Calcium Carbonate replaced arthropods from archaeological deposits

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Several species of woodlice, millipedes and centipedes have been recorded from archaeological deposits from south and east England and south Wales. Unlike insects which are abundantly preserved in waterlogged deposits, these related classes rarely survive, a factor probably resulting from physical differences in the exoskeletons. Under certain conditions, however, these differences promote the selective calcification of members of these classes and the woodlice, millipedes and centipedes described in this paper are all preserved as calcium carbonate replacement fossils. In sites where these are found insect cuticle often survives intact, sometimes acting as a mould in which internal casts are formed. Elsewhere, however, calcification extends to insects, dipterous puparia being the most frequently affected. In exceptional circumstances, beetles may be preserved in this manner.

A description of calcified species identified from archaeological deposits is followed by a discussion of the sites from which the fossils were recovered.

Introduction

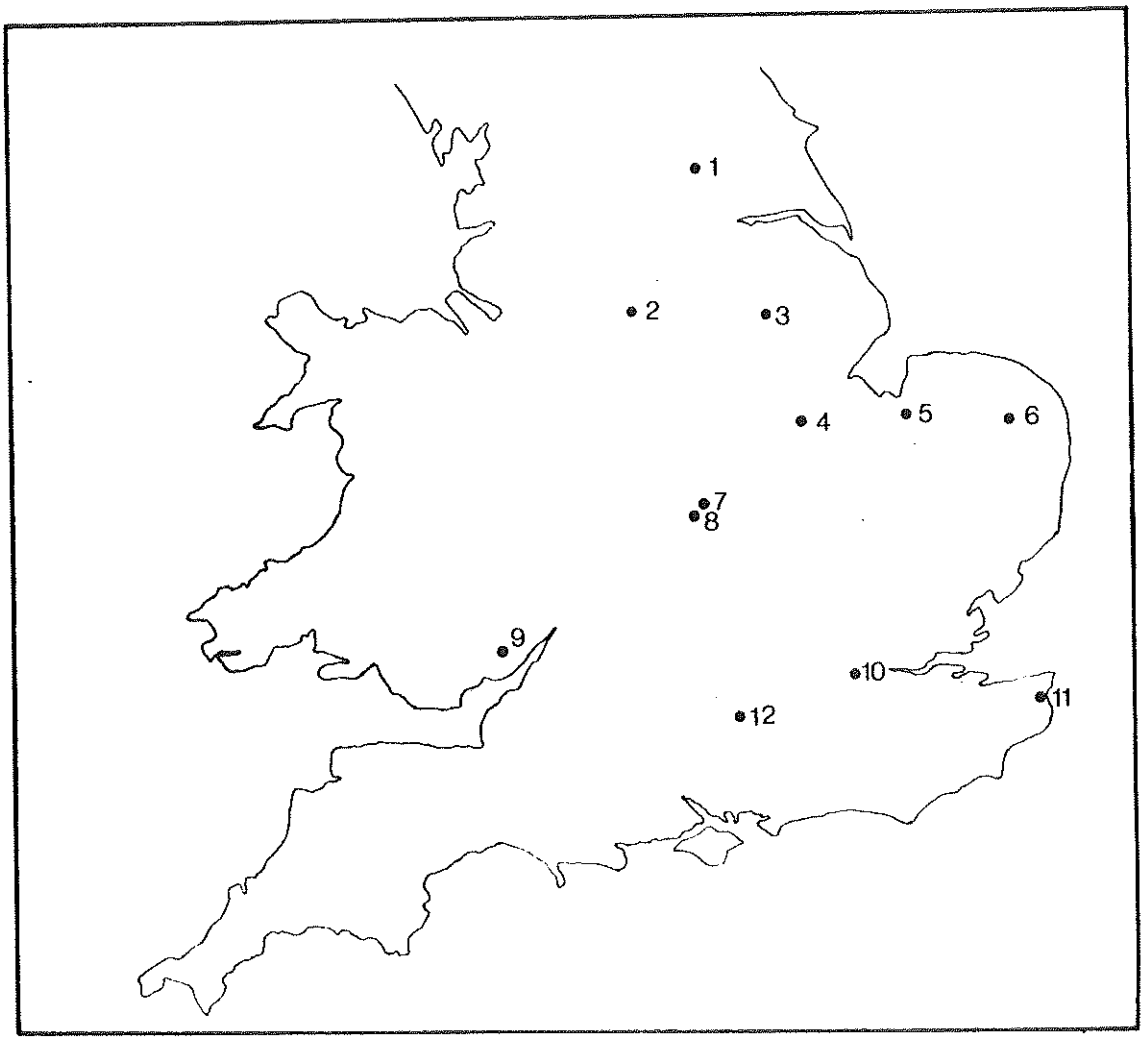
Insects, the largest class of Arthropoda, have been recorded from numbers of Quaternary and archaeological sites (Coope, 1970, 1975 Osborne 1969). These insect remains are made up of the highly

resistant cuticular exoskeletons which survive, largely unaltered, in waterlogged deposits (Coope 1965). In terms of palaeoecological studies, the most important of these insect remains are Coleoptera (beetles), although Diptera (flies), Hymenoptera (ants and wasps) and Hemiptera (bugs) are commonly present in fossil assemblages. Other arthropods preserved by the survival of their resistant exoskeletons include spiders and mites, (Koponen and Nuorteve 1973, Karppinen and Koponen 1974, Girling 1977), and freshwater Crustacea such as Daphnia.

Three classes of terrestrial Arthropoda, woodlice (Isopoda) millipedes (Diplopoda) and centipedes (Chilopoda), although today found commonly in many situations, rarely survive in Recent deposits. Millipede segments have been recorded from a Roman Well at Droitwich (P J Osborne, personal communication) and there is a single record of a woodlouse Porcellio scaber Lat. from Pliocene deposits, (Bell 1920), but generally, the exoskeletons of these animals are not robust enough to survive after death. Currently, however, investigations of archaeological deposits from south and east England and Wales are showing that under certain conditions isopods and myriapods may be preserved. Unlike insects and arachnids, the exoskeletons of these animals do not usually survive as unaltered cuticle, instead, these structures are replaced by calcium carbonate ($CaCO_3$). Five species of woodlice together with three millipedes and a centipede have been identified from sites (Plate 1) where preservation by $CaCO_3$ has been recognised. These are often accompanied by calcified dipterous puparia and, rarely, calcified beetles.

Replacement of organic tissues by minerals is not uncommon in archaeological deposits, for instance, the replacement of wood by metal has been discussed by Keepax (1975). Iron, especially, replaces wooden handles.

LOCATION OF SITES WITH CALCIFIED ARTHROPODS



1 York
2 Conisborough Castle
3 Flaxengate, Lincoln
4 Empingham
5 Castle Rising
6 Norwich
7 St.Peter's Street, Northampton
8 Towcester
9 Usk
10 Southwark, London
11 Stonar
12 Winklebury

Plate 1

leather holders, grasses and insects juxtaposed with objects made of this metal. Preservation by calcification is also a commonly observed process, affecting both artifactual and biological material, although little attention has hitherto been paid to calcified arthropods.

Preservation of arthropods by alcification

All arthropods have cuticle exoskeletons of which an important component is chitin, a polysaccharide. Amongst certain insects pronounced sclerotization by tannins produces highly robust outer skeletons. The most successful terrestrial arthropods, notably insects and most arachnids posses cuticle with a waxy outer layer, important in controlling water loss, although the distribution, thickness and effectiveness of the epicuticular lipids varies throughout these animals. Woodlice, with the exception of the desert living species Venezillo arizonicus, lack this waxy layer (Sutton 1972) and in millipedes and centipedes it is usually less well developed than in most insects. Differential waterloss in spiders, insects, millipedes and woodlice has been plotted by Cloudsley - Thompson(1955), and the cryptic mode of life adopted by isopods and myriapods is a direct response to their need to conserve water. The presence or absence of the waxy epicuticle appears to be a determining factor in the post-mortem survival of arthropod exoskeletons: by effectively water-proofing them, the lipid layer helps protect sclerites against bacterial and fungal decay. This may partly account for the abundance of insect remains in ecent deposits. The greater permeability of isopod and myriapod cuticle, whilst generally leading to rapid decay after death, does allow the entry of water which in hard-water regions, is charged with $CaCO_3$ which brings about mineral replacement of the original structures. Hence, the state of post-mortem preservation of the arthropods strongly reflects the properties of original exoskeleton. The tendency to calcification accords well with Richard's (1951) division of arthropods into

hydrophilic and hydrophobic categories. Crustacea which readily calcify are included in his hydrophilic category whilst insects fall largely into the hydrophobic category. Richards does however note that certain insect larvae and adults are partly or wholly hydrophilic. This may be a relevant factor in the often abundant preservation of dipterous puparia in this manner, alternatively, calcification of these animals may result from particular depositional processes or interaction with substances in the surrounding matrix in specialised situations such as cess-pits.

Calcification of arthropods does not completely replace the exoskeleton; personal observation indicates that when such fossils are dissolved in dilute HCl, transparent cuticle remains. There is a distinction between the cuticle residues from Isopoda and Myriapoda which contain $CaCO_3$ in life, and insects which do not. (Certain Diptera do contain $CaCo_3$ deposits, but these do not form true structures, Richards loc. cit.). In the former, the cuticle remaining after HCl treatment often retains its skeletal shape and even ornamentation, but residues from calcified puparia and tinid beetles consist of formless and disaggregated masses of cuticle. The contrast in these residues suggests that a different mechanism may be involved in the deposition of $CaCO_3$ in these fossils.

Calcification is demonstrably a post-mortem feature amongst plants and animals which do not contain $CaCO_3$ in life. There are a number of indications from calcified woodlice, centipedes and millipedes that the $CaCO_3$ in these animals is also mainly deposited after death although some of the original $CaCO_3$ in the living tissues may survive. The most obvious of these is the change in the physical structure. Calcified woodlouse exoskeletons are always more robust than those of modern individuals of the same species; this is especially apparent amongst the more heavily armoured species such as Armadillidium vulgare. Attempts by the author

to weigh arthropod exoskeletons before and after dissolving them in HCl to determine the weight of $CaCO_3$ have been hampered by lack of sufficient fossil material and the accuracy of such measurements must therefore be questioned. Nevertheless, a trend from weight loss of about 85% in fossil woodlouse perionites to about 70% in modern material has been observed. A weight loss of about 65% from modern, dead, colourless individuals whose exoskeletons have survived in sheltered situations suggests that some natural decalcification had taken place after death. An 85% weight loss from calcified puparia is similar to that of fossil woodlice. Measurements from botanical material from Usk indicate a weight loss from calcified blackberry seeds of about 20%, suggesting that in this case calcification is superficial. This is supported by the virtually unaltered appearance of the seeds after HCl treatment. Elsewhere, however, replacement of botanical material is more complete, and Keepax has recorded 100% replacement of wood in certain samples from St. Thomas Street, (Keepax 1975).

Another factor supporting the hypothesis that the $CaCO_3$ in such isopods and myriapods is mainly of post-mortem origin is that simple analyses of other common soil constituents show them to be consistently higher in fossil than modern material, suggesting that these, too, are derived after death. One such element is phosphorus, present in all true soils but greatly concentrated by plant and animal material and hence, important in many archaeological soils,(Limbrey 1976). Spot tests for P show that not only are values for fossils always much higher than those of modern individuals, even after allowing for the breakdown of organically bonded phosphates, but that values are significantly higher for animals such as puparia whose habitats of decaying animal and plant material, almost certainly present in the depositional environment, are rich sources of P. Values for iron are also higher in fossil than modern material. The preliminary indications from these spot tests that common soil constituents appear to be present in calcified material demonstrates the need for micro-analysis of the chemical composition of calcified cuticle in order to understand the processes leading to its formation.

In all of the deposits investigated, three animal classes, woodlice, centipedes and millipedes when recorded, are always present as replacement fossils. Dipterous puparia are usually the most abundant arthropods, and while these are predominantly calcified, in some calcareous deposits their exoskeletons survive as intact cuticle (ie 'normal preservation') Instances have been noted of normal preservation and calcification occuring at the same site for instance, at Southwark, London. Exceptionally, the intact cuticle of a puparium forms a cast in which an internal mould of $CaCO_3$ is formed, as in the Norwich specimen shown in plate 2. Similar casts formed externally around arthropod remains have also been noted from other sites. Beetle sclerites, when present, usually survive as intact cuticle but two instances of calcified beetles have been noted; Ptinus or Tipnus sp. from Lincoln's Flaxengate and Usk, and also from the latter site, a single calcified Staphylinus sp.. As these deposits probably include cess material, a feature probably common to many urban deposits, it is interesting to speculate on the possible role of such substances as uric acid and/or the increased bacterial activity of such deposits, in attacking the outer, waxy layer of insect cuticle, to permit calcification to take place.

Identification

Scanning electron microscope studies of replaced fossils show that very detailed replication of minute structures has often taken place. One example is the highly ornamented exoskeleton of a puparium shown in plates 3 and 4. The characteristic surface sculpture of Porcellio scaber has been observed in fossil specimens from several sites, although the tricorn structures illustrated by Sutton (1972) have not been found and possibly do not survive. In other instances however, surfaces have been obscurred by lime concretions. For the most part, replacement is detailed

Plate 2

Dipterous puparium from Norwich with internal cast of $CaCO_3$

(Wild, X 20)

Plate 3
$CaCO_3$ replaced puparium from Southwark (S.E.M. X 30)

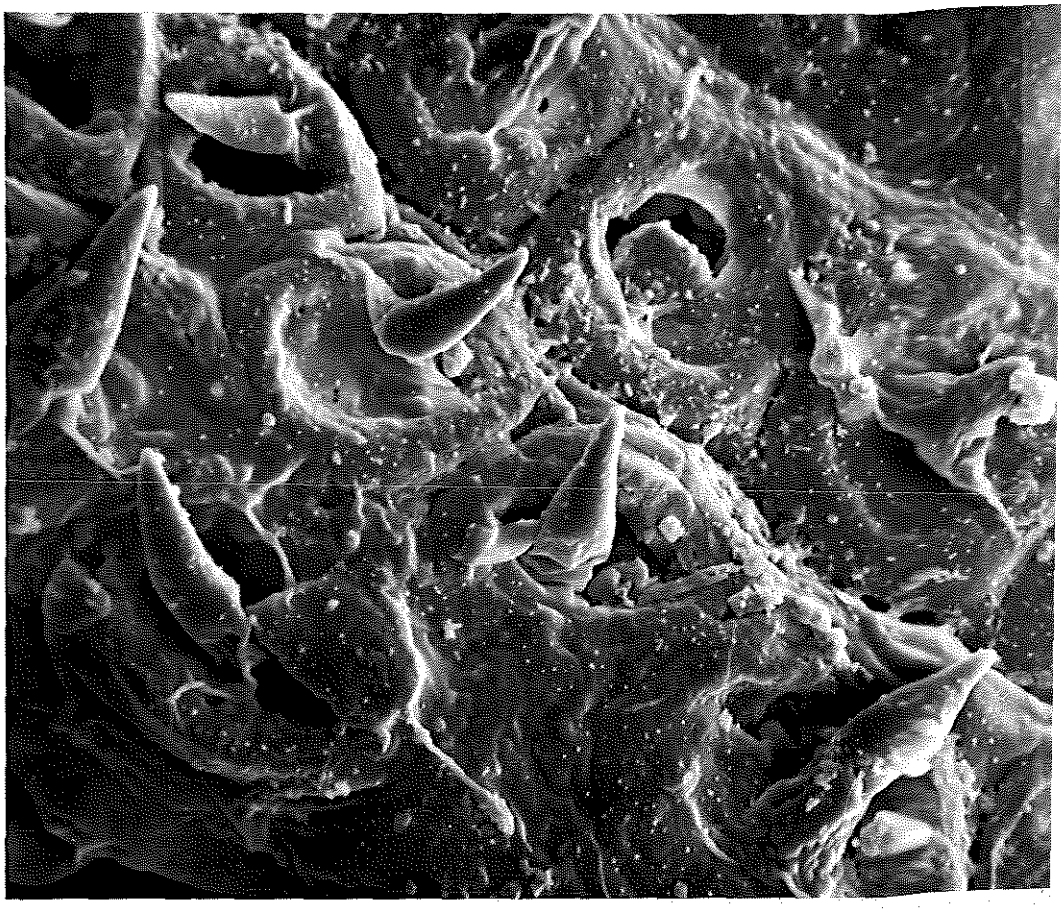


Plate 4
Detail of above (S.E.M. X 1000 -)

enough to permit at least preliminary identification.

The main drawback to naming replaced arthropods is the incomplete nature of the fossils. Like insects, isopods and myriapods are usually recovered as disarticulated body segments and the diagnostic appendages are missing. Exceptionally, however, near complete specimens are recovered although the peripheral leg and antennal joints rarely survive unless they are concreted to the body. Puparia are usually recovered whole except for setae and bristles, but even when normally preserved, these puparia are difficult to identify.

One problem applicable to all arthropods which undergo incomplete metamorphosis is the identification of juveniles, even complete, modern examples of which present difficulties to the zoologist. Isopoda and Myriapoda, after hatching, progress through a series of stadia which become more like the adult. Juveniles have fewer body segments than adults, and in species with compound eyes fewer ocelli. One post-embryonic woodlouse from a Southwark deposit has been recorded, although further identification has proved impossible. Other differences are illustrated in plates 5 and 6 where the juvenile Oniscus asellus head is more rugose than the adult head, which, although broken, is seen to be much smoother.

The use of identification keys is limited by the absence of appendages, particularly the antennal flagellum in the case of woodlice, but within the restriction imposed by the incomplete fossils the keys of Sutton et.al. (1972) for woodlice, Blower (1958) for millipedes and Eason (1964) for centipedes have proved valuable. The main method of identification, however, is comparision with modern reference material and all specifically named fossils in this paper have been compared directly with modern specimens.

Plate 5
Oniscus asellus ; juvenile head. (S.E.M.X 30)

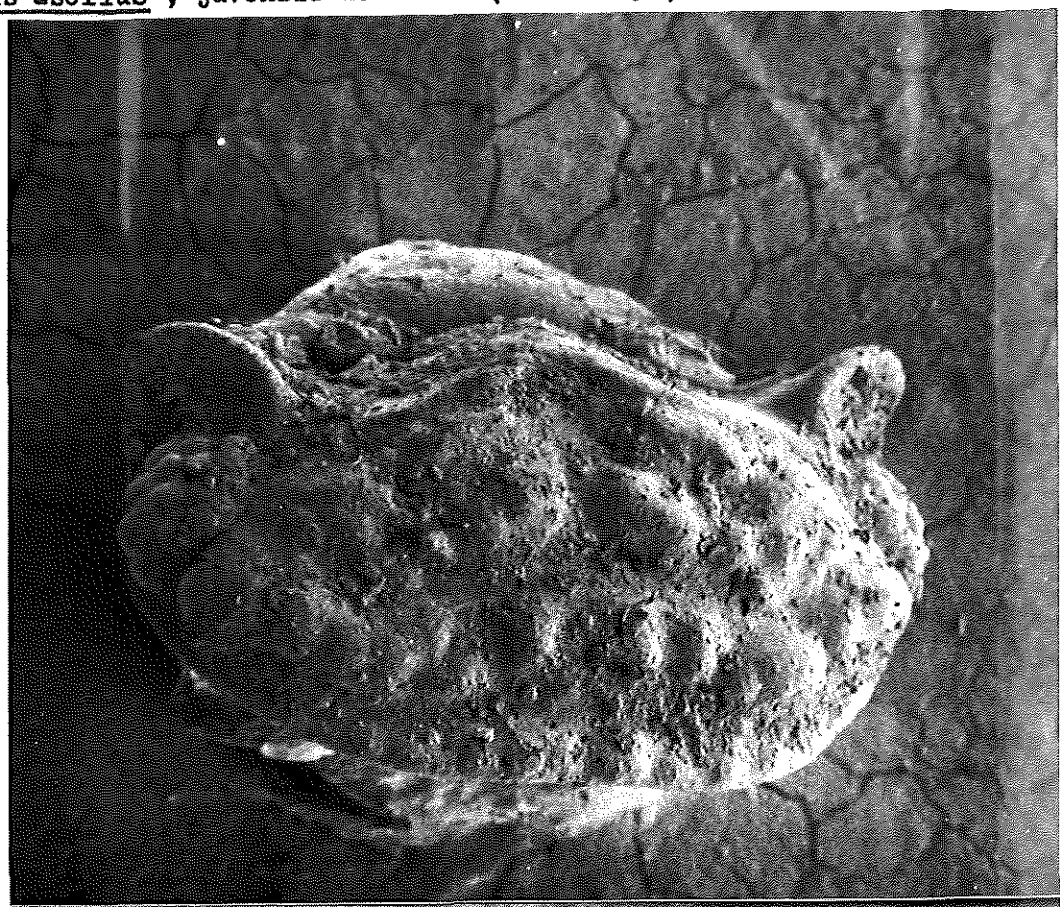


Plate 6
Oniscus asellus ; adult head with side lobe broken (S.E.M. X 30)

Notes on calcified Isopoda and Myriapoda

Notes on identifications of species recorded from archaeological deposits are given, and their ecological requirements, important in interpreting their possible significance, are summarised.

Woodlice

1. Armadillidium vulgare (Latrielle)

This species, the commonest of the pill bugs, has been recorded from Roman and later Southwark deposits and from Stonar Kent. Near-complete individuals in their characteristic 'rolled-up' positions have been observed, but identification is mainly based upon the shape of the tabular projection at the front of the head. This is one of the most heavily armoured species and calcified specimens are often massive, reflecting the original cuticle thickness. A. vulgare is restricted to calcareous soils except in coastal habitats (Sutton 1972) a significant factor when considering the Stonar record. This coastal site is on gravel, therefore the required calcium must have been provided by hard water drainage or sea-water spray. It is of interest to note that Cloudsley-Thompson (1958) records the species as living near builders' yards or houses in loose lime cement.

2. Oniscus asellus Linnaeus (Plates 5 and 6)

One of the commonest woodlice inhabiting open grounds, gardens and woods, this species is ubiquitous in the British Isles. Two fossil records only, at Flaxengate and Southwark, have been made of O. asellus, a factor which might reflect its preference for moister habitats.

3. Porcellio scaber Latrielle and ?Trachelipus rathkei (Brandt) (Plates 7 and 8)

The most difficult identification problem has been in separating fossil representatives of these species. The two members of the Porcellionidae

Plate 7

Porcellio scaber (S.E.M. X 30)

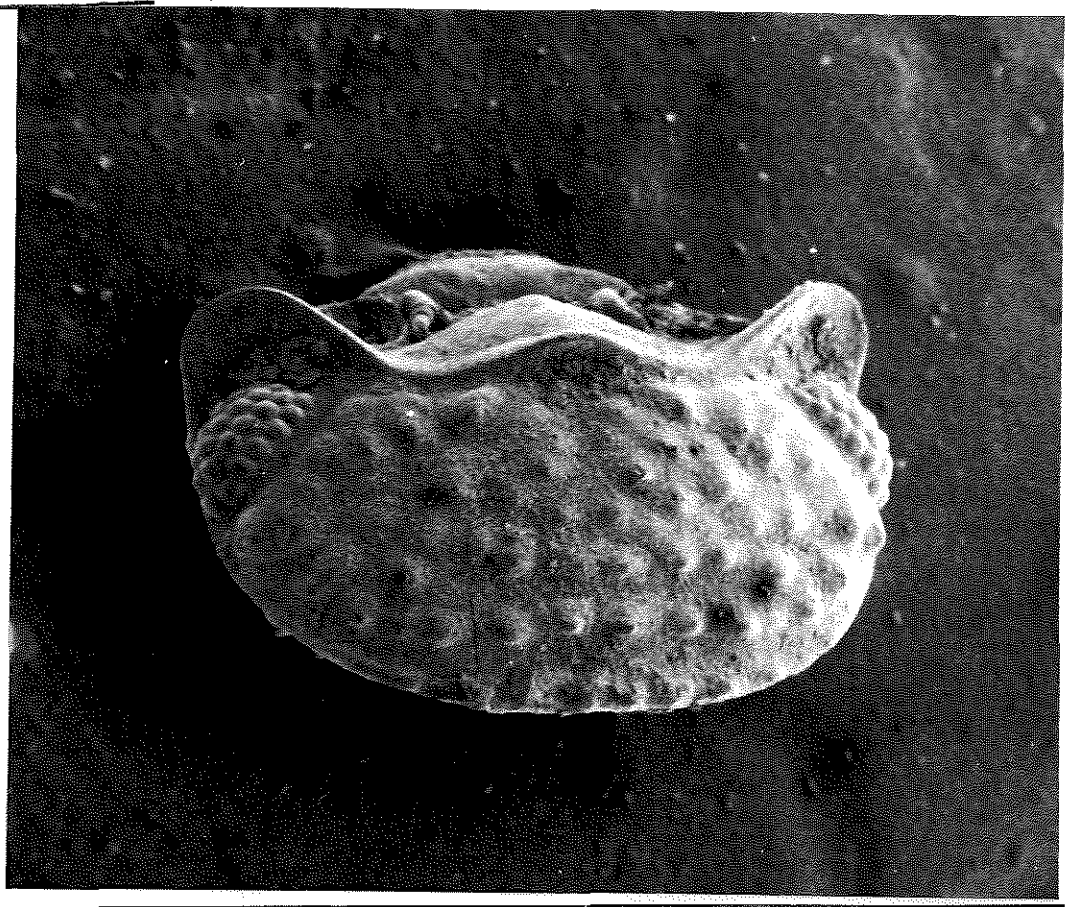


Plate 8

? Trachilipus ratheki (S.E.M. X 30)

family are superficially similar in appearance and the main diagnostic character is on the position of the psendotracheae on the underside of the body, a feature seen easily only in fresh specimens. Once identification is established on this character, other differences have been noted in modern specimens, for example, the shape of the head. Woodlice are however very variable and although most of the fossil heads in this group strongly resemble those of P. scaber (Plate 7) and a few have been tentatively ascribed to T. rathkai (Plate 8), more work needs to be done with these species. ~~There is a particular application of electron scanning techniques in investigating more morphological differences between these species.~~

P. scaber is commoner than T. rathekei and it is widespread over the country, occurring in a variety of situations including dry sand and chalk soils. Also, it is often found in synanthropic habitats. Amongst fossil records from archaeological sites, P. scaber appears to be the most frequently recorded species and sites from which large numbers have been recorded include Flaxengate in Lincoln. T. rathekei is less widespread and most modern records are limited to the south and south east midlands where poorly drained rough grassland provides an important habitat (Harding 1976). Confusion with the former species prevents an accurate assessment of its fossil record, but the numbers of calcified specimens which appear to be referable to T. rathekei are low.

4. Porcellio laevis Latridle

This species differs from other members of the genus in not passessing tubercules on the dorsal surface. A single fossil record of this species has been made from the late 13th century infill of a pit at Stonar. The large, smooth brown head recovered from this deposit was accompanied by a characteristically shaped telson which supported the identification. The species was formerly spread from Cumberland to the

south coast and was additionally known from Flint and Dumbarton (Edney 1954), but it now appears to be more restricted. P. laevis is strongly synanthropic, often occuring in vegetation refuse near dwellings (Web and Sillem 1906) and several authors suggest that man has been largely responsible for the spread of the species. Vandal (1961) infers a Mediterranean origin for the French population as the species occurs in its natural state in this region only and elsewhere is strongly dependent upon man. In Britain, its close association with man has led to the suggestion that it might not be a native species, (Sutton 1972, Harding 1976). As the following species is also regarded as questionably native, a discussion of both species follows its description.

5. Metophornorthus pruinosus (Brandt) (Plate 9)

The fossil head from Roman Southwark shown in Plate 9 illustrates the poor development of the side-lobes of the head which is one characteristic of this species. It is strongly synanthropic, to the point of becoming a nuisance in favourable situations in France (Vandal 1961) and it favour farm yards, dung heaps, stables and compost heaps. Like the preceding species, old capture records for M. pruinosus indicate that it was formerly more widespread.

The Roman and 13th century records for M. pruinosus and P. laevis may provide useful data when assessing their status in this country. As these records suggest that the species existed in Britain at least during historical time, it is possible that both are indiginous and lived in this country in their natural state until available habitats were greatly increased by the activities of man (and more recently, curtailed by changes in farming practices). If parallels can be drawn between the colonisation of this country by insects and

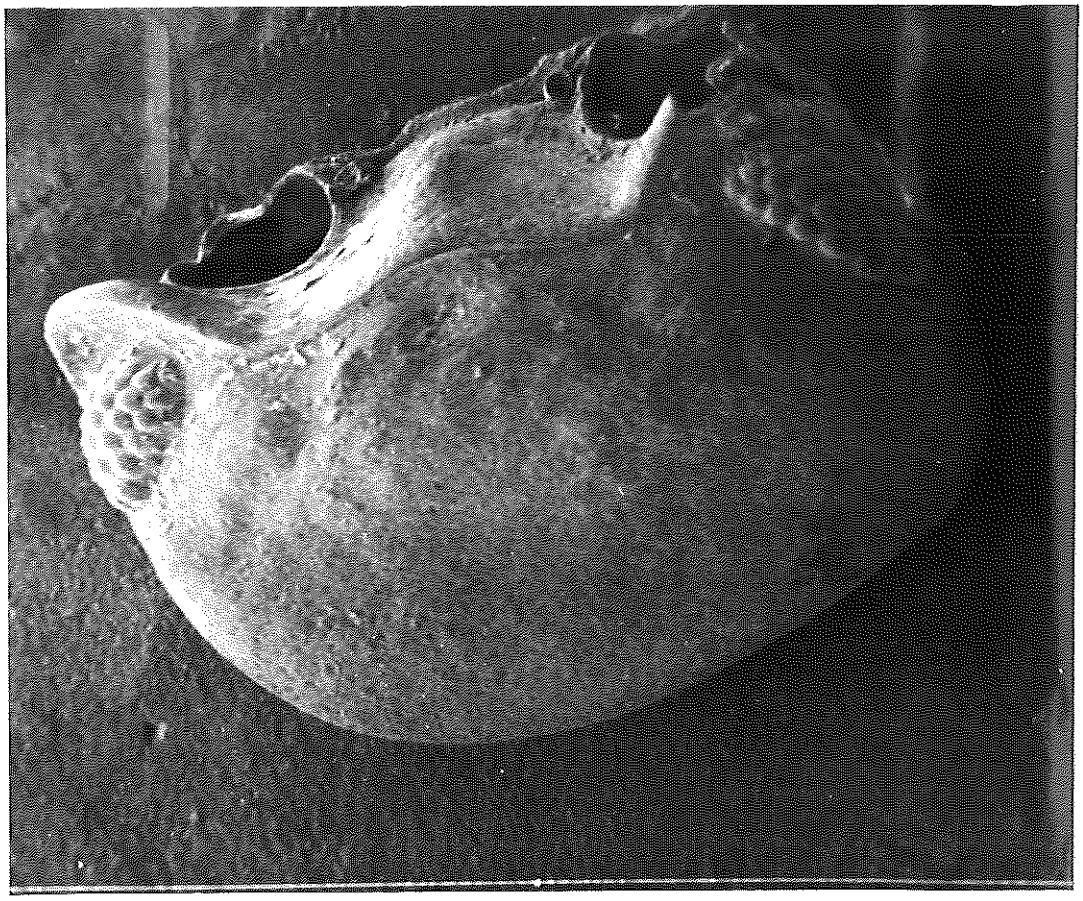


Plate 9

Metoponorthus pruinosus head from Southwark
(S.E.M. X 30)

woodlice, it is of relevance to note that Osborne (1974) has shown that after the close of the Devensian (= last) Ice Age, immigration to Britain of large numbers of thermophilous insects was accomplished within 500 years. Equally important, however, the woodlouse records lie within the period when numbers of introductions of beetle species has been demonstrated from archaeoentomological studies. Most introductions are of beetles associated with stored foods and the majority can be traced to Roman times, (Osborne 1971). Woodlice certainly have been transported by man, as is indicated by the cosmopolitan distribution of such species as A. vulgare, but they are less liable to be transported than insects which are infesting store products. One possible mechanism for the accidental transportation of the two species particularly M. pruinosis, which is a stable-dweller, is their inclusion in straw bedding for imported livestock. Whether or not these woodlice are introductions, their fossil records indicate that the species are not very recent arrivals in this country.

Millipedes

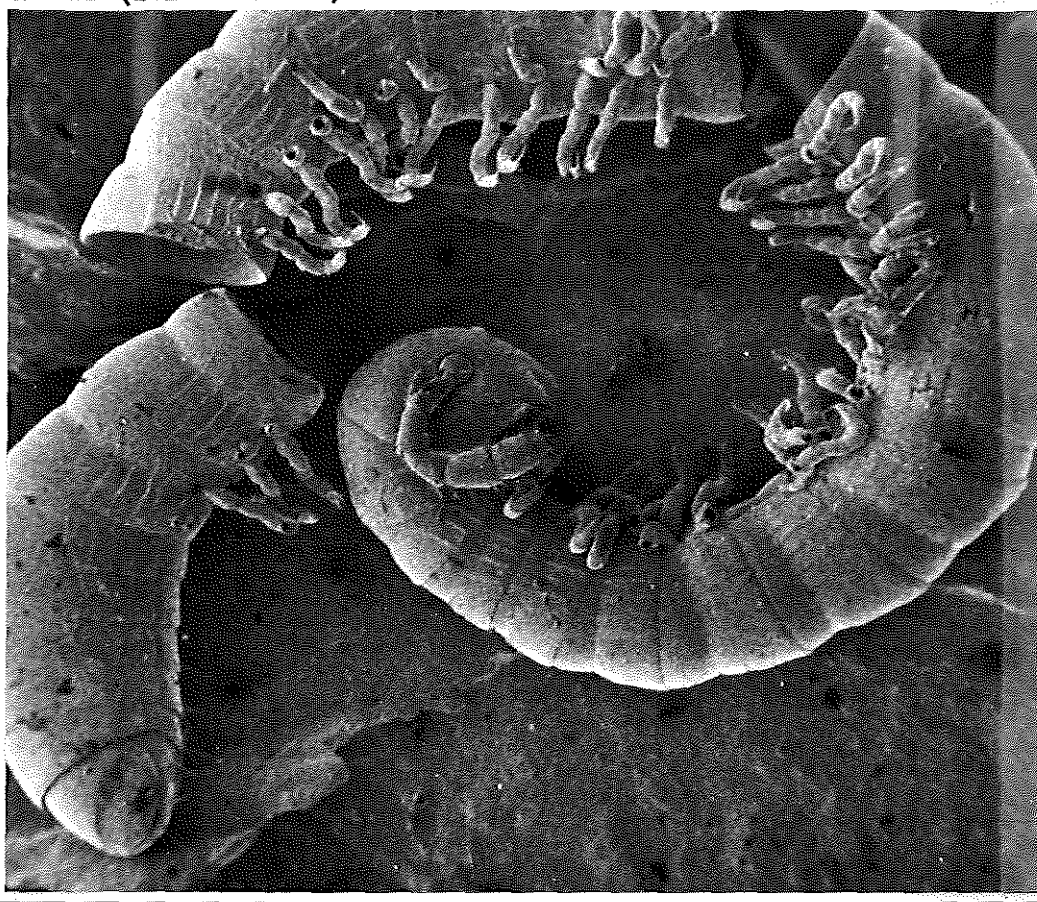
1. Blaniulus guttulatus (Bosc) (Plates 10 and 11)

This species, known as the 'Snake-millipede' is a common agricultural pest. It is often found in vegetables, although these are usually damaged before infestation, (Cloudsley-Thompson 1958).

2. Polydesmus coriaceus Porat (Plate 12)

Identification of this species rests upon the remarkably preserved modified gonopod shown in plate 12, although the pattern of sculpturing on the dorsal surface is also characteristic. P. coriaceus is widespread in Britain, although it is rarely common. In eastern Europe, the species is synanthoropic (Blower 1958).

Plate 10
Balaniulus guttulatus from Iron Age pit at Winklebury camp.
view of whole animal (S.E.M. X 100)



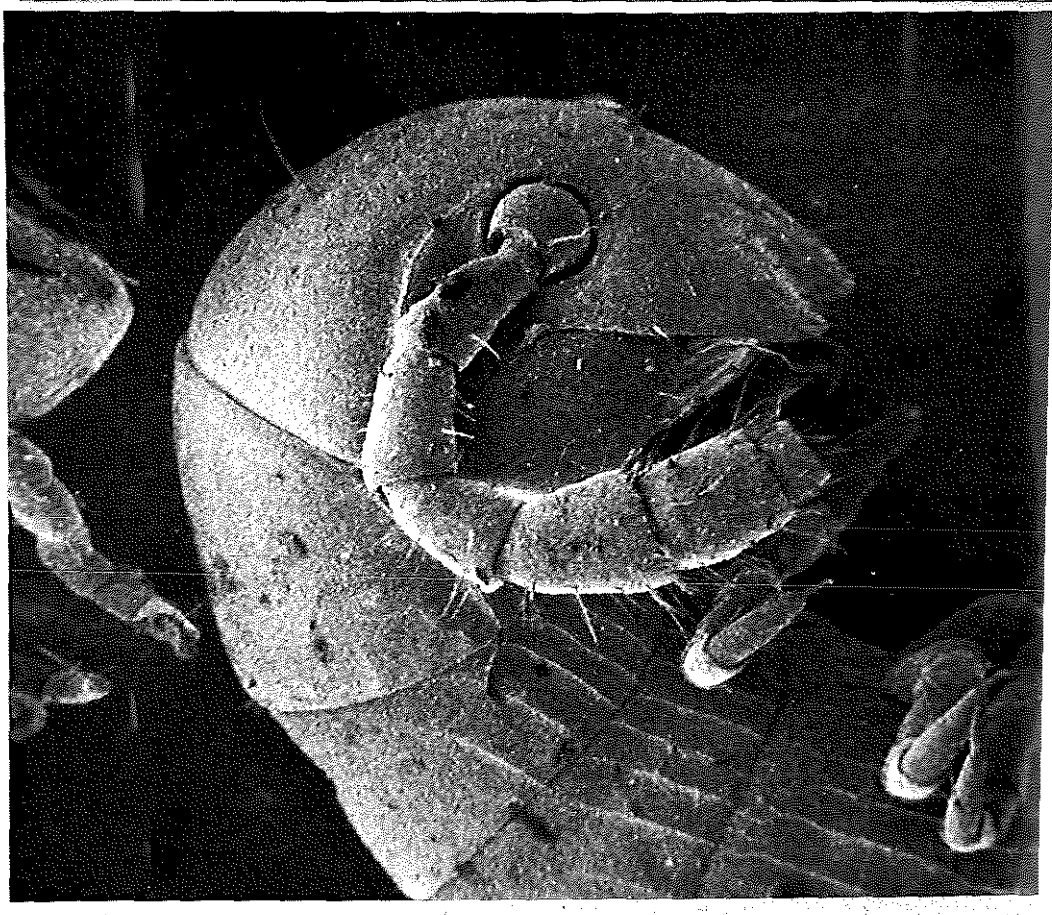


Plate 11
Head of above (S.E.M. X 300)

Plate 12
Polydesmus coriaceus from Winklebury Camp.
Isolated telopodite of gonopod (S.E.M. X 1,000)

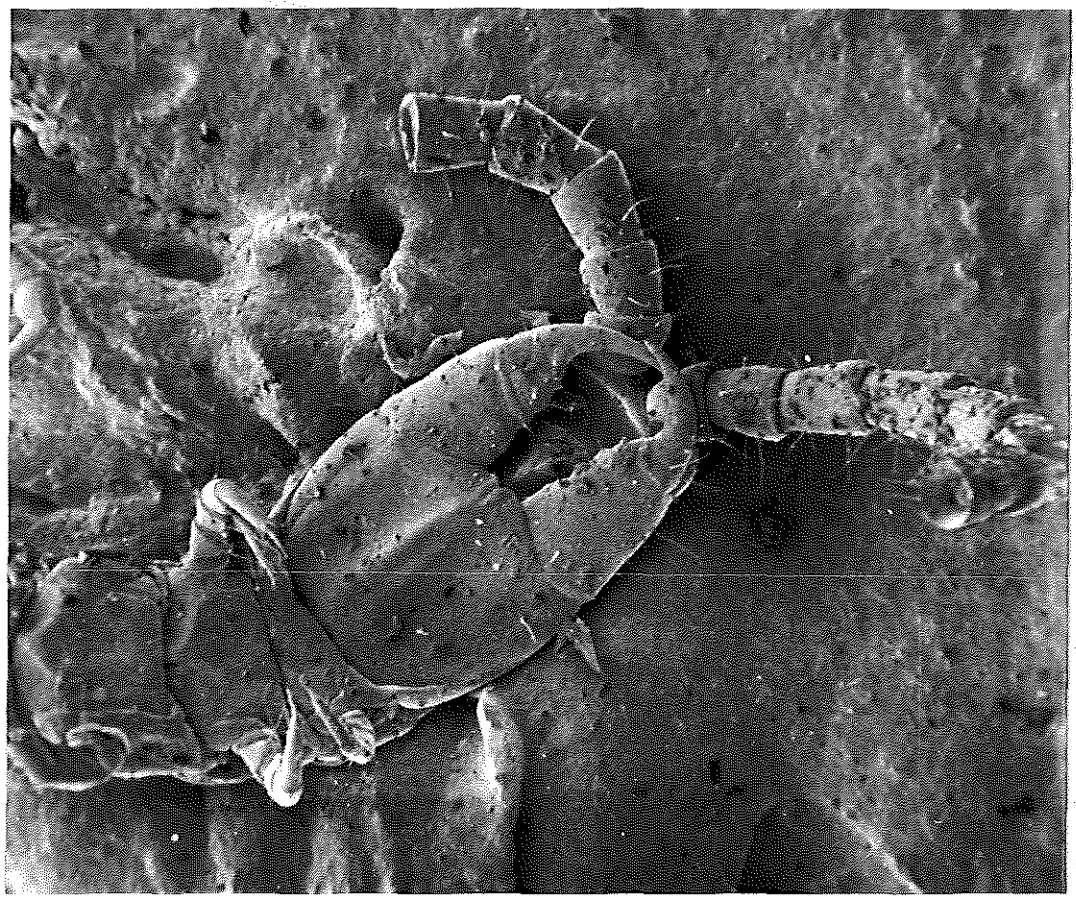


Plate 13
Centipede head from Winklebury Camp
(S.E.M. X 300)

Centipede

? Geophilamorpha (Plate 13)

The head of a slender centipede resembles those of the order Geophilamorpha and less strongly, scolo pendramorpha. The head lacks ocelli which are found singly or in groups on Lithobiomorpha. In rectangular cephalic capsule, and the shape of the clypeus and forcipules are similar to a number of Geophilamorpha species, but more definite identification has not been made.

B. guttulatus, P. coriaceus and the centipede were all recorded from Winklebury. A number of finds of polydesmidae millipede segments have been made at other, especially urban, sites.

Discussion of sites

Laboratory at the Ancient Monuments

The archaeological sites from which replaced arthropods have been recovered are shown in Plate 1, the results of investigations of calcified arthropods from these sites are briefly discussed below.

Flaxengate, Lincoln

The town of Lincoln has grown up in a gap in the Lincoln Cliff, a north-south ridge of Lias and Lincolnshire Limestone, rocks of the Lower and Middle Jurassic. One of the sites excavated by the Lincoln Archaeological Trust is Flaxengate, Medieval deposits from which have yielded large numbers of calcified woodlice. The commonest species is P. scaber or T. rathkei and there are records of A. vulgare, Polydesmid millipedes and Diptera. Also recorded at this site were one of the two occurrences of calcified beetles.

Southwark, London

Much of Southwark lies on the Thames Floodplain Terrace, itself overlying Eocene deposits of London Clay, and the area owes its hardwater status

Plate 13

Centipede head

(Plate mounted on bottom of page 19)

to the Thames which drains large areas of Chalk. Calcified arthropods have been recorded from several of the multi-occupational sites excavated by the Southwark and Lambeth Archaeological Excavation Committees. Records include M. pruinosus, P. scaber and O. asellus from a pre-Early Flavian ditch infill at 199 Borough High Street, where these and other calcified arthropods were accompanied by normally preserved beetles and other insects (Girling in preparation). Calcified and normally preserved insects were also described from St. Thomas Street where calcified writing tablets have been described by Wild in the same publication (Girling in SLAEC 1978) and from the waterlogged infill of a 17th century ditch cutting into earlier deposits at Chaucer House (Girling 1978b).

Stonar, Kent

Situated in Recent Drift deposits of sand and gravels overlying Upper Chalk, Stonar also lies in a hardwater region. Excavations by Mr N Macpherson-Grant (report in preparation) have revealed a Medieval deposit containing calcified arthropods, including the questionably native species P. laevis. A colour difference between white and orange/brown calcified puparia from the site was attributed to the uneven distribution of Fe in the deposit.

Winklebury, Hampshire

Millipedes and centipedes (Plates 10-13) were recovered from the infill of Iron Age pits cut into Upper Chalk at this hillfort site (Smith 1977). Other than that they are post Iron Age, the age of these arthropods cannot be established with certainty because soil activity in this dry upland area extended to the base of the pit infills, as evidenced by worm casts observed in the sections. Also Keepax (1977) in her discussion of contamination of archaeological deposits, has drawn attention to the

accumulation of fresh seeds in one of the pits. Certain features observed in the calcified arthropods from this site, however, do suggest that the remains are not very modern. There were no traces of tissue on the brittle $CaCO_3$ sclerites and all exoskeletal colouration had disappeared except for slight traces of red in the position of the once carmine coloured red repugnatorial glands of B. guttulatus. (Personal observation suggests, however, that colour loss may occur within a short time after death.) The most important feature of the Winklebury remains was the robustness of the $CaCO_3$ framework which may indicate post-mortem enrichment from the surrounding chalk rubble.

Northampton and Towcester

At St Peter's Street, Northampton, a small amount of biological material from a pit cutting a late-Saxon Grubenhous included claoified Polydesmid millipedes and puparia (described in Williams in press). Calcified polydesmid millipedes were also recorded from rich normally preserved insect faunas from Mr A E Brown's Roman excavations at St Lawrence Street, Towcester (Girling unpublished). Calcification at both sites might reflect the Oolite and Lias bedrock of the area.

Conisborough Castle and Castle Rising

Calcified puparia have been recovered from Medieval deposits at Conisborough Castle and Castle Rising. Whilst the former is in a region of Carboniferous Limestone, Castle Rising is within the limit of Chalky Boulder Clay overlying Carstone, both possible sources of $CaCO_3$.

Norfolk

Arthropods recovered from a number of urban deposits by Mr P Murphy have been sent to the author. Many of these are preserved normally, including the puparium in which an internal cast has formed (Plate 2), but there are

a number of replaced arthropods, including A. vulgare, P. ?scaber millipedes and puparia.

Empingham

A single calcified woodlouse head, recovered by Dr P C Buckland amongst an insect assemblage from the Roman Well (Buckland in press) is a juvenile specimen of P. scaber a species typically found on the dry calcareous soils on the Middle Jurassic rocks of the area.

Usk, Glamorganshire

Dr G Hillman noted replaced arthropods amongst calcified botanical remains from a 17th centry cess deposit and these, together with untreated material were sent to the author. The commonest remains were puparia, including numbers of external casts, and at this site, the second record of replaced beetles was made. Although much of SE Wales is an area of Old Red Sandstone Usk lies on the margins of an outcrop of Silurian limestone.

York

The calcified arthropod records described so far are based upon replaced individuals recovered from samples during post-excavation analysis. At York more extensive spreads of calcified arthropods, mostly puparia have been observed in situ in a 17th century drain at Bishopshill (Buckland 1977) and an early 18th century drain at Skeldergate (personal communication Dr P C Buckland and Mr A MacGregor). Such examples indicate that in suitable hardwater areas, material receiving a constant inflow of water, as in accummulations of material in drains, may form widespread Tufa like deposits.

Conclusion

In any area of calcareous bedrock, drift or hardwater drainage, calcified deposits in archaeological sites may be encountered. Investigation of a number of such deposits indicates that $CaCO_3$ replacement of arthropods may be a common process, particularly amongst classes which lack the waxy epicuticles so well developed in insects. All records of replaced arthropods are potentially significant; in addition to the inherent value of such faunal information in interpreting the depositional environment, the occurrence of calcified arthropods provides records of hitherto little known classes. As more calcified arthropods are investigated an understanding may be gained of the faunal history of woodlice, millipedes and centipedes, although the sporadic occurrence of suitable deposits makes it unlikely that these will be as well documented as insects. Nevertheless, the possible occurrence of calcified arthropods should be considered by archaeologists excavating in calcareous and hardwater regions.

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