flot is examined in aliquots in a Petri dish and the remains quantified approximately, to the best standard practicable without listing individual sclerites. Sorting is not as meticulous as for the previous three methods and it is accepted that some fossils will be overlooked, that the oversights may not be wholly random, and that the estimation of numbers will sometimes be wrong. The resulting lists may be used, albeit cautiously, for the calculation of approximate statistics (see below). There are reservations, discussed below, concerning this and the next method.

Semi-quantitative rapid-scan recording: In practice this rather than rapid scanning has normally been used. The methods are the same, but quantification is on the five-point scale. Assemblages can be recorded extremely quickly, but with an obvious penalty in accuracy of the lists and (probably to a lesser extent) of the statistics calculated from them.

Rough-scan recording: Discussed above; now redundant. Rough-scan lists for samples from 16–22 Coppergate have been re-recorded to a higher level where practicable, the remainder being demoted to non-quantitative status.

Non-quantitative scanning: Sometimes employed as a way of noting the general nature of an assemblage in a very crude way, but originally introduced to allow interesting species records to be incorporated into the site database (prepared using a system, described by Kenward, unpublished software and user guide), usually in the case of odd samples (duplicates, perhaps, or 'spot finds') from sites otherwise mainly recorded by one of the methods previously listed. It is useful for the second purpose but generally not used otherwise since the advent of assessment recording.

Assessment recording: This represents a development of rough scanning, designed for application to assessments prior to the main phase of work, either to material collected from exploratory 'evaluation' excavations (of developer-funded sites) or to selected samples from a large corpus in store in the post-excavation assessment stage of an excavated site, following 'MAP2' (English Heritage 1991). Such material must be dealt with extremely quickly. It must be emphasised that the method demands that the recorder is sufficiently familiar with the material to identify most remains at a glance and to recognise ecological groupings subjectively. The flot, or part of it, is examined in aliquots in alcohol. A note is made of common or ecologically significant species, and of the communities present, quantification being restricted to expressions such as 'dominant' or 'a few'. Most flots can be recorded in a few minutes in this way, and the results have been found satisfactory for the preparation of evaluation reports (which include a crude interpretation), for the selection of deposits requiring further investigation, and for determining the scale of work likely to be required in the main post-excavation stage. There can be no objection to using this method for strictly exploratory work, but the dangers of employing records made in this way for report preparation are recognised. Unfortunately, I fail to see an alternative which is feasible given the time-scale and funding of evaluations of sites threatened by development. Few of the sites so recorded will receive any further funding for archaeological excavation, so it is better to have a subjective record of this kind than none at all.

Discussion

Most of the methods listed above might be considered a poor or very poor substitute for 'doing the job properly' (i.e. detailed recording). In fact, while I believe that for some research applications there is certainly a place for 'detailed' recording, and while adoption of that method is essential during the training of every researcher, there are good reasons for applying the less time-consuming techniques in the great majority of cases.

For most purposes, especially where acquisition of *archaeological* information from large and complex sites is paramount, I have argued that recording numerous assemblages from many and diverse archaeological deposits in a small amount of time is the primary requirement. For this, quantitative scan recording is in my view ideally suited. Where work is essentially routine it is often hard to justify more than semi-quantitative scan recording, which can provide a reasonably reliable basis for the calculation of statistics. I do feel that it is desirable to detail- or, perhaps more realistically, very carefully scan record, a range of material from a major site early in any full study, if only in order to become

acquainted with its fauna; the assemblages from most occupation sites, particularly urban ones, tend to be qualitatively rather uniform, so this process of 'learning' the fauna is entirely practicable. I should perhaps confess that the lists from my current scan recording are probably at least as accurate as those I made by detailed recording in the 1970s, as a result of gradually increasing familiarity with the range of taxa encountered on occupation sites in general.

One problem which arises from scan recording in IMS is related to 'difficult' groups which would normally be divided into (probably) monospecific 'types' for quantification purposes. These include, for example, *Cryptophagus* species and Aleocharinae. It is relatively easy to divide these up into types on filter paper, where they can be seen *en masse*, but hard to retain an image of all the types when they are seen isolation while being recorded in spirit. In practice, a brief description has generally been noted, and the likelihood of some inaccuracy is accepted as inevitable.

The matter of employing data from assemblages recorded other than fully quantitatively requires some consideration. Semi-quantitative recording of organisms is, of course, not new. Phytosociologists have used such scales for recording plant cover for decades (e.g. Shimwell 1971, 109–20).

At first sight, the calculation of an index of diversity or of relative proportions of ecological groups from assemblages recorded on a five-point scale may appear practically shaky, if not theoretically absurd. The numbers 6 and 15 as translations of 'several' and 'many' were, however, chosen on the basis of an inspection of the distribution of numbers of individuals in the ranges 4–9 and 10 or more, and considerable experience has proved that statistics based on such methods are generally—or at least acceptably—close to those from fully quantitative recording. Comparison of statistics from fully and semi-quantitative records, based on conversion of numbers, will it is hoped be presented in a future paper. In addition, a selection of assemblages has been recorded by both fully and semi-quantitative scanning, in some cases by more than one operator. The statistics calculated from these records have almost always proved similar, and certainly there would not be any difference in the interpretation placed on the material. The exceptions were mainly where several taxa were extremely abundant but had been recorded only as 'many', converted to 15. The solution to this problem is, of course, crude estimation of numbers, perhaps as 50, 100, or more, as appropriate. There is not room to argue this out in detail, but some simple arithmetic applied to species lists such as those from Tanner Row (Hall and Kenward 1990) or Coppergate (Kenward and Hall, forthcoming), or even to some made-up numbers, will show that the semi-quantitative method provides a remarkably robust basis for the estimation of statistics, at least for typical urban assemblages.

A disadvantage of scan recording lies in the many remains which may not be fully identified in order to save time. It has been stated above that species represented by few remains (usually single sclerites or fragments thereof) which would be difficult to identify are *not* identified unless it is believed that they are of importance in archaeological interpretation. This is not as illogical a statement as might at first appear—in almost all cases the remains are identifiable on first inspection sufficiently closely to allow their potential importance to be judged. If it is suspected that, for example, they have climatic significance, they will be identified, or at least set aside for future consideration. What *is* lost, of course, is a large amount of information about the distribution of hard-to-identify rarer species in space and time—but devoting resources to such problems cannot be justified unless funded from an appropriate source, such as the Natural Environment Research Council.

Over a thousand insect assemblages from York have now been scan recorded by the writer and co-workers, and the method is believed to be much the most appropriate for most applications. Even for 'rural' material it has proved useful. The writer now generally scan records with the material in alcohol, noting sclerites as they are seen in the Petri dish. Any remains needing further inspection are picked out onto damp filter paper. Remains likely to require future access (for further identification, for photography, or as vouchers) are put into a small vial within the jar containing the flot. If time is especially short, sclerites of each taxon are recorded until 'several' or 'many' individuals are represented, and that taxon is ignored thereafter unless it becomes clear that an estimate of a much larger number is needed. Re-recording has shown that some remains are missed by recording flots in IMS in this way,

but not with a frequency which has a important effect on the statistics or interpretation.

Where there is time, justification, and funding, the remains are picked out on to filter paper by an assistant and sorted into groups of similar remains. This is the method currently preferred. The writer checks the flot quickly, recording 'other orders' (e.g. Diptera puparia, beetle larvae, water-flea ephippia and mites) during the process, then the material on the filter paper is quantified. There is not much point in using semi-quantitative recording when fossils have been picked out in this way, as counts can be made quickly unless numbers are huge, when an approximation can be used, rather in the way the size of bird flocks is estimated (by counting individuals in a representative area and multiplying up). In practice, common and easily identified taxa are often picked out into a vial of alcohol and recorded by the assistant. Another variation is for the author to sort the remains from the flot, recording them and passing them directly to a vial, only difficult remains being placed on filter paper. The precise method will be determined in any case by personal taste, experience, the nature and importance of the material and other circumstances.

Although the writer has re-examined a very large number of rough- or rapid-scanned samples, it was with the aim of improving recording, not of making a systematic study of the efficiency of the methods. However, some useful observations may be made.

In contrast to the records made by scanning, some early rapid scanning lists have proved, on re-recording at a higher level (scanning), to have produced inaccurate statistics. These have generally changed from interpretatively bland to significant, where species associated with foul matter were under-recorded, for example. In perhaps two or three cases (in well over a hundred) an assemblage which appeared to have interpretative significance on the basis of the rapid-scan record was shown to be otherwise when re-assessed, principally because the 'several' and 'many' records for some species proved to be exaggerations. Such cases appear to have been aberrations, and were doubtless the result of fatigue and boredom towards the end of an over-long recording session, or were caused by interruption during recording. It should be remembered that, in the early stages of 'scanning' the Coppergate material, there was a gradual and largely undocumented transition from what is here called 'rough' to what is now defined as 'rapid' scanning, and in some cases there may have been confusion between at the re-assessment stage as to which had been employed; lists *explicitly* recorded as rapid scans were very reliable. In the great majority of cases the statistics from rapid scanning—properly carried out—represent the fauna of the subsample passably well, in other words well enough to provide a reliable archaeological interpretation. The emphasis here is on the phrase *properly carried out*, and where this is not practicable, 'assessment' recording is preferable since it is explicitly subjective. I feel intuitively uncomfortable about employing rapid scanning, but rationally must accept that its use is sometimes justified by circumstances.

A few minor points are worthy of mention. It has been found that recording can be affected by such small methodological details as whether the forceps or writing instrument are generally held in the free hand during scan recording in alcohol. When the pencil is held, a more thorough written record tends to be made; when the forceps are mostly in the hand fewer remains seem to be missed as the dish is more thoroughly explored. It has been found difficult to record beetles and bugs and 'other orders' at the same time, and finding rarities in a dish tends to lead to blindness to common taxa. Similarly, insects tend to be overlooked in flots rich in plant remains. When a long series of samples is rapid-scan recorded, there is a marked tendency to under-record common remains, because they have been seen so often. This is particularly true of remains such as mites, fly puparia and other groups not employed in calculating statistics, but common beetle species have occasionally been overlooked too. This problem, parallels to which are well known to animal behaviourists and industrial psychologists, applies to assessment recording also; an antidote would be to spend a few minutes on some other task between samples, dealing with the associated paperwork or doing a little light administration. It is, in any case, essential to re-examine each dishful at least quickly; I also find it useful to examine a small part of the flot under a higher power. Finally, I have found it necessary to complete the whole of the rapid-scan recording of any subsample in one unbroken effort—so much needs to be held in the mind that any interruption may lead to considerable inaccuracy if recording is not re-started.

Conclusions

Detailed recording will in some applications be desirable, will remain intellectually more satisfying, and is an essential stage in the development of palaeo-entomological skills. This last statement may seem to carry the arrogant implication that, once trained, the 'expert' can be given a free hand to record subjectively. This is not intended, and one reason for writing this paper has been to present the dilemma faced by those who work within the constraints of contract archaeology. In the face of present-day funding and time-scales more rapid methods of recording are essential if sufficient information is to be retrieved within time and cost limits. Scan recording, fully- or semi-quantitative, has proved very useful in this respect, and can be adopted with few reservations; it is certainly essentially objective. Where time is very short, during post-excavation assessments or for samples from preliminary excavations, assessment recording has been found satisfactory; the degree to which it is subjective parallels that manifested by almost any 'expert', a doctor during diagnosis, or a jobbing builder assessing carrying loads, for example. The clear separation of these two techniques (scan recording and assessment recording) has the advantage of making it plain that the one is reasonably objective, the other essentially subjective. Rapid-scan recording can be resorted to for certain applications, but the resulting species lists must be used with considerable caution since the level of accuracy is not entirely certain.

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