# The application of microfossils in assessing the provenance of chalk used in the manufacture of Roman mosaics at Silchester

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**Abstract**

Microfossils recovered from chalk tesserae in mosaics from the Roman town Calleva Atrebatum, modern Silchester, southern England, are used to suggest a provenance for the source-rock. The microfossils include foraminifera characteristic of late Cretaceous (Campanian) foraminiferal biozone BGS20 (*quadrata* macrofaunal biozone) and subzone BGS21i (basal *mucronata* macrofaunal biozone). Calcareous nannofossil assemblages from the same tesserae are poorly preserved, preventing precise age determination, but confirm an age of Santonian to Campanian. As indurated chalk beds of this age are not present in the chalks of southern England, it is probable that calcretized chalk, formed by secondary calcification beneath Palaeogene rock cover, was used to manufacture the tesserae. This suggestion is supported by a comparative analysis of chalk tesserae from the Norden Roman site in Dorset. Although the provenance of the chalk in some of the Silchester tesserae can be placed only within a broad geographical area of downland in southern England, others apparently originated in the Dorchester-Swanage-Portsdown area, some 100 km to the southwest of Silchester. None of the tesserae appear to have been constructed from chalk found near Silchester.

*Keywords*: Roman mosaics; tesserae; microfossils; southern England; provenance; Norden; Silchester

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## 1. Introduction

Microfossils are used widely by geologists to determine the relative age of rock sequences for the Phanerozoic Eon, the last 542 million years of geological time (see Gradstein et al. 2004), and sometimes for rocks of still earlier periods of geological time (e.g. Sergeev 2006). This process is based on the identification of species that characterise rock successions formed during successive time intervals. Thus, the Cretaceous chalk rocks that crop out over wide areas of England are characterised by successive (evolutionary) fossil faunas and flora that can be used to correlate rocks of similar age between the Yorkshire coast and southern England. This methodology has been widely applied to the rock succession of Britain since the time of the engineer geologist William Smith in the early 19th century (Winchester 2001).

Microfossils occur in a wide range of rock types including limestone, sandstones and mudstones. Their minute size (generally < 1mm) makes them ideal for use in biostratigraphy, especially with very small samples. For this reason, microfossils are typically used to establish the biostratigaphy of boreholes drilled for oil exploration where rock material recovered is limited or broken up into small chips. An overview of different microfossils and their applications in dating and correlating rock sequences is given in Armstrong & Brasier (2005). Microfossil groups used for these purposes include calcareous (e.g. ostracods, foraminifera, nannofossils), phosphatic (e.g. conodonts), siliceous (e.g. diatoms, radiolarians) and organic-walled forms (e.g. spores, pollen, dinoflagellate cysts).

Microfossils have also been recovered from a variety of archaeological and historical remains including building materials, art and ceramics (e.g. Perch-Nielsen 1973; Quinn & Day 2007; Quinn 2008) and indeed from Roman mosaics (Jones 1989). In this paper we apply techniques of microfossil biostratigraphy used widely in geology to establish the biostratigraphical age of chalk rocks used in the construction of Roman mosaics in southern England. Using this information, it is possible to suggest a likely geological provenance of these rock types from the chalk rock succession. We take, as a pilot study, tesserae sourced from Roman mosaics in the town of Calleva Atrebatum, modern Silchester. For comparison, we have also examined chalk artefacts from the Norden Roman site near Corfe Castle, Isle of Purbeck, Dorset.

## 2. Mosaics at Calleva Atrebatum

The Iron Age and Roman settlement of Calleva Atrebatum (Silchester) is situated between Basingstoke and Reading in northern Hampshire, southern England (Fig. 1). The town stands relatively high on a gravel-topped spur and looks east and south over the clay lowland. The position of the site was determined to some extent by the presence of gravel, which was a source of water and was easily cleared for agricultural purposes, and contrasts with the heavily wooded clays below the site. Archaeological excavations have revealed many buildings within the Roman town walls, including private houses dating to the late first to the fourth centuries AD

(Boon 1974). The majority of rooms had plain floors of mortar, *opus signinum*, gravel or timber, but those in the principal rooms were generally tiled or tessellated, frequently incorporating patterned mosaics. The rocks used appear to have been sourced mainly from southern England and the white background to the mosaics was made from a hard chalk (Allen & Fulford 2004; Boon 1974). Though chalk was used in mosaics throughout the Roman period in Britain, it is a distinctive feature of the earliest pavements at Silchester, and also, for example, of the celebrated black and white, geometric pavements from the late first century AD palace at Fishbourne (West Sussex; see Cunliffe 1971).

## 3. Microfossil groups in the Chalk tesserae

Five loose, chalk tesserae from the ongoing excavations of insula ix at Calleva Atrebatum have been examined for calcareous microfossils (see Table 1). Microfossils most commonly found in the chalk are calcareous nannofossils and foraminifera, but ostracods are also present. The microfossils from the Silchester tesserae are housed in the biostratigraphical collections of the British Geological Survey, Nottingham (registration numbers MPA54160 to 54164, see Table 1), and those illustrated are registered in the type and figured collection of the BGS (MPK13618 to 13628). Coccolith preparations and remaining rock samples from the Silchester tesserae are held in the collections of the Natural History Museum, London (MP-NF1188-1193). Material from the Norden Roman site is registered with BGS numbers MPA54216-54221.

Calcareous nannofossils include coccoliths and nannoliths, which have a geological record extending back to the late Triassic (Erba 2005). They are widely used to establish the biostratigraphy of Mesozoic and Cenozoic age rocks (see Bown 1998). Coccoliths are tiny (2-20 µm) calcite plates that are produced by a group of single-celled planktonic algae, the coccolithophores. Nannoliths are similar sized fossils which occur with coccoliths but whose biological affinities are unproven. Calcareous nannofossils are the smallest fossils in the chalk, but they are enormously abundant and form its bulk. However, their small size also makes nannofossils vulnerable to diagenetic alteration (particularly recrystallization during burial); in hard chalks it is common for the majority to have been severely altered by recrystallization leaving low diversity assemblages of resistant species.

Foraminifera are marine, single celled organisms that construct a test (the ‘shell’) either by using dissolved calcium carbonate in the sea water or by cementing together sand- and silt-sized grains. The tests, which are generally about 0.2 to 1 mm in size, vary considerably in morphology (Armstrong & Brasier 2004). The group has a record extending back to the Cambrian (Scott et al. 2003) and they are widely used for biostratigraphy (see Jenkins & Murray 1989).

Ostracods are crustaceans that have a body completely enclosed in a bivalved, calcite carapace. Generally about 1 mm long, the carapaces may be smooth or ornamented. Ostracods live in all aquatic environments from the deep ocean to temporary ponds, and have a geological record extending back to the Ordovician. The use of ostracods in British biostratigraphy is summarised in Bate & Robinson (1978).

## 4. Methods for recovering microfossils

In order to release microfossils from the chalk, the tesserae were crushed to about 3-5 mm grains, soaked in white spirit for 30 minutes and then boiled in sodium hexametaphosphate ($[NaPO_3]_6$) to disaggregate the rock. Despite their hard (indurated) nature and incomplete disaggregation, the tesserae yielded sufficient foraminifera and ostracods to permit biostratigraphical age determinations.

For study of the coccoliths ca. 2 $mm^3$ of chalk was crushed, suspended in buffered distilled water, allowed to stand for one minute to remove coarser fragments then pipetted as a dilute suspension onto a microscope slide. For techniques of coccolith preparation, refer to Bown & Young (1998). As is usual in hard chalks the majority of the coccoliths have been severely altered by recrystallization but enough specimens remain in some samples to allow useful biostratigraphical age determinations.

Fragments of rock tesserae have also been processed for organic-walled microfossils (dinoflagellate cysts, spores and pollen) using standard palynological techniques (see Wood et al. 1996). The samples did not yield useful organic-walled microfossils. In contrast, tesserae sourced from clay-rich rock sequences (Allen & Fulford 2004) are known to yield useful palynological data.

## 5. Geological setting of Calleva Atrebatum

The town of Calleva Atrebatum stands on the Silchester Gravel, one of a series of Quaternary river terraces associated with the River Kennet (Fig. 1). The solid geology around the town is dominated by Palaeogene rocks, particularly the Eocene (about 34-56 million years old) London Clay and Bagshot Sands formations. The London Clay Formation is up to about 90 m thick in the Reading District and comprises dark grey clays and silty clays with a more sandy uppermost part. The overlying Bagshot Sands Formation consists of about 20 m of orange/brown, fine- to medium-grained sand with flint pebbles (notably at the base) and thin beds and laminae of grey clay and silt. Mathers & Smith (2000) have summarised the Geology of the region.

The Chalk lies below Palaeogene rock cover around Silchester, the nearest outcrops to the north are around Reading, and to the South around Basingstoke (Figs 1, 2). To the north of Silchester, the youngest exposed chalks are of Early Santonian, *Micraster coranguinum* biozonal age (Fig. 3) and, to the south the youngest beds seen at the surface are of Late Santonian, *Marsupites testudinarius* biozonal age. As will be discussed later, this chalk is too old to be the source of the tesserae found at Calleva Atrebatum.

A brief overview of the upper part of the White Chalk Subgroup in southern England places the Silchester tesserae into a geological context (Fig. 3): for further details see Hopson (in press). The White Chalk Subgroup comprises four formations, which are briefly described here, from the oldest to youngest:

1. The Seaford Chalk Formation (Coniacian to Santonian age) is generally between 50 and 80 m thick, but is often reduced in thickness by erosion prior to the deposition of the Palaeogene rock succession. It comprises firm white chalk with regularly spaced nodular and tabular flint bands and thin marls near the base.

2. The Newhaven Chalk Formation (Santonian to Campanian) is generally between 45 and 75 m thick, but is again affected by sub-Palaeogene erosion, and comprises soft to moderately hard, smooth white chalk with marl seams and some flints (including *Zoophycus* trace fossils). Phosphatic chalks are known in restricted areas.

3. The Culver Chalk Formation (Campanian) is generally between 65 to 75 m thick, but is significantly thinner where synsedimentary channelling occurred. It comprises

soft white smooth chalk, relatively marl free, with numerous large nodular flints and, in the upper part, tabular flint bands.

4. The Portsdown Chalk Formation is the youngest chalk in southern England (Campanian). It may be 65 m or more thick, but pre-Palaeogene erosion reduces this and in some areas it has been entirely removed. The formation comprises soft white chalk with marl seams (particularly in the lower part) and flint bands (although it is less flinty than the Culver Chalk Formation below). The lowest part contains several intervals rich in fossilized mollusc (inoceramid bivalve) shell debris.

## 6. Biostratigraphical results

### *6.1 Foraminifera*

Foraminifera from the Upper Cretaceous Chalk Group of southern England have been examined in detail (cf. Bailey et al. 1983, 1984; Hart et al. 1989; and references therein) so that the distribution of species is well known. Wilkinson (2000) adapted and emended existing biostratigraphical schemes and applied them to high resolution mapping carried out by the British Geological Survey. Foraminifera recovered from the Silchester tesserae were compared with this large dataset.

The fauna recorded in the Silchester tesserae are shown in Table 1 and key specimens are illustrated in Figure 4. Species include *Gavelinella usakensis,* which is particularly noteworthy as this species enters the record in the highest Newhaven Chalk Formation, immediately below the Arundel Sponge Bed. Its first occurrence defines the base of foraminiferal biozone BGS20 (Wilkinson, 2000) (subzonal indices were not observed). Tesserae containing this species originate from the Campanian-*quadrata* macrofaunal biozone, and the chalk can be inferred to be highest Newhaven to basal Portsdown Chalk (Fig. 3). Foraminifera such as *Bolivinoides decoratus, Gavelinella monterelensis, Gavelinella clementiana, Gavelinella usakensis* and *Gavelinella thalmanni* (Fig. 4) are characteristic of foraminiferal subzone BGS21i, and the *B mucronata* macrofaunal biozone ('mid'-Campanian). In southern England, this fauna occurs no lower than the Farlington Marls (see Fig. 3), a little above the base of the Portsdown Chalk Formation, and usually ranges through to the Cretaceous/Palaeogene boundary.

### *6.2 Ostracoda*

Two very imperfectly preserved ostracod specimens (see Table 1, MPA54161) are the only representatives of these microfossils, and include a fragment of *Cytherella* sp. and a better preserved specimen of *Bythoceratina* cf. *umbonatoides* (Fig. 4.11). They could not be identified to the species level, and no biostratigraphical information can be drawn from these long-ranging genera.

### *6.3 Calcareous nannofossils*

Late Cretaceous nannofossil biostratigraphy is well-established and one of the main means of global correlation during this interval. Nannofossils from the British Chalk have been studied in detail by Crux (1982) and Burnett (1998), the ranges of most species are well-known and there is a high resolution biozonation scheme (Burnett 1998). The calcareous nannofossils recovered from the Silchester samples are summarised in Table 1.

Recrystallization is a major problem and is probably the reason that most calcareous nannofossil specimens are generally overgrown by later crystal growth or have been completely obliterated from some tesserae by this process (Fig. 5). Sample MPA54162 only contained *Micula staurophora*, this is a common, resistant nannolith that first occurs in the mid Coniacian and, in England, is indicative of the upper part of the White Chalk Subgroup (Seaford Chalk to Portsdown Chalk Formations). Samples MPA54160 and especially MPA54161 contained rare but slightly better preserved and more diverse nannofossils. *M. staurophora* is again the dominant species, but *Watznaueria barnesiae, Lucianorhabdus cayeuxii, Broinsonia* sp., *Eiffellithus turriseiffelii, E. eximius, Reinhardtites* sp. and *Zeugrhabdotus* sp. were also seen. The occurrence of *E. eximius* indicates a minimum biostratigraphical age of Campanian (see Fig. 3). The occurrence of *Lucianorhabdus cayeuxii* constrains the maximum age to Santonian.

## 7. Biostratigraphical provenance of the chalk tesserae from Silchester

Preservation of microfossils varied between the tesserae with the best results for all groups coming from MPA54160 and MPA54161 (Table 1). Calcareous nannofossils indicated a Santonian-Campanian age for these tesserae, the benthic foraminifera indicate foraminiferal biozones BGS20 and 21i, both of which are indicative of the Campanian (Fig. 3).

Foraminiferal biozone BGS20 occurs in the uppermost Newhaven, Culver and basal Portsdown Chalk, which can be seen extensively in the South Downs and into the Marlborough and Berkshire Downs of southern England, although not in the immediate vicinity of Calleva Atrebatum. Foraminiferal subzone BGS21i is only rarely seen in southern England as the upper part of the Chalk Group, the Portsdown Chalk Formation, was removed by erosion over much of southern England, prior to the accumulation of Palaeogene age rocks. The Portsdown Chalk, which has its type section at Farlington, near Portsdown, is seen in small areas in the Studland and West Lulworth area, but it is more extensive at outcrop in the Ringwood-Dorchester-Swanage area (Fig. 2). In all of this area, only the basal part of the formation can be seen; it is more completely developed on the Isle of Wight. The only other area where chalk of this age is found in England is to the northeast in Norfolk.

Hence, none of the chalk used in the construction of the tesserae could have originated in the area of Calleva Atrebatum. Here the chalk at outcrop is too old: the youngest exposed strata fall within the Seaford Chalk Formation, the *Micraster coranguinum* macrofaunal biozone (Mathers & Smith, 2000). Although MPA54160 might have originated in many places along the Marlborough or South Downs (foraminiferal biozone BGS20 and the *quadrata* macrofaunal biozone are geographically extensive), MPA54161 and MPA54162 are geographically more restricted as there are few areas with chalk of biostratigraphical age BGS21i (*B. mucronata* macrofaunal biozone) in southern England.

The analysis of the microfossils recovered from the tesserae indicate that the chalk came from at least two different stratigraphical horizons - one of BGS20 foraminiferal biozonal age and two from slightly younger chalks of BGS21i subzonal age. Hence, the microfossil biostratigraphy places the origin of the chalk tesserae within the very highest Newhaven to basal Portsdown Chalk formations (Fig. 3). However, this age determination presents a conundrum. The chalks at this stratigraphical level are soft and, in part, marly. Nowhere in southern England are there hard, primary indurated beds of chalk of *quadrata* and *mucronata* biozonal age suitable for the manufacture of tesserae. Therefore, the chalk used in the manufacture of the tesserae must have been subject to secondary cementation. The questions arise how did this take place and what clues to the source rock of the tesserae does this provides?

## 8. Comparative analysis of chalk tesserae from Norden

Samples of the source rock from which the chalk tesserae at Silchester were manufactured are unavailable. However, the manufacture of chalk tesserae is attested at the Roman settlement at Norden, near Corfe Castle, Dorset (Fig. 2), where over 1500 examples and associated waste chippings were found on a working floor of the late first century AD. In addition, sawn slabs of chalk for use in wall decoration or as floor tiles were also found from contexts ranging from the second through to the late third and fourth centuries. The Norden site has also produced evidence of the working of other lithologies including Kimmeridge Shale, Kimmeridge Clay dolomite cementstone and Purbeck Marble for personal ornaments, tableware, tesserae, wall veneers and mortars, from the late first through to the third and fourth centuries. It was concluded that this range of items was being made from these materials for export, rather than for consumption at the site (see Sunter 1987, pp 30-43; Allen & Fulford 2004, p. 29). Given that the majority of the other (non-chalk) lithologies used to make the early Roman tesserae at Silchester and elsewhere in southern Britain were either present at Norden or provenanced to the Isle of Purbeck, it seemed appropriate to test whether the chalk at Silchester had a similar origin. Therefore, a chalk rock specimen (BGS registration number MPA 54222) from the Norden site was thin-sectioned to determine its petrological texture and composition. The rock specimen is a hard, white, porcellaneous fine-grained limestone, with sporadic spar-calcite filled fractures. The thin section identifies the specimen as a calcite-cemented chalk and thus a calcrete, that is, it possessed secondary calcareous cement formed sometime after the initial deposition of the chalk. The foraminifera in the Norden rock specimen include both small, globular planktonic forms (predominantly *Hedbergella delrioensis, H. brittonensis,* rare *H. planispira* and very rare *Whiteinella* sp.) and larger, multi-chambered, planispiral benthonic varieties (including *Gavelinella usakensis, G.* cf. *stelligera, ?Loxostoma eleyi, Gavelinella* sp. and *Arenobulimina* sp.). Some additional fossils include poorly preserved radiolarians, ostracods, occasional fragments of echinoid spines, and bivalve mollusc shell. The fossil assemblage appears to be from the Campanian, biozone BGS20 (equivalent to the *G. quadrata* macrofaunal biozone) or BGS21i (lower part of the *B. mucronata* macrofaunal biozone; see Fig. 3), that is, from the same stratigraphical level as that of the Silchester tesserae.

To determine whether this rock specimen was representative of chalk utilized to make tesserae at Norden, several tesserae were also analysed for foraminifera (Table 2). Foraminifera are very poorly preserved and rare, but four tesserae (BGS MPA54216-54218 and 54220) include *Gavelinella usakensis*, and one (MPA54216) yields a poorly preserved specimen assigned to *Gavelinella monterelensis*. Not only did this fauna confirm that the tesserae were similar to those in the rock specimen, but they were also essentially similar to those at Silchester.

## 9. Geographical provenance of the chalk tesserae at Silchester

By comparison with the Norden chalk material, the source rock for the chalk tesserae at Silchester was also probably indurated as a consequence of secondary cementation. Calcretized chalk is seen to occur most commonly where the overlying Reading Formation (Palaeogene age) is a mudstone. This calcretized chalk occurs as masses, some of considerable size: blocks up to 2x1x 0.5m have been brought to the surface during modern ploughing. Calcrete is hard enough to be cut and polished, has a marble-like appearance, and is hard-wearing.

Unlike the discrete indurated beds that occur in the lower part of the Chalk Group **(Ian, please provide ref.)**, chemical precipitation causing secondary induration, takes place over wide areas of southern England and, in itself cannot be considered useful to determine the provenance of the chalk tesserae. However, secondary cementation is usually associated with areas where Palaeogene deposits (preferably mudstones) rest on top of chalk

All that can be concluded for Silchester tessera MPA54160 is that it probably comes from a locality where the Palaeogene rests on chalk of *quadrata* biozonal age. This biozone is geographically widespread so that this sample may have originated from one of many localities along the chalk downlands of southern England.

The chalk used for Silchester tesserae MPA54161 and MPA54162 however, has a far more restricted distribution as outlined above. They could not have come from the area around the archaeological site; the chalk of the tesserae are much younger than the chalks of the Silchester area, and an origin in the Dorchester district or the Lulworth-Swanage-Portsdown area (see Fig. 2), some 100 km to the southwest of Silchester, seems likely.

There is no evidence for a quarry at Norden (Sunter 1987) and it may have been the case that the calcrete blocks were dug up during cultivation or otherwise brought to the surface by erosion, and then, as with the other lithologies represented at Norden, transported to site for working. Although other sources of chalk in southern England were clearly being exploited by the Romans, the addition of chalk to the range of stone types exploited in the Isle of Purbeck and then distributed considerable distances for employment elsewhere, gives further weight to the importance of that area and its associated manufacturing sites, like Norden, for the provision of materials for making mosaics and other decorative building materials from the later first century AD onwards (cf. Allen & Fulford 2004; Allen et al. 2007).

## 10. Conclusions

The tesserae manufacturers at Calleva Atrebatum used chalk from the upper part of the White Chalk Subgroup and specifically from foraminiferal biozones BGS20 (*quadrata* biozone) and BGS21i (basal *mucronata* biozone) age to manufacture the tesserae. They favoured the hard, marble-like calcrete, which formed by secondary calcification at the top of the chalk, because primary indurated beds of this age are not present in Southern England. They collected the calcrete where the top of the chalk is, or was, beneath Palaeogene rock cover. They collected their material along the downlands of southern England, such as along the South Downs and Marlborough Downs (where chalk of BGS20 biozonal age is widespread), and in the Dorchester-Swanage-Portsdown area (where chalk of BGS21i subzonal age is restricted), which lies to the southwest of Silchester on the southern English coast. Biostratigraphically well-dated tesserae could not have been collected from the area around Calleva Atrebatum itself, as the chalk in this area is too old. These results challenge the assumption that the nearest source of chalk would necessarily have been the most likely to have been used in the manufacture of Romano-British mosaics or employed for other decorative purposes. The association of chalk tesserae with the Isle of Purbeck, Dorset, adds a further dimension to the Romano-British exploitation of the natural resources of a limited geographical area which played a very significant role in the supply of stone and other materials to the Roman province of Britain and beyond. The results thus open up the possibility of distinguishing between sources of chalk exploited largely for local consumption and those with a wider, regional or provincial market. More generally, the microfossil technique that we identify here, applied to the provenance of tesserae from Calleva Atrebatum, may have wide utility to recognising the source of stone used in mosaics across the whole of the Roman Empire.

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**Figure and Table captions**

Figure 1. Geological sketch map of the Silchester area, after the British Geological Survey, 1:50,000 geological sheets for Reading (268) and Basingstoke (284). a) Geology between Reading and Basingstoke; b) details of geology in the Silchester area. Lower part of figure shows Legend, and the geographical position of Calleva Atrebatum in southern Britain.

Figure 2. Distribution of the Portsdown Chalk Formation and Chalk Group below the Portsdown Chalk Formation, Dorset-Hampshire region, southern England (see inset map for geographical location in Britain). Open squares show the location of the Silchester and Norden Roman sites mentioned in the text.

Figure 3. Stratigraphy and selected bioevents in the Santonian-Campanian Chalk of southern England. Left hand column shows the four upper stages of the Cretaceous System. Age assignments are from Gradstein et al. (2004). Maastrichtian age chalks do not occur in southern England.

Figure 4. Selected species of foraminifera (Figs. 4.1-10) and ostracod (Fig. 4.11) recovered from Silchester tesserae. Foraminifera and ostracod are all from

MPA54161. All scale bars are 100 µm. 1. *Gavelinella usakensis* (Vasilenko, 1961) (spiral view) (MPK13618). 2. *Gavelinella* cf. *pertusa* (Marsson, 1878) (umbilical view) (MPK13619). 3. *Gavelinella monterelensis* (Marie, 1941) (spiral view) (MPK13620). 4. *Gavelinella monterelensis* (Marie, 1941) (peripheral view) (MPK13621). 5. *Gavelinella clementiana* (d'Orbigny, 1840) (spiral view) (MPK13622). 6. *Gavelinella clementiana* (d'Orbigny, 1840) (umbilical view) (MPK13623). 7. *Verneuilinoides muensteri* Reuss, 1854 (MPK13624). 8. *Bolivinoides decoratus* (Jones, 1875) (MPK13625). 9. *Stensioeina pommerana* Brotzen, 1936 (spiral view) (MPK13626). 10. *Stensioeina pommerana* Brotzen, 1936 (apertural view) (MPK13627). 11. *Bythoceratina* cf. *umbonatoides* (Kaye, 1964) (Right valve, lateral view) (MPK13628).

Figure 5. Recrystallized chalk engulfing coccolith (arrow) in tessera from Calleva Atrebatum. Scale bar represents 5 µm.

Table 1. Microfossils and biostratigraphical age assignments for chalk tesserae from Calleva Atrebatum (Silchester). The tesserae sample numbers are those of BGS collections. Sample numbers in brackets are Hampshire County Museum Service Accession numbers.

Table 2. Foraminifera and biostratigraphical age assignments for chalk tesserae from Norden, near Corfe Castle. The tesserae sample numbers are those of BGS collections. The material was sourced from the Dorset County Museum in Dorchester (registered number 1972.14.9, see Sunter 1987).

Fig 1

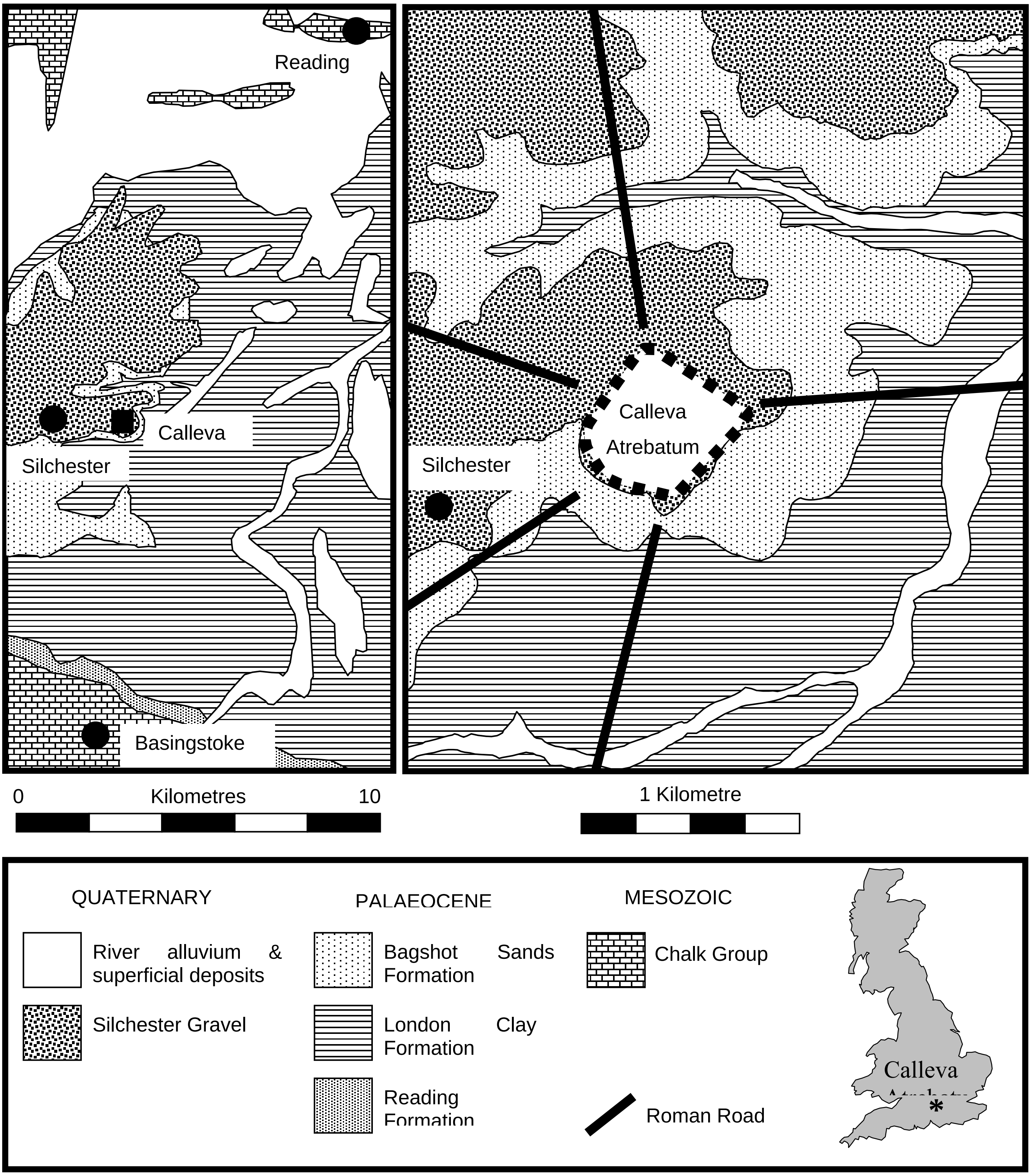
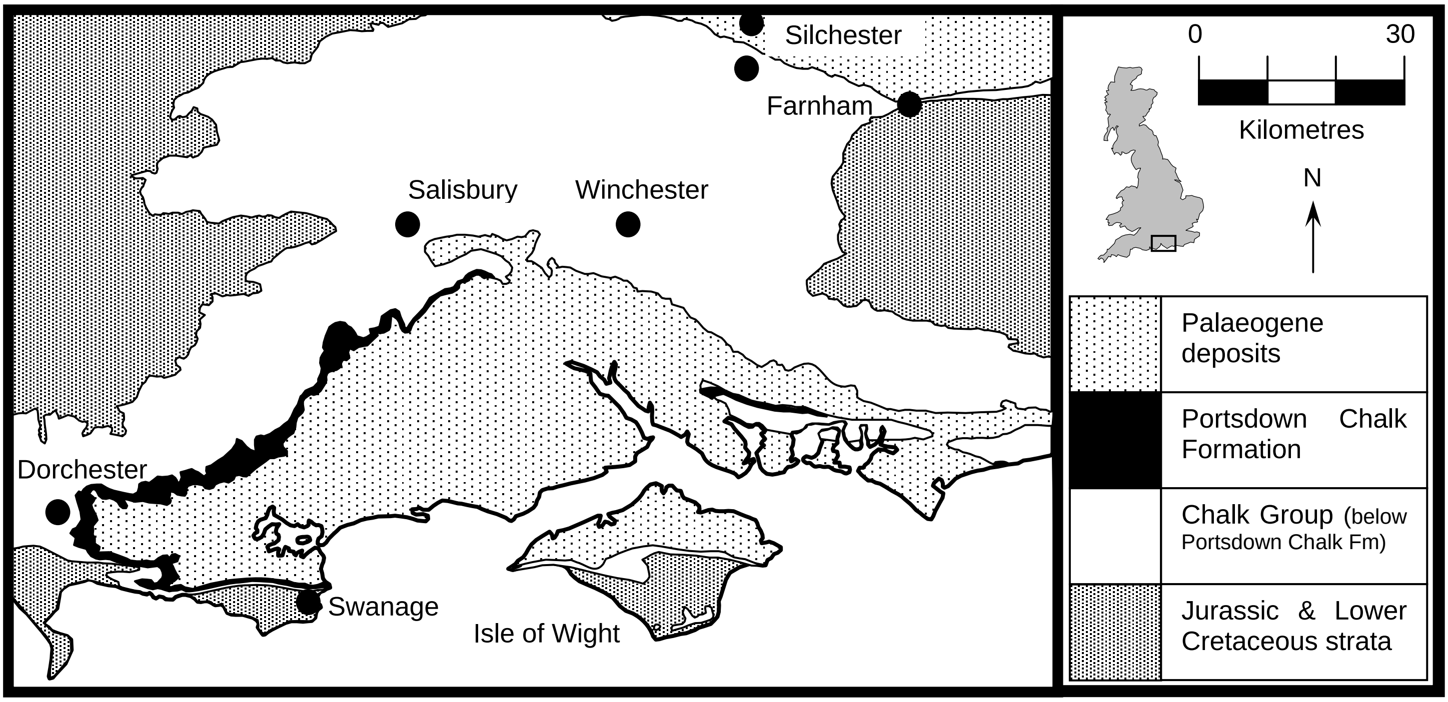

Reading
Calleva
Silchester
Basingstoke
Calleva
Atrebatum
Silchester
0
Kilometres
10
1 Kilometre
QUATERNARY
River alluvium & superficial deposits
Silchester Gravel
PALAEOCENE
Bagshot Sands Formation
London Clay Formation
Reading Formation
MESOZOIC
Chalk Group
Roman Road
Calleva

Fig 2


Silchester
Farnham
Salisbury
Winchester
Dorchester
Swanage
Isle of Wight
0
30
Kilometres
N
Palaeogene deposits
Portsdown Chalk Formation
Chalk Group (below Portsdown Chalk Fm)
Jurassic & Lower Cretaceous strata

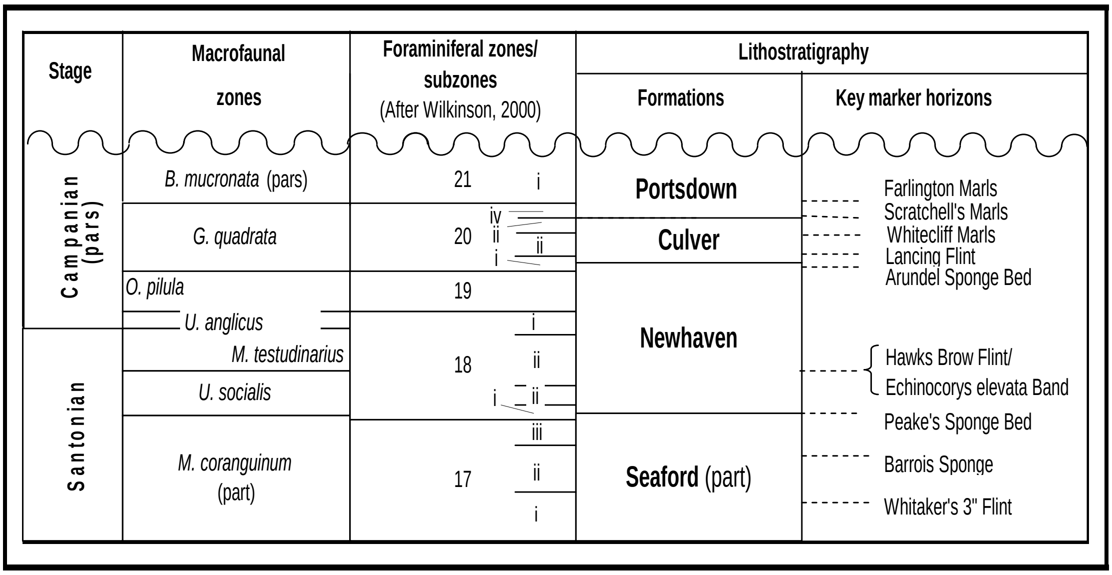

Stage
Macrofaunal zones
Foraminiferal zones/ subzones
(After Wilkinson, 2000)
Lithostratigraphy
Formations
Key marker horizons
Campanian (pars)
Santonian
B. mucronata (pars)
G. quadrata
O. pilula
U. anglicus
M. testudinarius
U. socialis
M. coranguinum (part)
21 i
20 iv ii i ii
19
18 i ii i ii
17 iii ii i
Portsdown
Culver
Newhaven
Seaford (part)
Farlington Marls
Scratchell's Marls
Whitecliff Marls
Lancing Flint
Arundel Sponge Bed
Hawks Brow Flint/ Echinocorys elevata Band
Peake's Sponge Bed
Barrois Sponge
Whitaker's 3" Flint

Fig 3

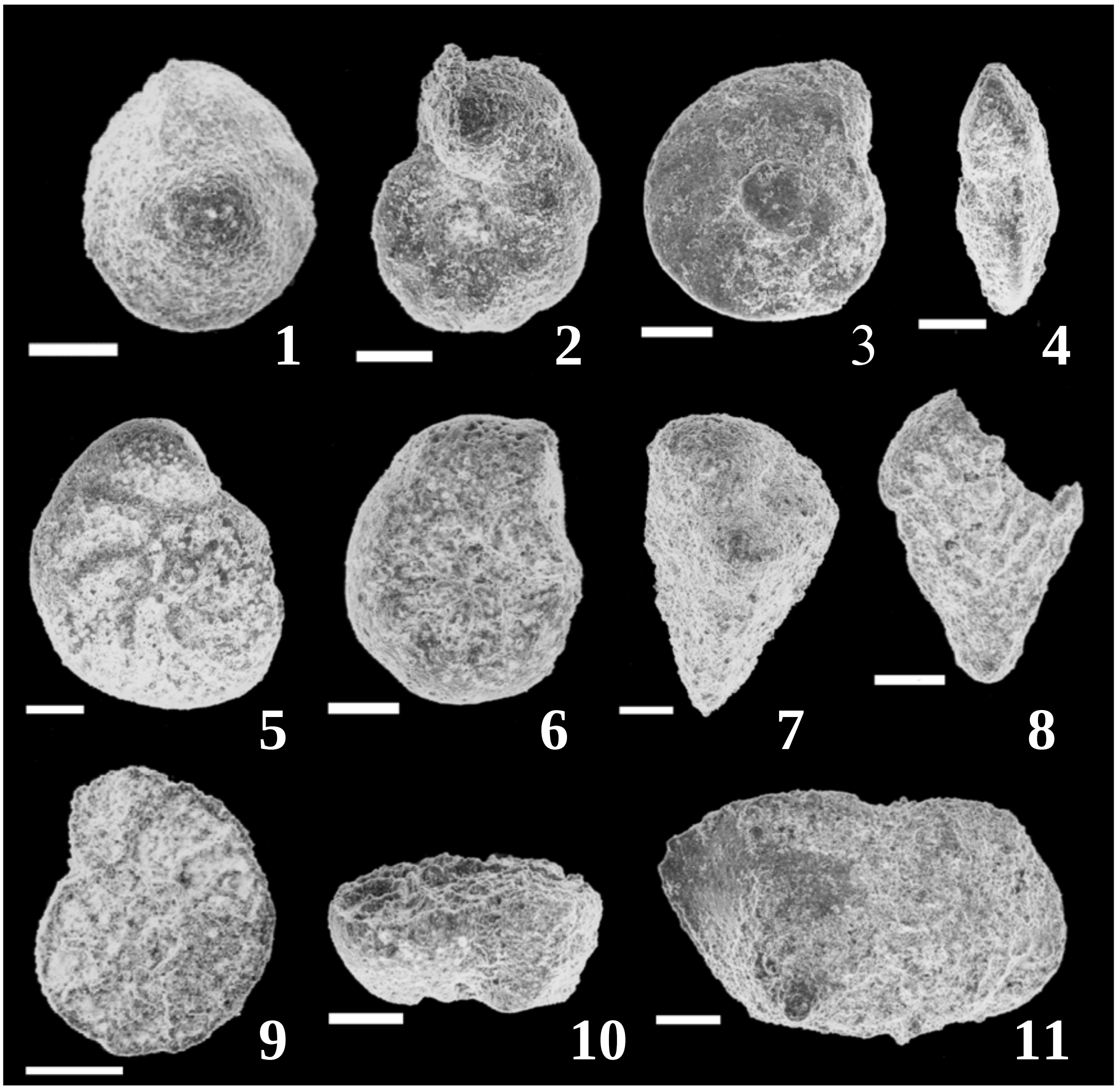



Fig 4

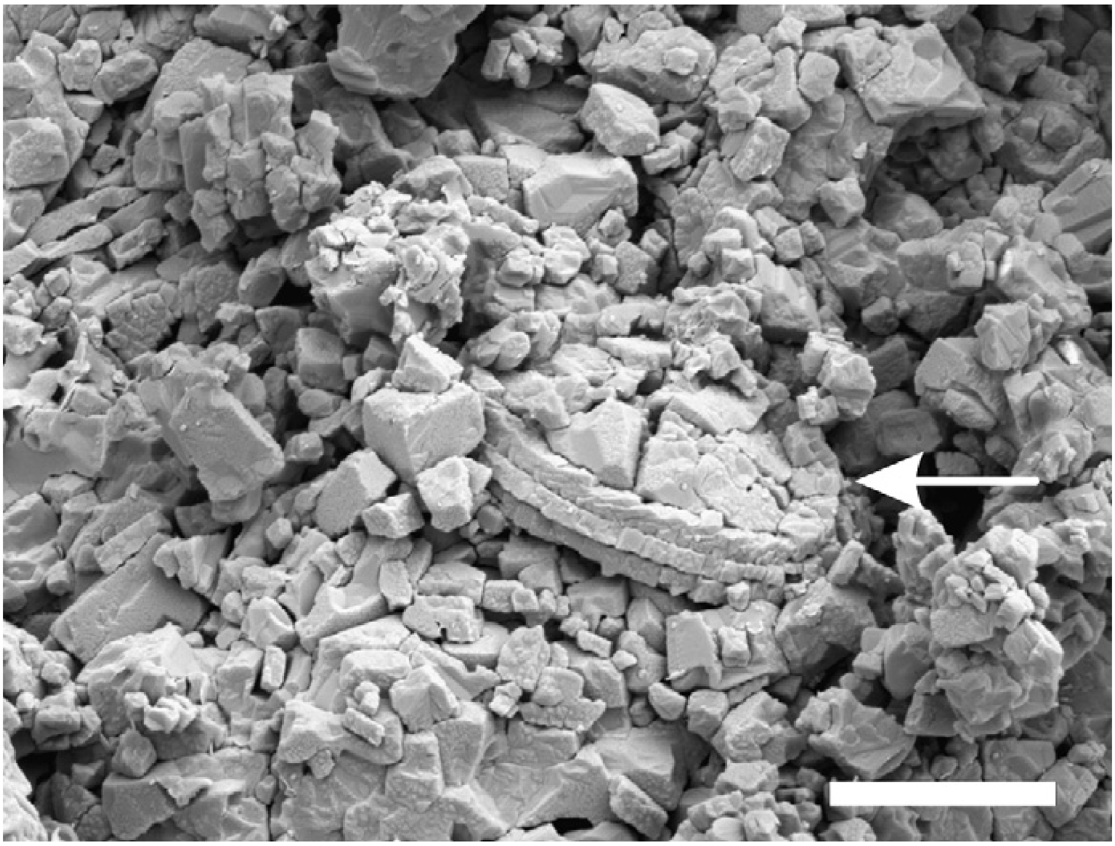


Fig 5

Table 1

| **Registration number** | **Microfossils Recorded** | **Age** |
|---|---|---|
| A.1997.25 (a)<br>MPA54160 | **Foraminifera:** *Gavelinella usakensis, Gyroidinoides nitidus, Globorotalites michelinanus, Heterohelix striata,* ?*Osangularia cordieriana, Praebulimina* sp, *Stensioeina* sp cf *pommerana* | Foraminiferal Zone BGS20 (*quadrata* Macrofaunal Zone) |
| | **Ostracoda:** Barren | -- |
| | **Calcareous nannofossils:** *Lucianorhabdus cayeuxii Micula staurophora, Watznaueria baensiae* | ?Santonian - Maastrictian |
| | **Foraminifera:** *Bolivinoides decoratus, Gavelinella clementiana, Gavelinella lorneiana, Gavelinella monterelensis, Gavelinella cf pertusa, Gavelinella thalmanni, Gavelinella usakensis, Gyroidinoides nitidus, Stensioeina pommerana, Verneuilinoides munsteri* | Foraminiferal Subzone BGS21i (*B. mucronata* Macrofaunal Zone |
| A.1997.25 (b) | **Ostracoda:** *Bythoceratina* sp, *Cytherella* sp | -- |
| MPA54161 | **Calcareous nannofossils:** *Broinsonia* sp., *Eiffelithus eximius Lucianorhabdus cayeuxii, Micula staurophora, Watznaueria baensiae, Zeugrhabdotus* sp. | ?Santonian - Maastrictian |
| | **Foraminifera:** *Astacolus* sp, *Bolivinoides* sp aff *decoratus, Gavelinella clementiana, Gavelinella monterelensis, Stensioeina pommerana* | Foraminiferal Subzone BGS21i (*B. mucronata* macrofaunal Zone |
| | **Ostracoda:** Barren | -- |
| A.2001.10 (a)<br>MPA54162 | **Calcareous nannofossils:** *Micula staurophora* | Middle Coniacian - Maastrictian |
| | **Foraminifera:** Barren | -- |
| | **Ostracoda:** Barren | -- |
| | **Calcareous nannofossils:** *Micula staurophora* | Middle Coniacian - Maastrictian |
| MPA54163 | **Foraminifera:** Barren | -- |
| | **Ostracoda:** Barren | -- |
| | **Calcareous nannofossils:** Barren | -- |
| A.2002.15 | | |
| MPA54164 | | |

Table 2

| Tesserae sample assignment | Foraminifera recorded | Biostratigraphic |
|---|---|---|
| MPA 54216 | Gavelinella clementiana, G. lorneiana, G. monterelensis, G. pertusa, G usakensis, Globorotalites michelinianus, Gyroidinoides nitidus, Osangularia cordieriana, Stensioeina pommerana, Verneuilinoides munsteri | Foraminiferal subzone BGS21i (mucronata macrofaunal) biozone. Campanian Stage |
| MPA 54217 | Gavelinella usakensis, Gavelinella sp., Verneuilinoides munsteri | Foraminiferal biozone BGS20 (quadrata macrofaunal biozone) Campanian Stage |
| MPA 54218 | Gavelinella stelligera, G. usakensis, Osangularia cordieriana | Foraminiferal biozone BGS20 (quadrata macrofaunal biozone). Campanian Stage |
| MPA 54219 | Gavelinella lorneiana | Uncertain |
| MPA 54220 | Gavelinella cf. involutina, G. lorneiana, G. usakensis, Gyroidinoides nitidus, ( Osangularia cordieriana, Quadrimorphina trochoides | Foraminiferal biozone BGS20 quadrata macrofaunal biozone) Campanian Stage |
| MPA 54221 | Gavelinella sp., Stensioeina pommerana | Uncertain |