

# THE STRATIGRAPHIC DISTRIBUTION AND PRESERVATION OF FOSSIL VERTEBRATES IN THE OXFORD CLAY OF ENGLAND

by

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## Summary

Vertebrate fossils are abundant in the basal beds of the Oxford Clay of the East Midlands. Large brick pits in the Peterborough district still yield large reptile skeletons as well as an abundant micro-vertebrate fauna. Preservational styles vary with changes in lithology and there is a correlation between vertebrate abundance and organic carbon content. Vertebrate carcasses are subjected to a number of taphonomical processes which coupled with a variety of sedimentological and diagenetic processes acting on the exposed skeletons produce a spectrum of preservational types.

## Introduction

Fossil marine vertebrates are frequently found in bituminous shales and, in some formations, can be a major part of the nekton. Most palaeontologists are familiar with the often beautifully preserved marine reptiles from European Jurassic bituminous shale formations, such as the Lower Lias of Dorset, and Upper Lias of Yorkshire, both in England, and the Posidonia Shales of Holzmaden, West Germany. Such specimens occur infrequently compared to the large number of fragmentary skeletons and isolated bones and teeth that are also found at these localities.

The Oxford Clay of Central England is in part bituminous, especially in the lower parts of the sequence, and yields an abundant and diverse vertebrate fauna, which although consisting largely of marine vertebrates, also contains a few terrestrial elements.

The Lower Oxford Clay has long been famous for the beautiful preservation of some of its vertebrate remains, and because of the abundance of fresh material, it is a suitable formation on which to base a study of marine vertebrate taphonomy and preservation.

A detailed examination of vertebrate remains from the Callovian transgressive episode, represented in Central England by the Upper Cornbrash, Kellaways beds, Lower and Middle Oxford Clay (Callovian, Middle Jurassic) and Upper Oxford Clay (Oxfordian, Upper Jurassic) shows that a broad spectrum of preservational styles can be recognised, which are in part lithologically dependent. Changes in abundance and diversity are also recognised through the succession. Each of the preservational styles is controlled by a variety of taphonomic, sedimentological and diagenetic factors.

Kauffman (1981) has shown that taphonomic studies on marine vertebrates can yield important palaeoecological and sedimentological data. He examined the fish and marine reptiles of the West German Posidonia Shales (Lower Jurassic, Toarcian) and drew conclusions about the level of oxygenation at the sediment/water interface. Unfortunately the material examined occurs on large slabs of indurated shale which have been prepared from below, prohibiting examination of the upper surface of the specimen, a surface which is crucial to learn about the activities of epibionts and the degree of weathering of bones that took place on the sea floor.

In the Lower Oxford Clay it is usually possible to free the fossils completely from the matrix simply by washing, thereby being able to examine the specimen from all aspects.

Mercian Geologist, vol. 10, no. 3,  
1986, pp. 161-186, 17 figs.,  
plates 9, 10 and 11.

## Localities

The main part of the field work was undertaken in the extensive brick pits (described below) in the Peterborough and Whittlesey districts (Fig. 1). Six brick pits were in operation at the commencement of the project, with the pit at Dogsthorpe (National Grid Reference TF 219 019) being the most important locality. Pits at Yaxley (TL 178 932), Norman Cross (TL 173 916), Orton (TL 165 937), and two pits at Whittlesey (TL 252 976 and TL 250 976) supplemented the collecting.

The pit at Norman Cross was exhausted by October 1982 and fell into disuse. This pit is now partly flooded and has been designated a nature reserve. The remaining pits are all in full production, are highly mechanised and can be dangerous. It is necessary to obtain permission from the London Brick plc before entering these sites.

Other localities which expose the Lower Oxford Clay and have been examined are:- The borrow pit at Farcet (TL 200 958), and Gravel pits at Maxey (TF 135 075 at the time of study). Gravel pits in this district are often temporary, and fresh exposures are continually appearing and disappearing. Gravel pits at Baston (TF 110 130) were yielding Lower Oxford Clay vertebrates in 1978, but have not been examined in recent years by the author.

Pits exposing Middle and Upper Oxford Clay have been examined at Warboys, Cambridgeshire (TL 308 818), and Stewartby, Bedfordshire (SP 010 420). No systematic work has been carried out in these beds, as all visits to these localities were unproductive.

The Lower Oxford Clay was examined in brick pits at Calvert, and Bletchley, Buckinghamshire (SP 670 230 and SP 850 320 respectively), to observe the lithologies associated with specimens from these localities, that have accurately documented stratigraphic information, and are deposited in the collection of University of Leicester, Department of Geology.

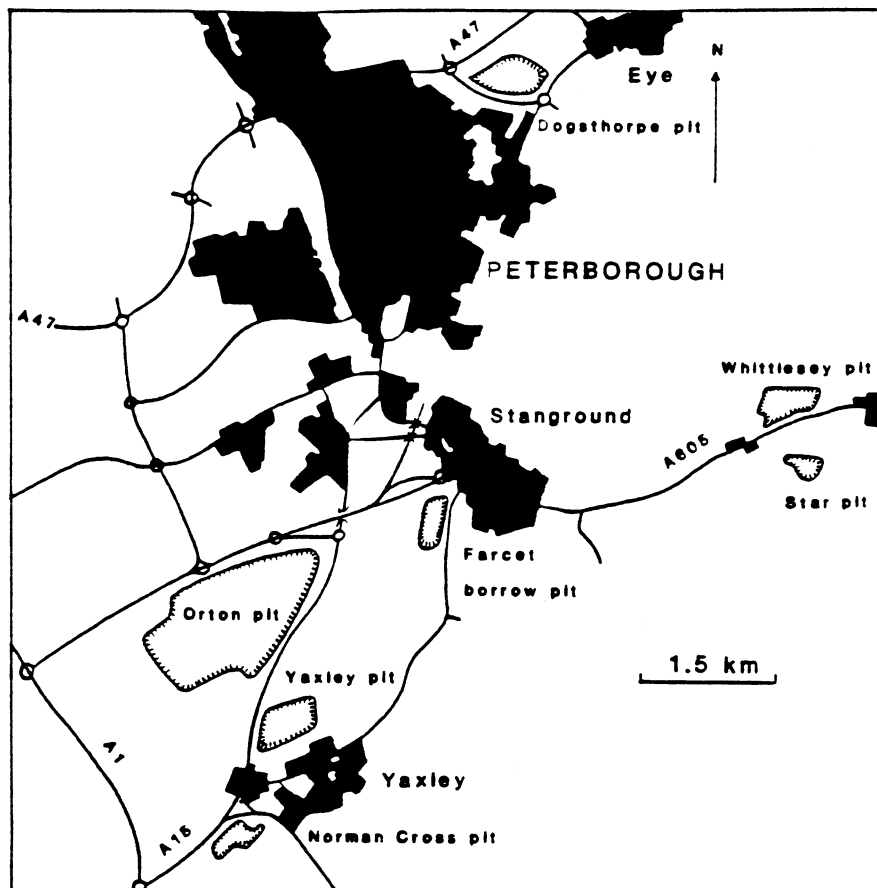


Fig. 1. Map of Peterborough district showing the main vertebrate bearing localities.

During this study, the chance discovery of an ichthyosaur by a site workman at a reservoir construction site near Milton Keynes, Buckinghamshire (SP 892 352), was brought to my attention. A systematic excavation of the skeleton was undertaken, and the results included within the scope of this project.

Visits to classic fossil marine vertebrate sites were undertaken for comparative purposes. These were:- Holzmaden, Baden Wurttemberg, West Germany, and Monte San Giorgio, near the sleepy village of Meride, Tessin, Switzerland. Collections from these sites were also examined in the Museum of the Department of Geology, University of Tubingen and the Natural History Museum, Zurich.

## **Methods**

Although extensive collections of vertebrates from the Oxford Clay, especially the Lower Oxford Clay, can be found in museums all over the world, this type of study requires the examination of *in-situ* specimens. It was therefore necessary to undertake extensive field work to collect fresh material.

Vertebrate remains can usually be found on any visit to a pit in the Lower Oxford Clay, but are rare in the Middle and Upper Oxford Clay. (A visit to a pit in the Middle or Upper Oxford Clay will probably not bring forth any fossil vertebrate material, except perhaps for isolated fish teeth).

Material has been obtained by occasional visits before 1982, almost daily visits during the summers of 1982, 83 and 84, and visits at monthly intervals during other seasons to the brick pits near Peterborough. This ensured that all newly exposed parts of the pits could be examined before being covered by overburden.

Methods used to extract the clay from the pits, the nature of the overburden, and also economic factors can bias sampling. It has not been possible to assess how much effect these had on collecting, but it is assumed that the increased abundance of macro-vertebrates in the basal beds of the Lower Oxford Clay may be partly due to the greater amount of exposure of these beds.

Of the pits examined in the Peterborough area, six are operated for brick production, one for gravel extraction, and the other was a borrow pit for a road construction programme, and is to be used for refuse disposal. Each pit has its own advantages and disadvantages for the collector of fossil vertebrates as outlined below:-

### **1. Gravel Pits**

To the north of Peterborough extensive excavations for river gravels expose the Oxford Clay floor of the flat lying Fens. Due to severe drainage problems, it is often necessary for the operators to dig large sumps and drainage ditches in the base of the workings. These sumps frequently create fresh exposures of the Kellaways beds and the Oxford Clay. Gravel pits towards the eastern edge of the fens sometimes expose the vertebrate bearing horizons of the Lower Oxford Clay, and Kellaways Sand. Unfortunately these workings flood easily, and during winter and in wet summer the pit floor may be inaccessible.

### **2. Farcet Borrow Pit**

During construction of the Peterborough inner ring road, a large borrow pit was excavated to obtain material for the construction of road embankments. The pit is to be used for refuse disposal now that construction of the highway is complete. The pit has exposed part of a glacial channel filled with boulder clay, cutting down to the base of the Lower Oxford Clay, much of which is heavily cryoturbated at the contact. Beneath the channel, the pit extends into undisturbed Kellaways beds and exposed the top of the Upper Cornbrash. The excavation was made by large earth scrapers which left comparatively gentle gradients to the sides of the pit allowing easy access to beds that are normally only rarely exposed in the drainage ditches of the large brick pits. This pit has been one of the most productive over a short space of time. Disposal of refuse was due to start during the summer of 1985.

### 3. Brick pits at Dogsthorpe, Orton, and Yaxley

These pits are all operated by London Brick plc, using large dragline excavators which stand on top of the workable beds and dig the clay beneath. At Dogsthorpe and Yaxley the overburden is stripped off by earth scrapers, leaving a clean surface of unweathered Lower Oxford Clay. At Orton the overburden is also removed by a dragline.

This method exposes a wide strip of basal Lower Oxford Clay, usually beds 10 to 12 (bed numbers after Callomon 1968, see below) along the foot of the working face. The width of this exposure is dependent on the length, usually about 20m, of the jib of the dragline. At Orton the overburden is dumped on the pit floor in advance of the dragline working the brick clay, and consequently buries the strip exposed by the previous cut.

The length of time the freshly exposed basal beds remain accessible depends on two factors. 1) The length and height of the pit face. 2) Demand for bricks. During the economic recession of the late 1970's and early 1980's no night shifts operated in the brick fields, and as a consequence the newly exposed beds remained accessible for longer than normal. This also meant that the amount of newly exposed material was limited, but the advantage was that weathering was allowed to continue for a longer period. This resulted in many specimens being washed out of the clays.

At Dogsthorpe the overburden excavated during 1983 was sold for the construction of the Peterborough ring road, and as a result no overburden was dumped on the pit floor, except for that from the tidying up of the top and bottom of the working face which produced small rows of conical spoil tips parallel to the pit face. These spoil tips consist of a mixture of basal and top beds with broken bricks previously used to build temporary roads for the dragline. The spoil dumps are allowed to weather, often for several years, before being bulldozed during land reclamation. This results in large numbers of vertebrate remains being weathered out, and it is sometimes possible to assess whether the bones were derived from the basal beds or top beds by the presence or absence of broken bricks in the spoil.

Large concretions are frequently dropped on these spoil dumps, especially if the dragline accidentally excavates too deeply and also during the construction of drainage ditches and sumps. At Dogsthorpe and Yaxley the concretions are all from bed 10 and at Orton they come from beds 7/8 and 10. In all pits concretions can yield vertebrate remains. It is possible to determine the derivation of the concretions at Orton by their shape and the degree of brecciation.

### 4. Brick pits at Whittlesey

These pits are also operated by the London Brick Company, but are worked by "shale planers" which stand on the pit floor. This method breaks the clay into small pieces, and leaves no spoil. The floor of the pit is covered with "brick bats" (roads for the machinery, constructed from broken and mis-fired bricks) which hide the freshly exposed basal beds. There is very little overburden in this area and, what there is, is dumped in an old pit which is now becoming very overgrown. As a consequence the pits at Whittlesey are less productive for the fossil collector, although isolated bones are commonly picked up by the pit workmen. Here the workmen, unlike the workmen at Dogsthorpe, Orton and Yaxley, work in the pit bottom, and are only two or three metres from the face. The amount of material picked up by these men suggests that vertebrate remains might be fairly numerous hereabouts. Several visits to these pits have resulted in the discovery of a large caturid fish, shark fin spines, ichthyosuar and crocodilian remains. Before 1975 a large pit at Kings Dyke, (TL 237 970) was worked by dragline in the same fashion as the Yaxley and Dogsthorpe pits. It yielded the remains of a number of reptiles and fish. Historical accounts also suggest that the Whittlesey area was highly productive for vertebrate fossils (Leeds 1956, Porter 1861).

## Stratigraphy

The Oxford Clay forms an almost continuous outcrop from Weymouth, Dorset, to Scarborough, Yorkshire (Fig. 2). Its widest outcrop is in the East Midlands, where it floors the Fens of Cambridgeshire and Lincolnshire. On the wider parts of the outcrop extensive brick manufacturing operations have developed on the Lower Oxford Clay, especially around Peterborough and Bedford, and to a lesser degree at Calvert and Bletchley. A small brick field was developed at Chickerill, near Weymouth, but there are no longer any active pits in this area.

The large brick pits are the only sizeable exposures of the Oxford Clay inland. Coastal exposures occur east and west of Weymouth, and to the south of Scarborough, but there are no good coastal exposures of the Lower Oxford Clay.

The transgressive episode of the Callovian, with the return of ammonite bearing facies to the East Midlands, can be divided into five lithological units (Fig. 3). A lower rubbly limestone, the Cornbrash, is a coarse shelly limestone, often ferruginous, up to 2 m thick, with a rich fauna including bivalves, brachiopods, echinoderms and serpulids. Many of the fossils are worn and encrusted. Hardgrounds covered with *Lophamarsii* are commonly developed.

This is followed by the Kellaways Clay, which in places lies with sharp contact on the Cornbrash, but may pass from shelly limestone to a shelly clay and into normal clay without a sharp boundary. This unit is around 2 m thick, but it is not often seen and little is known about lateral thickness variations. The unit consists of uniform grey clay with occasional calcereous concretions and some pyrite. Fossils are usually poorly preserved, being restricted to internal moulds of ammonite body chambers and rare pockets of bivalves.

Upwards the Kellaways Clay becomes silty and passes into the Kellaways Rock or Sand. Both the base and the top of this unit are difficult to define due to the gradational nature of its boundaries, but again 2 m is about the maximum in the Peterborough district. The Kellaways Rock is a fine sand or silt with an appreciable clay content. In some areas it is cemented into a hard sandstone, but this is never continuous laterally for more than 2 or 3 m. The fauna includes a variety of ammonites and belemnites in super-abundance towards the top, along with small oysters transitional between *Catinula* and *Gryphaea*. Other bivalves occur sporadically, including *Pinna* and *Oxytoma*.

The fourth, and economically most important unit, is the Lower Oxford Clay. Up to 12 m of bituminous clays, shales and paper shales, are punctuated by shell beds composed of *Gryphaea* at the base and *Nuculaceans* and *Grammatodon* towards the top. The Lower Oxford Clay is highly fossiliferous with abundant ammonites, belemnites, bivalves, serpulids and wood. Rare crustaceans and echinoderms also occur. At the base it is possible to find vertebrates without too much difficulty. For a list of Lower Oxford Clay fossils see Duff (1975).

Traditionally the clays above the Lower Oxford Clay are divided into two units, the Middle Oxford Clay, followed by the Upper Oxford Clay. This division is based on faunal elements and it is not possible to distinguish Middle and Upper Oxford Clay on lithological grounds. I prefer to consider them as a single unit, the total thickness of which has never been seen. It is difficult to establish its boundaries in boreholes but a thickness of about 50 m seems probable. The unit consists of grey/green, slightly calcareous clays with low organic carbon content. The fauna includes abundant ammonites preserved as internal moulds in pyrite (Hudson, 1982), bivalves and brachiopods. The upper part of this unit (Upper Oxford Clay) is of Lower Oxfordian age.

The transgressive episode, of which the Oxford Clay is the major lithology, began in the late Bathonian in the East Midlands. Deposition of the Lower Cornbrash brought a return of marine sediments with ammonitic facies after the lagoonal limestones and paralic sands and clays of the Bajocian and Bathonian. Although the marine transgression began in late Bathonian times, clay deposition did not begin until the Lower Callovian. Initially the sheltered limestone lagoons of the Bathonian gave way to a current swept limestone sea with the deposition of the Cornbrash, followed by the Kellaways beds.

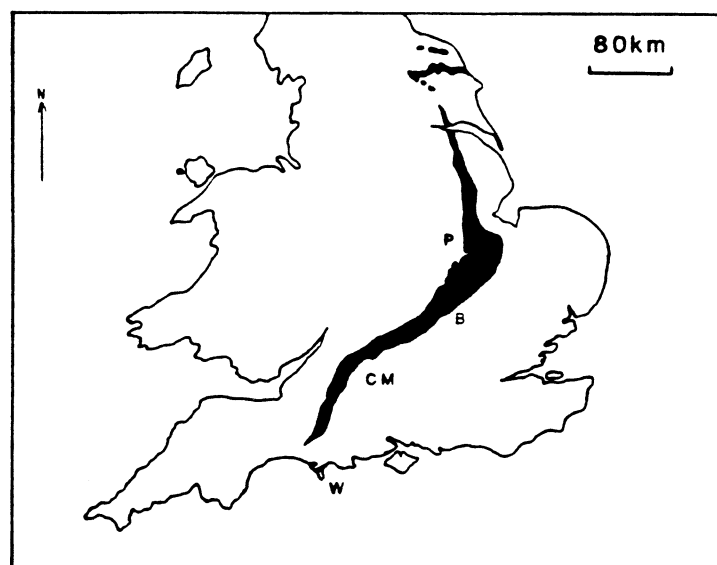


Fig. 2. Onshore outcrop of the Lower Oxford Clay in the British Isles, showing the main vertebrate bearing localities. Based on Duff (1975). B. Bedford, CM. Christian Malford, P. Peterborough, W. Weymouth.

There is a gradual increase in the clay content of the Kellaways Sand upwards as it passes gradationally into the Lower Oxford Clay. This boundary is diachronous over the country (Callomon, 1968), but in the Peterborough and Whittlesey areas it corresponds with the base of the Enodatum Subzone. The top of the Lower Oxford Clay is probably also diachronous with the overlying Middle Oxford Clay as defined lithologically. At Peterborough the upper boundary lies somewhere within the Lower Athleta Zone.

The total thickness of the Lower Oxford Clay in the Peterborough area is around 12m. In Buckinghamshire and Bedfordshire it is around 15 m thick. Most of the thinning at Peterborough occurs in the Jason Zone, and this affects the abundance of fossil vertebrate material. Good sections through the Jason and Coronatum Zones occur around Peterborough and lower beds down to the Kellaways Sand are usually accessible in dry summers in pit drainage ditches.

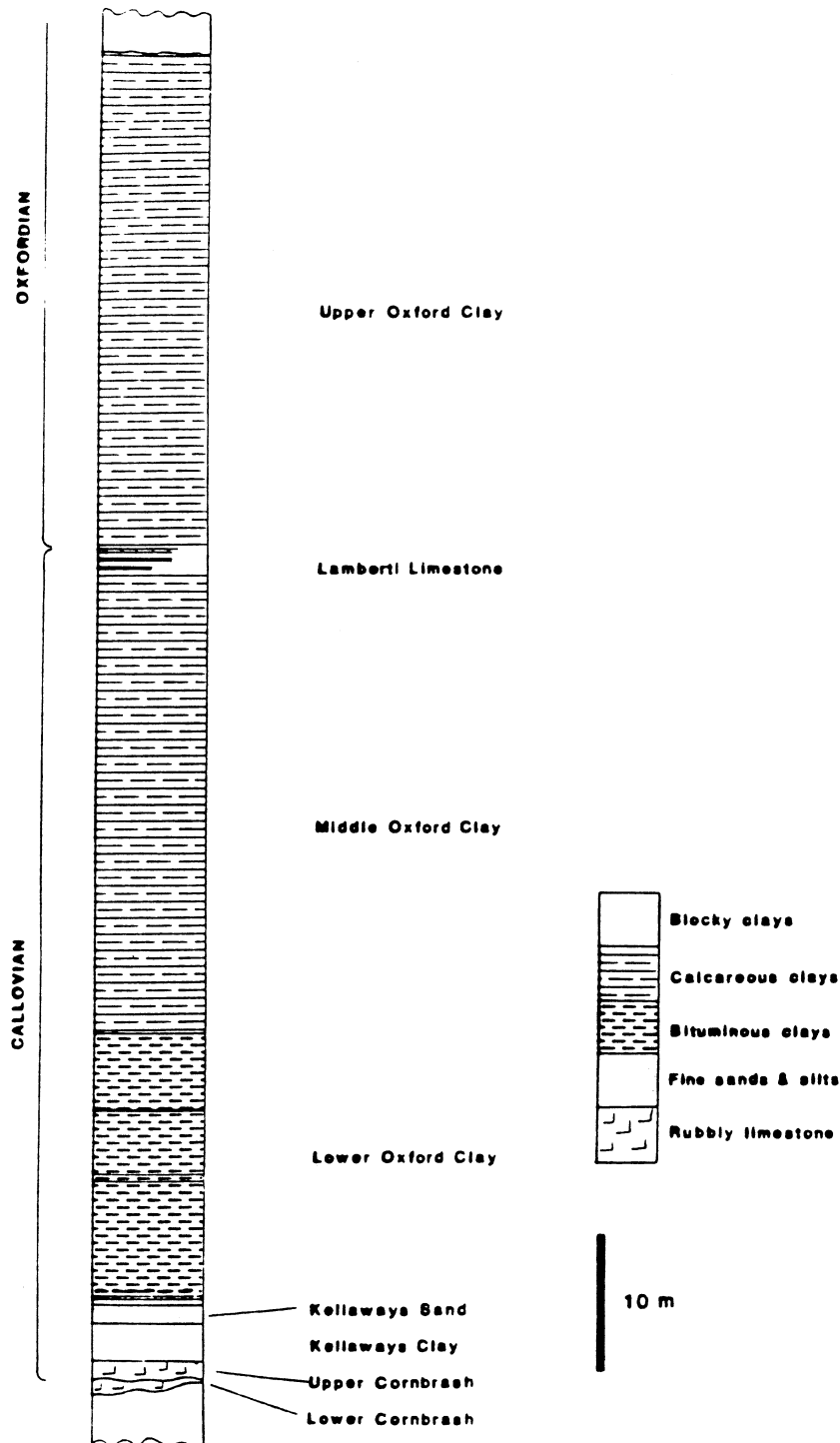


Fig. 3. Simplified stratigraphic log of formations within the Callovian transgressive episode in the East Midlands.

Only the pits at Yaxley and Whittlesey expose the junction with the Middle Oxford Clay, and at Whittlesey access is difficult due to the steepness of the face.

The Middle Oxford Clay is a slightly calcareous, non bituminous clay, and is not generally used for brick production, consequently exposures are rare. A rather weathered face at Norman Cross exposes several metres of clays with large septaria and yields abundant pyritised ammonites of the genera *Kosmoceras* and *Peltoceras*. Older pits that used to work these clays are now flooded as at Eye (TF 231 034), or have been filled in.

The only exposure of the Upper Oxford Clay is at Warboys, Cambridgeshire, where the clay had been worked for extruded pipe production until 1984.

Middle and Upper Oxford Clay vertebrate fossils are not as abundant as those from the Lower Oxford Clay, but sites at Eye, Warboys, Woodham and Weymouth have yielded small quantities of material.

Fig. 3 shows a generalised succession through the Callovian and Lower Oxfordian strata of East England. Details of the vertebrate bearing parts of the Lower Oxford Clay are shown in Fig. 4. Stratigraphical ranges visible in the Peterborough area are shown on Fig. 5.

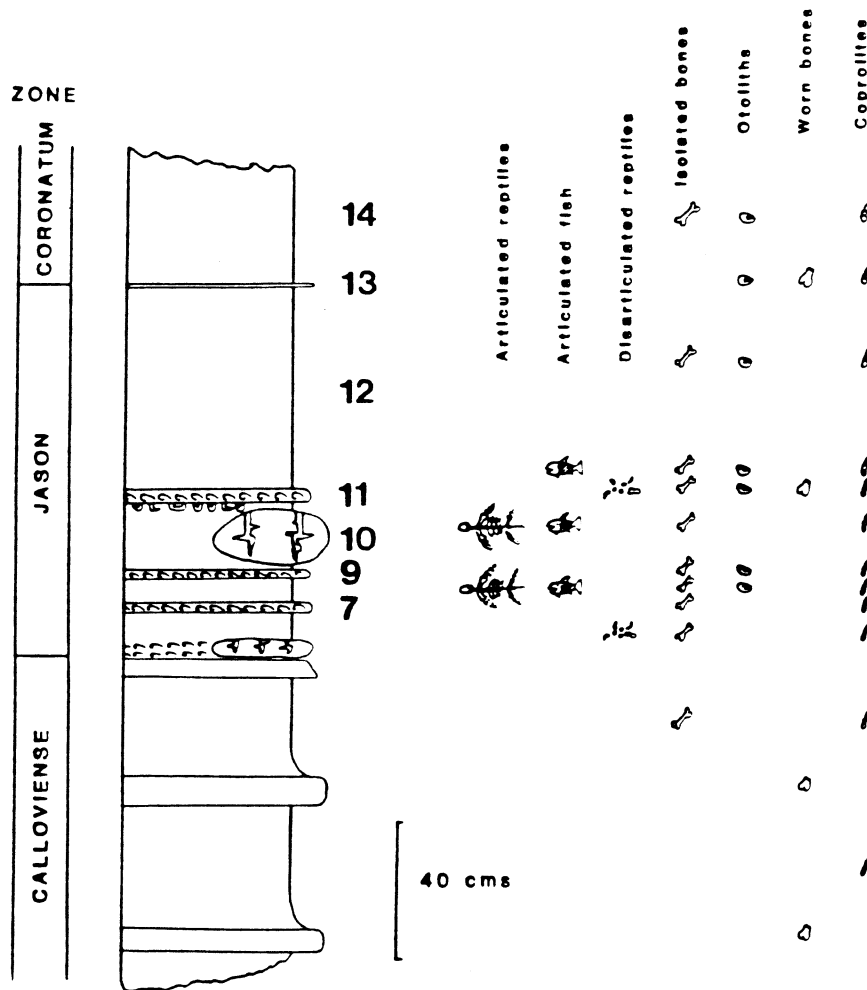


Fig. 4. Distribution of vertebrate preservational types in the basal Lower Oxford Clay of the Peterborough area. Bold bed numbers after Callomon (1968, p. 279).

## The Lower Oxford Clay vertebrate fauna

### Historical

Vertebrate remains have been recorded from exposures over most of the outcrop of the Lower Oxford Clay, and a number of sites have become famous for the beautiful collections of fossil fish and reptiles they have provided. The most notable of these being the old brick pits to the south of Peterborough, Cambridgeshire, (Leeds 1956, gives a map of the localities opposite p. 16), and Christian Malford, Wiltshire (ST 957 774).

Little is known about the stratigraphy of the Christian Malford sites, which were borrow pits dug for the construction of the Great Western Railway. Collections of beautifully preserved Christian Malford fishes exist in the British Museum (Natural History), Bristol City Museum, Devizes Museum, and a few other provincial museums. The locality is also well known for its beautifully preserved cephalopods, some of which display the tentacles and ink sac.

A large crocodylian, *Steneosaurus* sp. in Bath Museum is also recorded as coming from this locality, (Bath Museum, no number).

The sites at Peterborough which yielded material for the famous Leeds collection of fossil reptiles, and the lesser known collections of Swales, in Leicester Museum and Art Gallery, and of P.J. Phillips in the City Museum, Peterborough, are now flooded or filled with fly ash. However, as outlined above, the brick industry at Peterborough is very active, and furnishes many square miles of exposure of the vertebrate bearing beds from which the old collection were obtained.

Prior to the development of the Fletton brick making process, many small brick pits were in operation over the outcrop of the Oxford Clay. A few of these in the Lower Oxford Clay yielded vertebrate fossils.

A number of these historical sites in the Lower Oxford Clay have been identified from the literature, (Porter 1861; Judd, 1875; Jukes-Brown 1885, and Leeds, 1956) but these sites are now overgrown, flooded or inaccessible (Fig. 2).

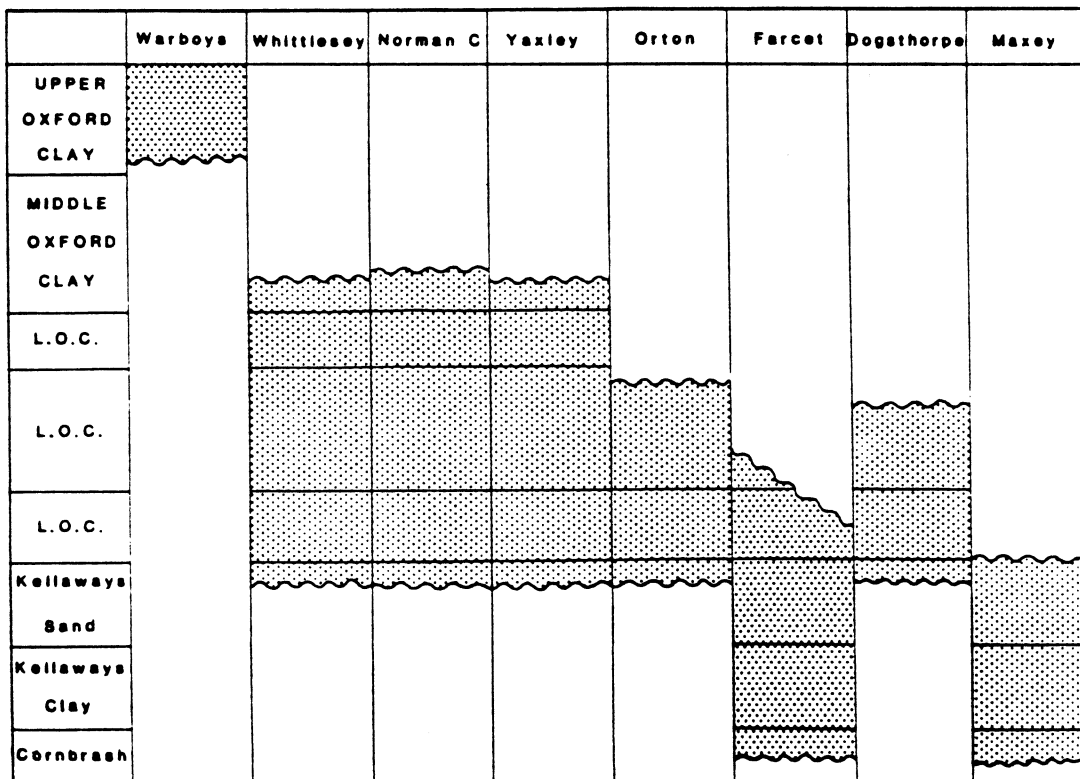


Fig. 5. Diagram showing the stratigraphical range of the Oxford Clay visible at various localities in the Peterborough area.

## **Museum collections**

To supplement the field data, material in the following museums has been examined. British Museum (Natural History), London, BM(NH)., Sedgwick Museum, Cambridge, SMC., Oxford University Museum, OUM., Leicestershire Museums and Art Gallery, LCM., Peterborough City Museum and Art Gallery, PCM., Buckinghamshire County Museum, Aylesbury, BCM., Dorset County Museum, Dorchester, DCM., and the collection of the department of Geology, University of Leicester, LEJUG..

Numerical records of Oxford Clay vertebrates in a number of other collections have been used to assess the abundance of taxa, but none of these specimens are referred to individually.

Vertebrates have been recorded from the Lower Oxford Clay for well over one hundred years. The fauna is diverse, consisting mainly of marine reptiles and fishes, although a poorly represented but nevertheless diverse terrestrial fauna of dinosaurs is known. There are also a few records of pterosaur remains from the Lower and Middle Oxford Clays. (Lydekker, 1890; Leeds, 1956).

The marine reptiles are the most abundant and are now very well known, due largely to the industrious collecting efforts of Mr Alfred Leeds at the turn of the century, which led to descriptions in a two part monograph by Andrews (1910, 1913). This has formed the basis for all of the more recent reviews of the fauna. (Appleby, 1956; Tarlo, 1960; and Brown, 1981). The dinosaur fauna was described by Seeley in 1889, and Woodward in 1905, but reviews have appeared more recently (Charig, 1980; Galton, 1980).

The fish fauna is less well known, and was mainly described at the turn of the century (Woodward 1897). Thies (1983) discovered several new species of neoselachian sharks based on teeth collected from shell beds in the Lower Oxford Clay of Bedfordshire. Fieldwork undertaken for this study has resulted in the discovery of several new fossil fish, including a new palaeoniscid and a giant pachycormid.

## **Stratigraphic distribution of vertebrates**

### **Upper Cornbrash**

Vertebrates have been recorded from the Upper Cornbrash (Lydeker 1889) at Stilton, Cambridgeshire (TL 170 890) but the exact locality is in some doubt. Most of this material appears to be of a fragmentary nature. More recently Upper Cornbrash vertebrates have been found in the top of the formation from the gravel pit at Maxey, where isolated bones, usually worn, are found in association with *Lopha marshii* and *Macrocephalites* sp..

### **Kellaways Clay**

No certain records exist of vertebrate remains coming from the Kellaways Clays of the East Midlands. Old brick pits in Northamptonshire, around Thrapston, and elsewhere in the Nene valley have yielded saurian remains (Judd 1875), some of which may have come from the Kellaways Clay, but there are no longer any exposures at these sites.

Existing exposures of Kellaways Clay at Thrapston, (SP 990 780) at Maxey gravel pit, at a refuse disposal tip at Fletton, (TL 180 956) and the borrow pit at Farcet, failed to yield any vertebrate remains during this project.

### **Kellaways Sand**

Macro-vertebrate remains occur frequently in the Kellaways sand of Cambridgeshire and Lincolnshire, despite most of the exposures being drainage ditches in pit floors. The remains are usually isolated and worn bones, sometimes encrusted with epibionts. Most of the material encountered appears to be sauropterygian, but some ichthyosaur material is known. An uncertain record of a sauropod dinosaur from this horizon is reported by Seeley (1889).

### **Lower Oxford Clay, Beds 1-6**

The basal beds of the Lower Oxford Clay are probably quite rich in macro-vertebrate remains, but I have not found any substantial quantities of material *in-situ*.

### **Lower Oxford Clay, Bed 7**

Bed 7 is a *Gryphaea* and ammonite coquina in a greenish clay matrix. Despite the limited amount of exposure (bed 7 is only well exposed at Farcet) a number of scattered vertebrate remains have been discovered. Material collected includes the remains of three crocodylians and some scattered ichthyosaurian bones.

At Orton a concretion horizon is developed at this level. The concretions can be up to 1.5 m long, 0.5 m wide, and as much as 20 cm thick. They are frequently highly brecciated, and re-cemented with coarse white calcite. Bones are commonly found within these concretions after they have been exposed in sumps in the pit floor. The concretion horizon is not developed at this horizon elsewhere, except perhaps at Maxey, although the correlation is a little tenuous.

The borrow pit at Farcet has good exposures through this shell bed, and has yielded the remains of at least two crocodylians. All the specimens consist of scattered elements, some of which display weathered fractured surfaces. These features must have occurred on the sea floor. (See ischium of PCM R. 248). The crocodylian LEIUG 88450, was associated with a large quartzite pebble encrusted with oysters, possibly a gastrolith, swallowed for bouyancy regulation (Taylor, 1981 and pers. comm.). Unfortunately this is of little value for determining the source area.

### **Lower Oxford Clay, Bed 8**

Fissile shales of bed 8 have yielded few vertebrates, there being only a single specimen believed to have come from this horizon. A perfectly preserved, complete specimen of *Cryptoclidus eurymerus* was reported by Charig and Horrell, (1971), from the base of the large brick pit at Orton (Pit LB 2/4 in their paper). They did not record the exact horizon, but commented that it was from the Jason Zone. Personal discussions with a number of workmen who helped at the discovery site suggested that the specimen lay some eighteen inches below the working face of the pit. When discovered, Orton pit was being excavated by a face shovel standing on a firm floor provided by bed 10. This suggests that the *Cryptoclidus* must have come from bed 8 since this is approximately eighteen inches below the top of bed 10. This is the only non-shell bed lithology that lies within the Jason Zone below the main concretion horizon of bed 10.

### **Lower Oxford Clay, Bed 9**

This *Gryphaea* shell bed has yielded only a single macro-vertebrate during my field season. The specimen is a fish fin ray 3 m long from the giant pachycormid fish *Leedsichthys*. It was found in the borrow pit at Farcet, during December, 1984, but because the bones of the fin are so fine, I decided not to collect the specimen.

### **Lower Oxford Clay, Bed 10**

Several complete or partially complete vertebrate skeletons have been collected from this horizon. Bed 10 is a highly bituminous (up to 10% organic carbon, Fisher, 1983) fissile shale with large septarian concretions whose formation was discussed in detail by Hudson (1978). Invertebrate fossils are abundant and include benthic and pelagic forms. The infauna is restricted, but certain infaunal and semi-infaunal elements are common. Vertebrates occur in both the fissile shales and in the concretions, where the shape of the concretion may be influenced by the shape of the vertebrate skeleton.

A recently collected suite of specimens from this horizon has been deposited in the collections of the Department of Geology, University of Leicester, by Mr P. Schultz, formerly of Towcester, Northamptonshire. This collection is well documented, with accurate location and stratigraphic data. Most of the material is enclosed in large concretions, although some is from the shale. Nearly all of the specimens were collected from the large pit at Orton.

Several fish and reptile specimens from this horizon were collected by the author from the pit at Dogsthorpe.

### **Lower Oxford Clay, Bed 11**

Bed 11 is a *Gryphaea* and ammonite coquina in a green clay matrix, containing a diverse invertebrate fauna dominated by cephalopods and bivalves. Burrows in the top of Bed 10 below are filled with the finer shell debris and clay matrix of bed 11.

Both macro and micro-vertebrates are common. The pit at Dogsthorpe has been the most productive for larger marine reptiles (e.g. Fig. 6) but this is due to the operator of the dragline, who leaves much of the shell bed intact in the floor of the pit. In the Orton and Yaxley pits this bed is removed and bed 10 is left as the floor of the pit. During this study the pit at Dogsthorpe produced on average three skeletons from bed 11 each time the dragline completed a cut along the face, (each cut takes six months, but this is dependent on economic factors). Many more skeletons have occurred since several were destroyed by the dragline leaving scrappy fragments lying around the pit floor.

**Lower Oxford Clay, Bed 12**

Bed 12 is a dark grey clay which is fissile in its lower part. Large patches of this bed have been exposed in the pit at Dogsthorpe, and have yielded the remains of a large pachycormid fish, and a number of other smaller fish. A gigantic fish fin, (Fig. 8) was found at an unknown level, thought to be within bed 12, at Farcet borrow pit.

**Lower Oxford Clay, Bed 13**

This bed, although only 2–3 cm thick, yields abundant vertebrate remains. The bed consists of a coquina of nuculacean bivalves and broken ammonites, with masses of small belemnites, coprolites and worn fragments of wood. It is highly pyritised and is conspicuous on weathered pit faces as a thin orange band, usually about 1 m above the floor of the large brick pits. At Farcet borrow pit it is present in a few places where the glacial channel has not cut too deeply.

All of the macro-vertebrates obtained from this level are isolated bones and teeth and only rarely are associated elements found. Usually the bones are broken, worn, encrusted with epibionts and have a thin coating of pyrite. Microvertebrates are also common at this level, particularly otoliths, most of which are slightly etched (Plate 9D).

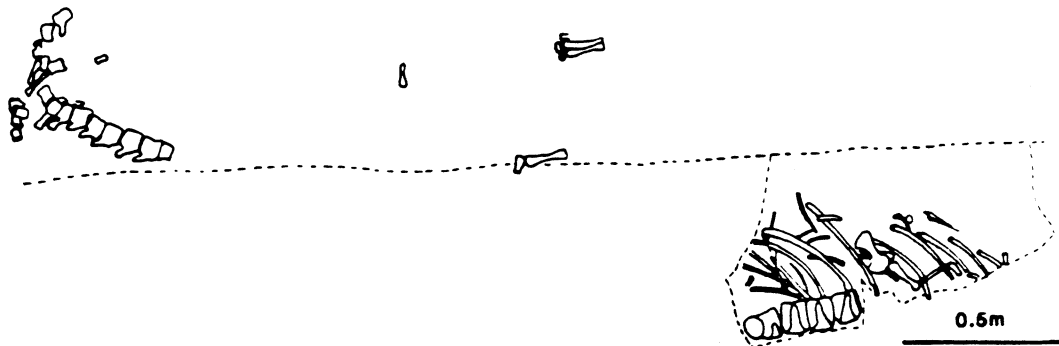


Fig. 6. Plan of in-situ skeleton of *Metriorhynchus* sp. LEIUG 90985. Lower Oxford Clay. Bed 10 and 11, Dogsthorpe, Peterborough.

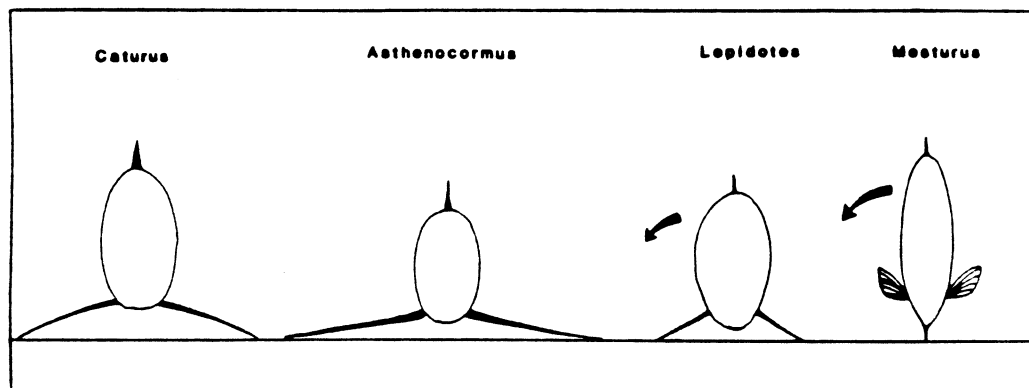


Fig. 7. Cross sections of fishes to show how body shape and pectoral fin morphology can influence the attitude of a fish carcass on the sea floor.

#### Lower Oxford Clay, Bed 14

During this study only micro-vertebrate material was found in this bed. This bed is the thickest unit within the Lower Oxford Clay. Fossils are less abundant than in some of the other horizons. The bed is made up of almost featureless bituminous shale, which is blocky when fresh, becoming slightly fissile after weathering.

#### Lower Oxford Clay, Bed 15

This is a nuculacean shell bed in which micro-vertebrate material is common. Only two associated ichthyosaur centra were collected from this level.

#### Lower Oxford Clay, Bed 16

This highly bituminous shale forms a useful marker horizon in the Peterborough brick pits, which stands out as a dark band on the pit face between two prominent shell beds.

During 1972 Mr P. Schultz discovered an almost complete, fully articulated, mature adult specimen of *Ophthalmosaurus* sp. from this level at the Orton pit. LEIUG 90986, which was excavated by Dr R. Clements of Leicester University (Fig. 9). This specimen is perhaps the most complete *Ophthalmosaurus* sp. to be collected from these pits in recent times.

#### Lower Oxford Clay, Bed 17

This nuculacean shell bed is well exposed in the abandoned pit at Norman Cross, where, in 1983, it was possible to walk along one of the pit faces at this level. Several unidentifiable fragments of very worn reptilian bone were found. Micro-vertebrates are also common at this level.

#### Lower Oxford Clay, Beds 18 to Top

Because of the limited amount of exposure, and inaccessibility of these higher beds, no macro-vertebrate material was found above bed 17 in the Peterborough district. Samples taken at these higher levels for microvertebrates all yielded fish teeth and otoliths.

#### Clays above the Lower Oxford Clay "Middle Oxford Clay"

Although historical records exist of vertebrates from the Middle Oxford Clay (Leeds, 1956, Lyddeker, 1889) several visits to exposures of these beds at Norman Cross, Cambridgeshire and Stewartby, Bedfordshire, failed to reveal any vertebrate specimens.

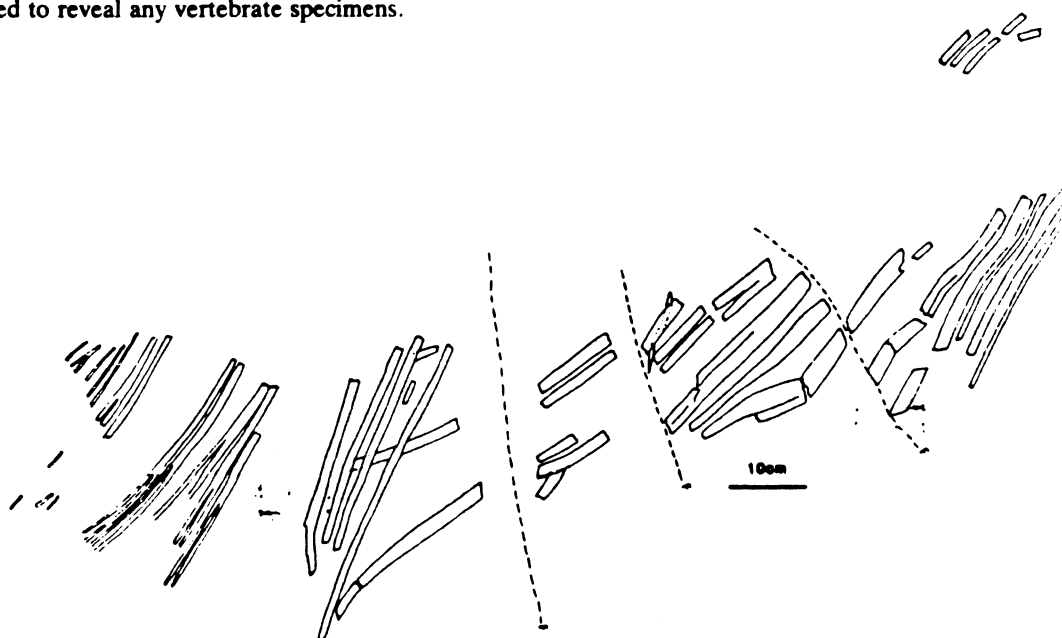
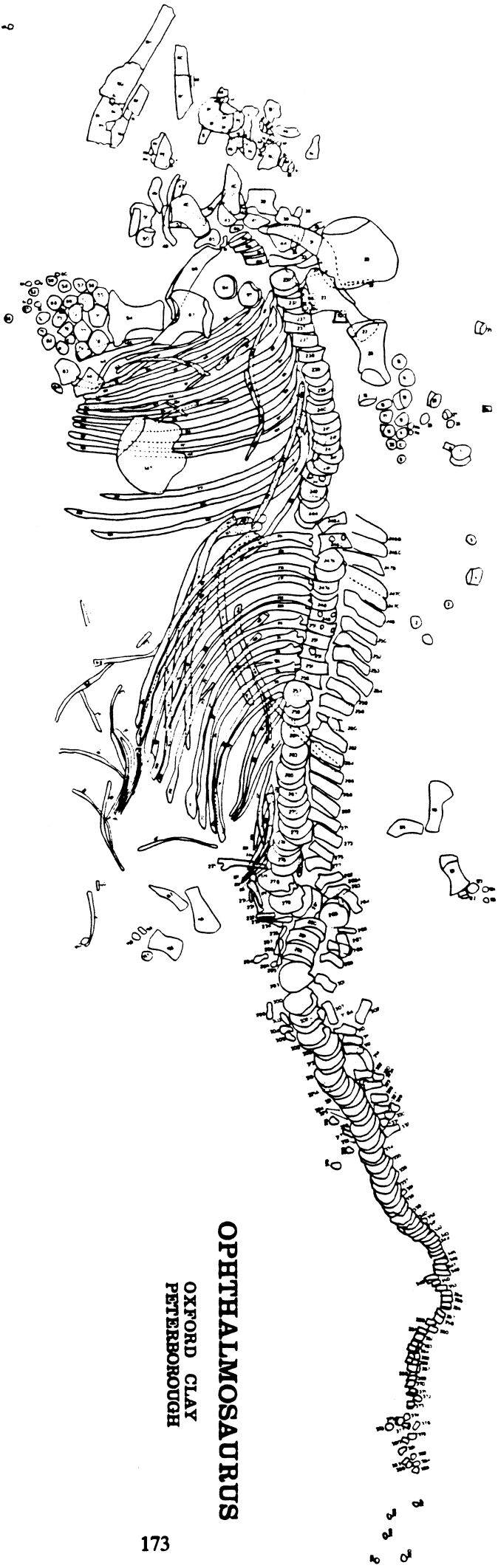


Fig. 8. Portion of fin of *Leedsichthys* sp. Lower Oxford Clay, Bed 12 or 14.



**OPHTHALMOSAURUS**

OXFORD CLAY  
PETERBOROUGH

Fig. 9. An almost complete, fully articulated, adult specimen of *Ophthalmosaurus* sp. from the Lower Oxford Clay (Coronation Zone) of Orton Pit. Discovered in 1972 by P. Shultz and excavated by Dr R.G. Clements of Leicester University. Cat. no. LEUG 90986. Ribs of the right side omitted for clarity.

## Lamberti Limestones

No records of vertebrates from this level exist, and no certain exposures of this bed are known today. A downfaulted block of Middle Oxford Clay at Stewartby shows a series of thin muddy limestones which might represent the Lamberti Limestone.

## Clays above the Lower Oxford Clay "Upper Oxford Clay"

The only large exposure of the Upper Oxford Clay in the East Midlands was that of the now disused brick pit at Warboys, Cambridgeshire (Callomon, 1968). Vertebrates have been recorded from this pit by Forbes (pers. comm.) but recent visits produced only isolated fish teeth. Fig. 10 shows the scattered remains of an ichthyosaurian from the Mariae Zone, of Warboys.

## Palaeoecology

Vertebrate skeletons are internal, multi-component systems, dominantly composed of a single mineral phase. Vertebrates are, therefore, useful as palaeoecological indicators, especially when invertebrates are absent due to diagenetic removal.

As the vertebrate skeleton is internal except for teeth and some types of dermal armour, a skeleton cannot be encrusted by epibionts until the animal has died and the bones exposed. Therefore, any epifauna on the surface of a bone must be post-mortem, and indicates the presence of oxygenated sea water at or near the sediment water interface. Vertebrate remains, therefore, conveniently avoid the argument that ensues with encrusted ammonites, as to whether encrusting took place whilst the ammonite was alive or whether encrusting was post-mortem (Seilacher, 1981).

Two mineral phases occur in fish skeletons, hydroxy apatite, and calcium carbonate; bones and teeth being composed of the phosphatic phase, and otoliths of the carbonate phase. These different phases are prone to different diagenetic effects which can affect the preservational potential of certain skeletal elements.



Fig. 10. Partial skeleton of an ichthyosaur, cf. *Ophthalmosaurus* sp. Upper Oxford Clay, Warboys, Cambridgeshire. Excavated by Dr C. Forbes. SMC J.68689.

## Vertebrate preservational styles in the Oxford Clay and adjacent strata

Andrews (1910) commented on the often beautiful preservation of some of the fish and reptile specimens, but preservation has until recently been virtually ignored by most palaeontologists and sedimentologists. Vertebrate palaeontologists have now begun to realise the importance of taphonomic studies on vertebrate remains for palaeoecological interpretations. Increasingly, papers are now appearing in which taphonomy forms at least a part of the discussion. (Camp, 1980; Milner, 1980). Studies on the taphonomy of recent aquatic vertebrates (Schafer, 1972; Wuttke, 1983) have shown that the decomposition and break up of a carcass is a complex process, and requires detailed observation. Attempts to do this with fossil marine reptiles from bituminous shales have been made by Keller (1976), and Brenner, (1976) on ichthyosaurs from the South German Posidonienschiefer.

### Vertebrate preservation

Although an examination of museum material can be informative for preservational studies, much data is lost when the specimen is taken from the ground and extracted from its matrix. An examination of museum material cannot show the attitude of the specimen as it lay in the ground, and in most cases, considering the loving care which some of the early amateur collectors of Oxford Clay vertebrates must have put into their work, it is surprising that very little data on stratigraphic occurrence, or on the attitude of the skeletons was recorded.

During the latter part of the last century, there was no established zonal scheme for the Lower Oxford Clay, and the first detailed section through these beds in the Peterborough district did not appear until 1929 (Brinkman, 1929). So, unless the collector had any knowledge of geology it was perhaps not easy to establish where in the sequence a specimen came from. This is unfortunate, in that the abundance of Oxford Clay material, with suites of specimens showing ontogenetic variation, and variation within populations, could have led to some interesting evolutionary interpretation, had detailed stratigraphic information been recorded.

An examination of several *in-situ* sauropterygians, crocodylians, ichthyosaurs and fish reveals that even in a seemingly monotonous sequence of clays, slight perturbations of current activity, oxygen level, firmness of substrate and rate of sedimentation can dramatically affect the style of preservation of the animals. Although the range of preservational styles forms an almost continuous spectrum, it is convenient to recognise five preservational categories based on taphonomic and sedimentological criteria. Fig. 11 shows the five preservational styles recognised in the Lower Oxford Clay.

#### 1. Articulated skeletons

Articulated skeletons are those in which all of the bones of the skeleton are present, and lie in positions showing true bone to bone relationships with adjacent elements of the skeleton. Teeth are usually present within the jaws, and in some cases coprolitic material may be present within the gut region. In exceptional cases there may be evidence of soft part preservation.

Such beautifully preserved specimens are rare, and restricted lithologically to only a few horizons within the Lower Oxford Clay. Most notably they occur within fissile highly bituminous shales of the Jason Zone, at the base of the Peterborough succession. These bituminous shales are interbedded with *Gryphaea* shell beds, which also yield large vertebrates. Within the fissile shales large sauropterygians, BM(NH) R. 8621, (Charig et al 1971), LEIUG 90988, Fig. 12, crocodylians, LEIUG 90987, and LEIUG 90988, Fig. 6, have been found, beautifully articulated, along with a small *Lepidotes macrochierus* Woodward, BM(NH) P. 61398. *Asthenocormus* sp. BM(NH) P. 61563, and *Hypsocormus* sp. BM(NH) P. 61397.

The fish all display perfectly articulated tails, fins and scales, and each specimen contains coprolitic material within the body wall. In the case of BM(NH) P. 61398 only the lower surface of the fish is articulated, the scales of the upper surface (right side of the fish) having been disturbed slightly, probably due to the escape of decomposition gases. The *Asthenocormus* sp. contains fragments of *Leptolepis* in the gut.

## 2. Disarticulated skeletons

The degree of disarticulation between specimens can vary considerably. Skeletons may be completely disarticulated, but with all the bones present and in association, or may be only partially disarticulated with more coherent parts of the skeleton, such as interlocking vertebrae, remaining articulated. Due to the large range covered by this category, there is less restriction lithologically, but there is a positive correlation between grain size and degree of disarticulation.

The *Gryphaea* shell beds within the Jason Zone represent non sequences and reworking events and frequently yield large reptilian skeletons. These are always disarticulated partly as a result of reworking of articulated specimens from the underlying shales, and partly due to storm activity upon specimens deposited during the event. A partly disarticulated *Ophthalmosaurus* sp. LEIUG 90984, and a juvenile plesiosaur of *Cryptoclidus* sp. LEIUG 90983, both from Dogsthorpe brick pit, were found within the same shell bed. Fig. 13 shows the position of the skeleton of *Ophthalmosaurus* sp. LEIUG 90984 and shows that parts of the skeleton, such as the shoulder girdle and a part of the rib cage, are articulated, but detached from the skeleton probably due to scavenging on the sea floor. Due to scavenging and perhaps disturbance by storm activity the juvenile plesiosaur, LEIUG 90983, (Fig. 14) shows no articulation of the skeleton.

Higher within the sequence, the deposit feeder bituminous shales, *sensu* Duff (1975), also yield disarticulated skeletons. The rare occurrences of vertebrates in the slightly calcareous shales of the Middle and Upper Oxford Clays are also usually disarticulated (Leeds, 1956; Forbes, unpublished data). Fig. 15 shows the skeleton outline of a large ichthyosaurian *Ophthalmosaurus* sp. BCM 1001 1983 from the deposit feeder bituminous shales of the Coronatum Zone at Milton Keynes, Buckinghamshire. This specimen is partially articulated, mainly on its left side, and partially disarticulated, especially towards the distal end of the vertebral column, the right side of the rib cage and the limbs. This should be contrasted with LEIUG 90984 in (Fig. 13).

The Milton Keynes specimen BCM 1008, 1983 remained partially articulated because the skeleton sank part the way into the muddy sea floor, the enclosing sediment therefore holding the skeleton together after the integument had decomposed.

Fig. 6, shows part of the skeleton outline of a large *Metriorhynchus* sp. LEIUG 90985, which was discovered lying partly in fissile shales and partly in an overlying *Gryphaea* shell bed. Within the fissile shales; the trunk, proximal part of the tail, shoulder girdle and limbs; remain fully articulated. The body cavity contains abundant cephalopod hooklets, presumably the gut contents. Of the parts of the skeleton found in the overlying shell bed the distal part of the tail was disarticulated, but even these bones were closely associated. This indicates that the carcass or skeleton had been completely buried by the fissile shale sediment, and partly re-exposed by storm activity rather than strong current activity. If current activity had been responsible for the reworking, the smaller elements of the tail (small vertebrae and chevrons) would have been washed some distance from the site of the articulated skeleton. Here it is clear that two specimens lie both in category one and category two, but for different reasons; the first due to a soft substrate and slow sedimentation rate, the second due to partial reworking.

## 3. Isolated bones and teeth

Isolated bones and teeth of fish and reptiles occur frequently throughout the Lower Oxford Clay sequence. Many are perfectly preserved. Isolated bones probably dropped from decomposing carcasses floating in the water column (Schafer, 1972), although some may have been derived from carcasses on the sea floor by scavengers. The most likely explanation for the occurrence of isolated teeth is that they were simply shed whilst the animal was still alive, as in present day reptiles, or like the isolated bones they may also have dropped from drifting carcasses. In the Lower Oxford Clay this category does not appear to be lithologically restricted.

## 4. Worn bones

Worn and eroded bones are common within the *Gryphaea* shell beds, nuculacean shell beds and the fine sand and silts that occur at the Kellaways beds-Lower Oxford Clay transition. These bones have been worn due to attrition by comminuted shell fragments and fine sand. In the fine sands and silts, at the base of the sequence the eroded bones are usually a pale yellow or buff colour on their surfaces, suggesting prolonged exposure on the sea floor. It is possible that some of the erosion may be due to biological activity, as some echinoderms and bacteria are known to feed on fish bone. (Brongersma-Sanders 1949). Echinoid remains have been found in some of the shell beds.

## 5. Coprocoenotic accumulations

Coprolitic material is abundant throughout the Lower Oxford Clay, but it is concentrated in the shell beds, mainly as irregular, buff coloured phosphatic masses and spindle shaped bodies often several centimetres long. Frequently these coprolites contain small bones and teeth.

The notable occurrence of vast quantities of otoliths in a nuculacean shell bed at the boundary between the Jason and Coronatum Zones at Peterborough (bed 13 of Callomon, 1968) may also be included in this category. Here the number of otoliths occurring in samples prepared for micropalaeontological examination far exceeded the number of fish teeth found in the same sample. This is due to the concentration of otolith elements in the guts of marine reptiles and fishes where phosphatic elements of the skeleton are preferentially digested by the gastric juices, and removed from the fossil record, whereas the calcareous otoliths are only slightly etched. (Fitch and Brownell, 1968). Such a process occurs in recent cetaceans and is responsible for concentrating slightly etched sacculiths of a limited number of fish species, often within a very narrow size range. The otoliths found in the nuculacean shell beds are all slightly etched, of a similar size, and there is a greater concentration of drop shaped otoliths compared to thin plate like-otoliths. (Plate 9D).

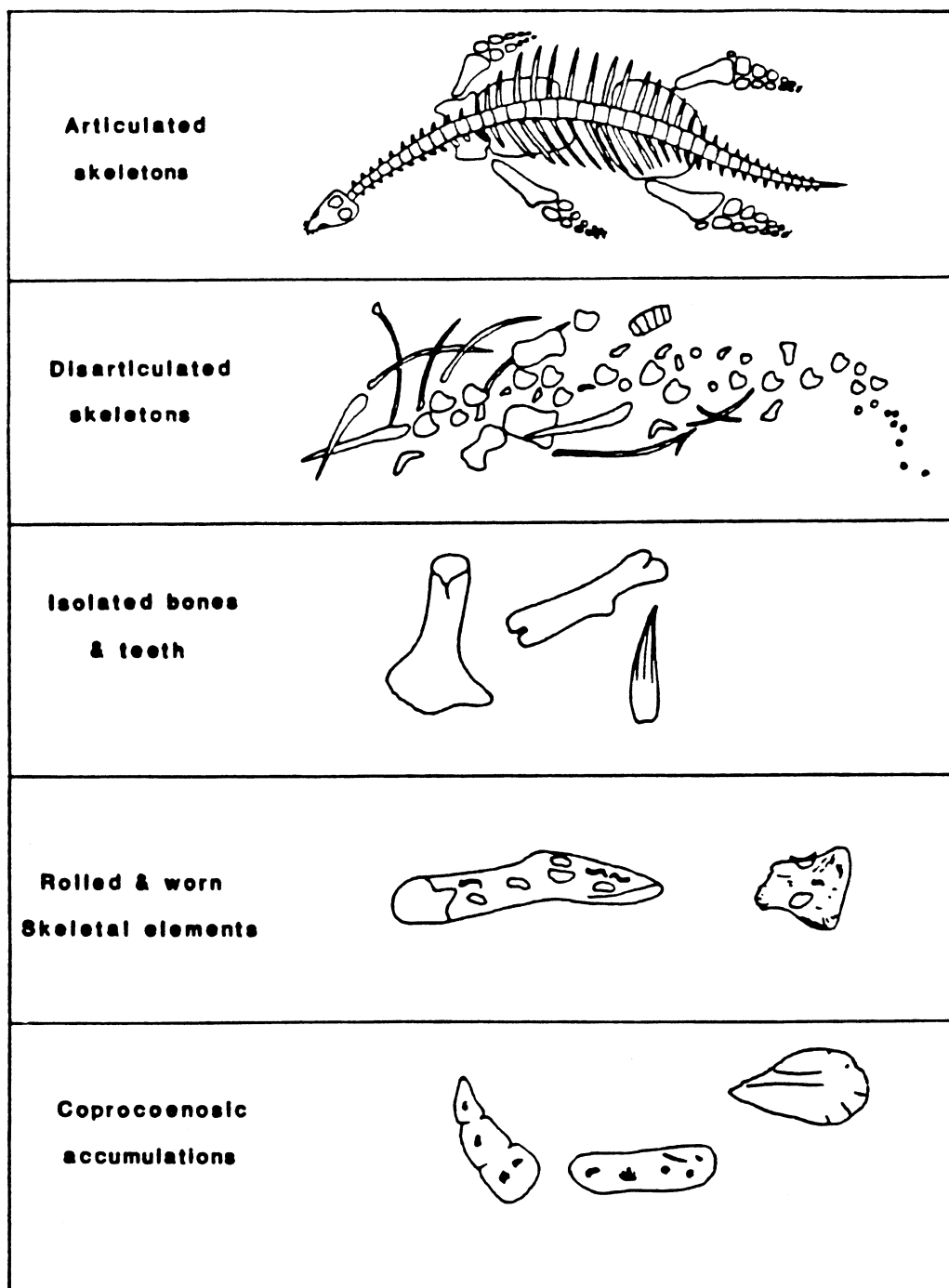


Fig. 11. Vertebrate preservational categories recognisable in the Oxford Clay.

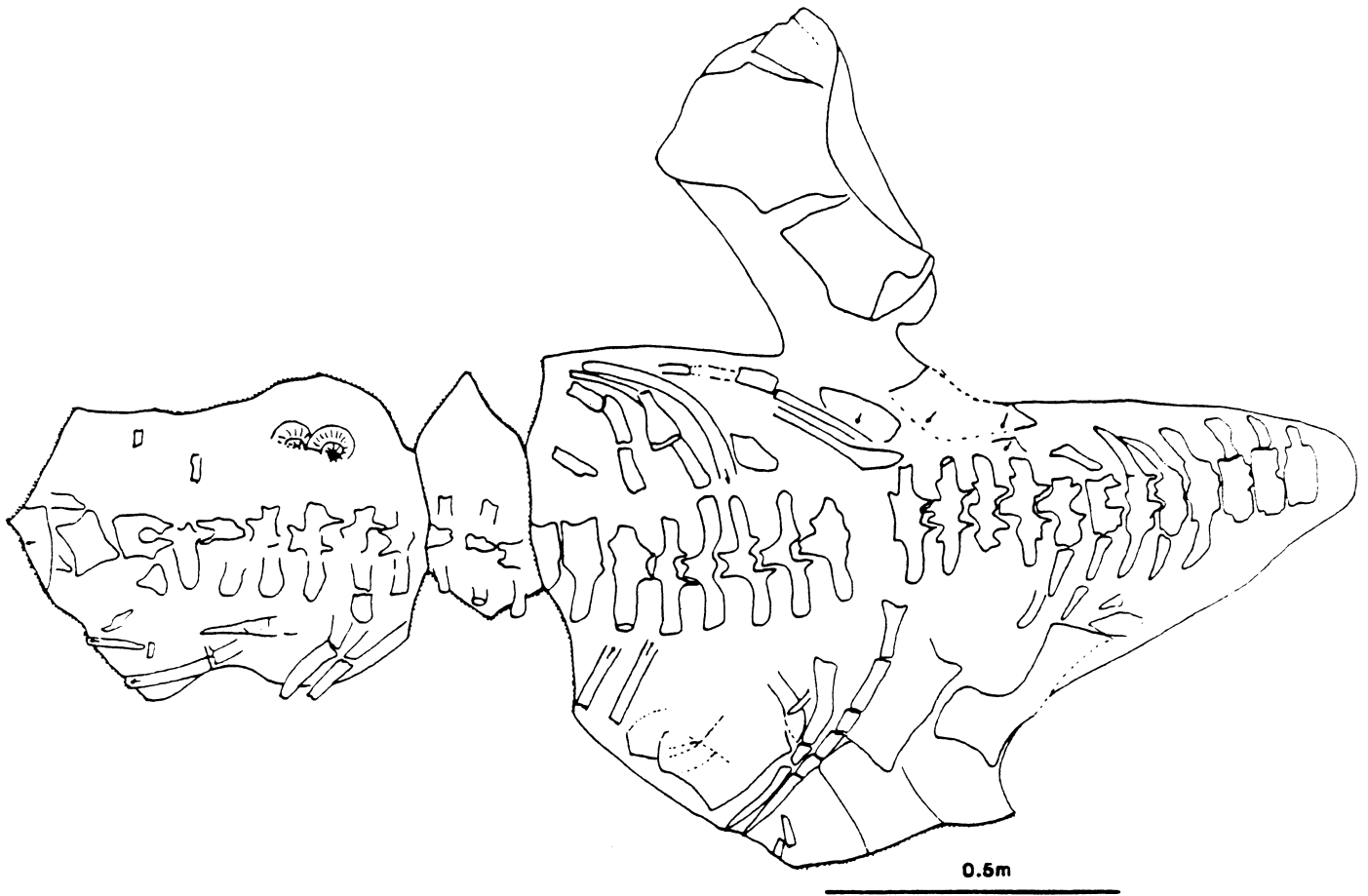


Fig. 12. Skeleton plan of sauropterygian, cf. *Cryptoclidus* sp. LEIUG 90988, enclosed in large septarian concretion. Lower Oxford Clay, bed 10, Orton pit, Peterborough.

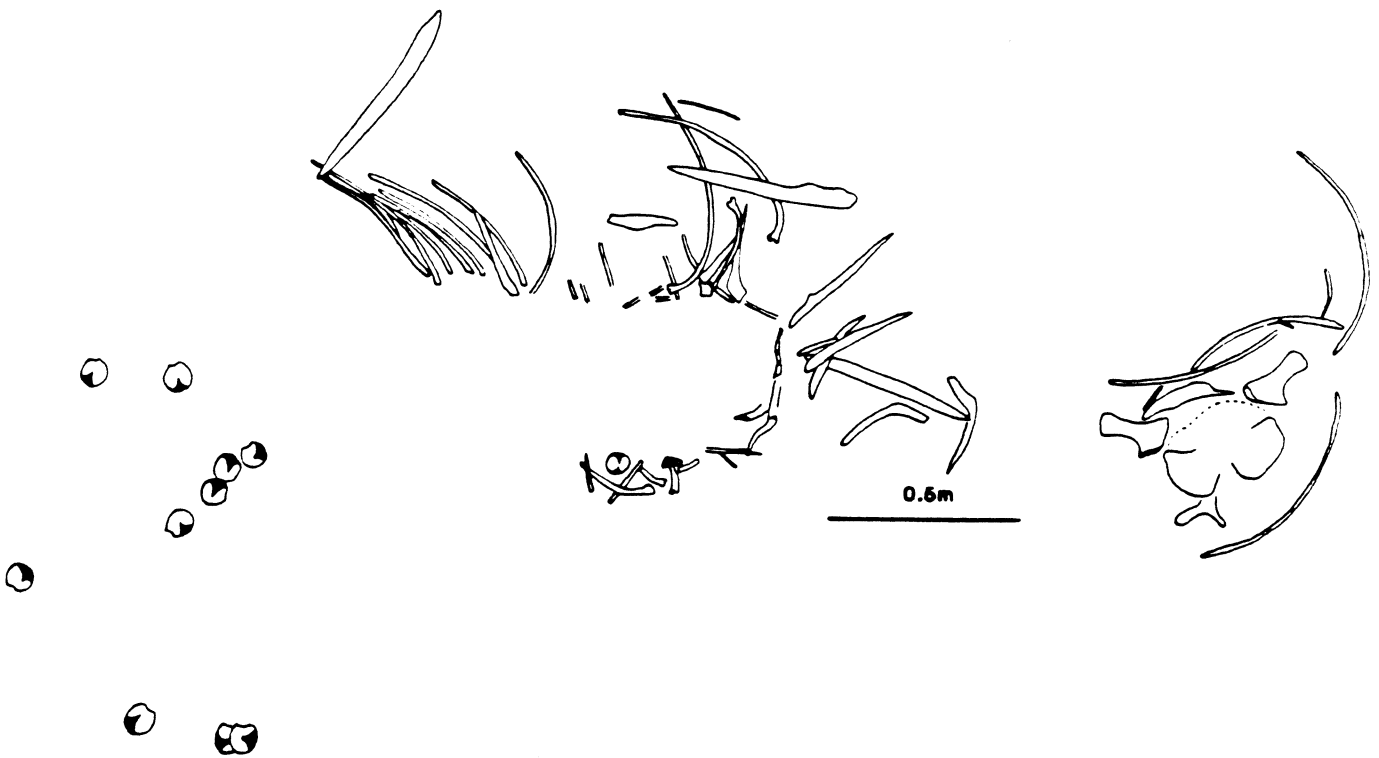


Fig. 13. Skeleton plan of *Ophthalmosaurus* sp. in-situ. Mostly disarticulated but with shoulder girdle still articulated. LEIUG 90984. Bed 11, Lower Oxford Clay, Dogsthorpe, Peterborough.

## Taphonomy

The following factors in part control the type of preservation of Oxford Clay vertebrates. They need not occur in the order listed.

1. **Death.** By old age, predation or disease.
  2. **Decomposition.**
  3. **Arrival on sea floor.**
  4. **Scavenging.**
1. **Death**

The cause of death is important in determining the state of the animal when it arrives on the sea floor. Three types of death are here invoked for Oxford Clay vertebrates. Death by old age, death by disease, and death by predation. Appleby (1979) has suggested that some ichthyosaurs may have sustained severe injuries to the shoulder girdle through excessive deceleration while swimming rapidly. Such accidents could result in the death of the animal.

Death by disease may result in a complete carcase, as will death by old age. Old age can usually be recognised in specimens by advanced ossification, but it is difficult, if not impossible to show that this was the cause of death. Disease can be recognised if it affected bone development (Delair, 1974), but again it is difficult to show that this was the actual cause of death.

Death by predation is very common, and can often be recognised by scars on bones or by large pieces of the skeleton being missing. Death by predation may involve the mutilation of the corpse and the subsequent detachment and loss of many parts of the skeleton. Plate 10 shows part of a frontal bone from the giant pachycormid fish *Leedsichthys* PCM F. 1 which was attacked by a crocodile, a tooth of which is embedded in the bone. The fish managed to escape, and the scar healed with new bone growth forming around the crocodile tooth. Obviously no healing takes place if the injury results in the early death of the animal.

Several specimens of *Ophthalmosaurus* sp. notably BCM 1008, 1983 and LEIUG 90986 are old individuals which display expanded ends to the ribs, this bone is diseased, probably arthritic and may have contributed to the death of the animal.

2. **Decomposition**

Soon after death has taken place the soft tissue begins to decompose. Bacteria within the gut infect the body tissues. Decomposition gasses build up, bloating the carcase which may then float for several days (Schafer, 1972). During this time the body continues to decompose, and parts of the skeleton may be exposed and drop to the sea floor. Scavenging will also take place while the carcase floats, assisting the breakdown of the animal.

3. **Arrival on the sea floor**

The arrival of the carcase on the sea floor has complex effects. It affects the attitude of the skeleton, and depending on the firmness of the substrate, it affects further decomposition processes.

The attitude of the carcase on the sea floor is largely dependent on the original shape of the animal, and whether the animal arrives on the sea floor intact.

4. **Scavenging**

Scavengers may be responsible for the complete break up of a carcase whilst it is floating or lying in the sea floor. It is difficult to establish whether missing elements of a skeleton are due to scavenging or predation by the killer. Small teeth of *Hybodus obtusus* associated with large reptile skeletons are probably from a scavenging shark rather than a predatory one.

## Ichthyopterygia

Ichthyosaurs usually arrive on the sea floor with their long axis parallel to the main current direction (Brenner, 1976) upside down and with the fore paddles slumped downwards (dorsally). They then roll over to one side. The upper flipper may point dorsally or ventrally. Often the upper flipper decomposes whilst pointing upwards in the water column, dropping its bones around the carcass.

Due to the extra weight of the skull, many specimens arrive rostrum first on the sea floor, and if the sediment is soft enough the rostrum will penetrate the sediment.

## Sauropterygia

All the long necked plesiosaur specimens examined arrived on the sea floor in a dorsal or ventral position, with flippers held out laterally, many have coiled necks, because the weight of the skull and neck vertebrae caused the neck to hang down in the water column while the carcass is floating. The head and neck therefore reach the sea floor before the torso and the neck coils as the body slowly sinks.

Few plesiosaurs have been found intact and *in-situ* so little data is available. It is likely that the weight of the large skull is sufficient for it to drop off a floating carcass undergoing decomposition. This might explain the occurrence of plesiosaur skulls found without post cranial elements of the skeleton.

## Crocodylia

The number of *in-situ* records of crocodile material from the Lower Oxford Clay is negligible. Two specimens were discovered during this study, one, a single fragmentary skull, and the other, a partial skeleton, broken by the dragline, of *Metriorhynchus* sp. LEIUG 90985, lying on its right side (Fig. 6).

## Fish

Several articulated fish specimens have been found, and many museum specimens can also be satisfactorily orientated. *Caturus* sp. which appears to be the most common of the articulated fish in collections, is mostly dorso-ventrally flattened, (Plate 9F) as also was a specimen of *Asthenocormus* sp. with only the tail in a lateral position. Specimens of *Lepidotes* sp. and *Hypsocormus* sp. were found lying on their sides. *Caturus* is a fusiform fish with large pectoral fins, it was probably stabilised by these on the sea floor (Fig. 7).

### A preservational case study of a partially articulated ichthyosaur

A partially complete skeleton of an ichthyosaur, *Ophthalmosaurus* sp. BCM 1983, 1008, from the Lower Oxford Clay, Coronatum Zone, at Milton Keynes, Buckinghamshire, has been examined in detail whilst still *in-situ* and is now a mounted specimen in Milton Keynes Library.

The specimen was discovered by Mr Les Fitchett, a construction worker employed by French Kier Construction plc. during the excavation of a reservoir at Caldecotte, Buckinghamshire (SP 892 352).

The specimen was a mature adult, approximately 5 m long, which possibly died from old age. There are no visible scars on any of the bones to indicate predation. Fig. 15 shows an outline plan of the skeleton as it lay *in-situ* prior to removal. Some skeletal elements do not appear on the diagram as they were disturbed by the excavating machinery, and cannot be accurately placed. These misplaced elements include part of a coracoid, the right ? ulna, part of the rostrum and numerous digits. Part of the rib cage was also slightly disturbed.

The skeleton was found lying partly within greenish bituminous shale and partly enclosed within a septarian concretion. Two thoracic vertebrae, detached from the main part of the skeleton, were enclosed in a pyrite concretion.

The specimen is an associated, partially articulated *Ophthalmosaurus* sp. Specific identification cannot be determined as the diagnostic coracoids (Appleby, 1956) are not sufficiently well preserved to show the anterior and posterior notches. The articulated parts of the skeleton include the left side of the rib cage and parts of the vertebral column. Some skull elements enclosed within the concretion, and some of those disturbed by the

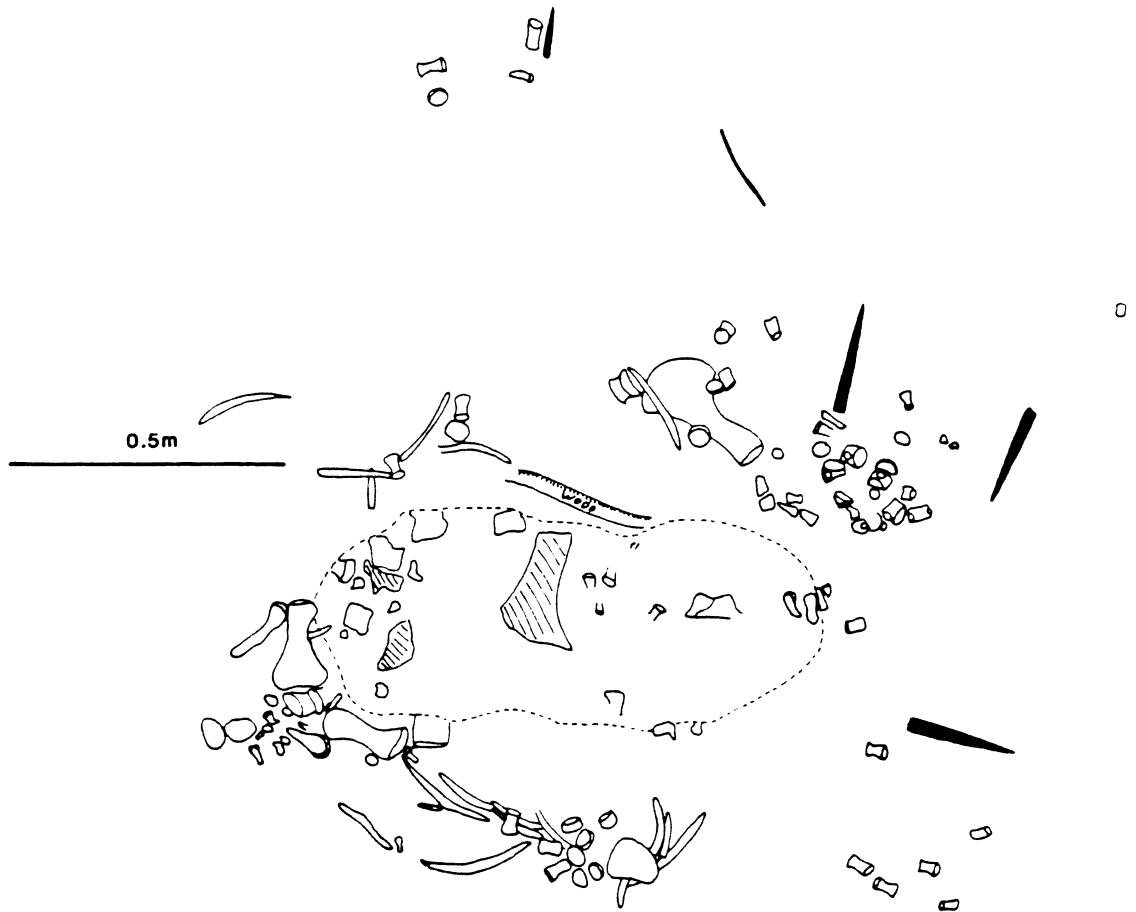


Fig. 14. Completely disarticulated skeleton of juvenile plesiosaurian, LEIUG 90983. Bed 11, Lower Oxford Clay, Dogsthorpe, Peterborough.



Fig. 15. Skeleton plan of *Ophthalmosaurus* sp. The dotted line indicates the part of the skeleton enclosed in a calcareous concretion. BCM 1001, 1983. Lower Oxford Clay, Coronatum Zone, Milton Keynes, Buckinghamshire.

excavator are also articulated. The remainder of the skeleton is disarticulated, but most of the individual bones have not moved from their original positions by more than a few centimetres. Thus the general shape of an ichthyosaur skeleton is maintained. A few elements, notably from the front limbs have been moved several tens of centimetres, suggesting that some scavenging of the carcass took place. Fig. 16 summarises the taphonomic history of the specimen.

The cause of death is hard to establish. None of the bones show teeth marks which are a common feature of predated specimens. Many of the elements of the skeleton indicate the specimen to be an old individual, including its size, and signs of advanced ossification such as fusion of the tibia and fibula of the right hind limb. This particular individual probably died of old age or disease.

It is difficult to elucidate the history of the specimen between the moment of death and its arrival on the sea floor, but the post-mortem drifting phase was probably short as the affects of scavengers would be more severe, with many of the peripheral elements of the skeleton being absent. The carcass sank to the sea floor and the rostrum penetrated the sediment, indicating that the carcass arrived on the sea floor head first, and with a velocity sufficient for the carcass to sink partially into the sediment.

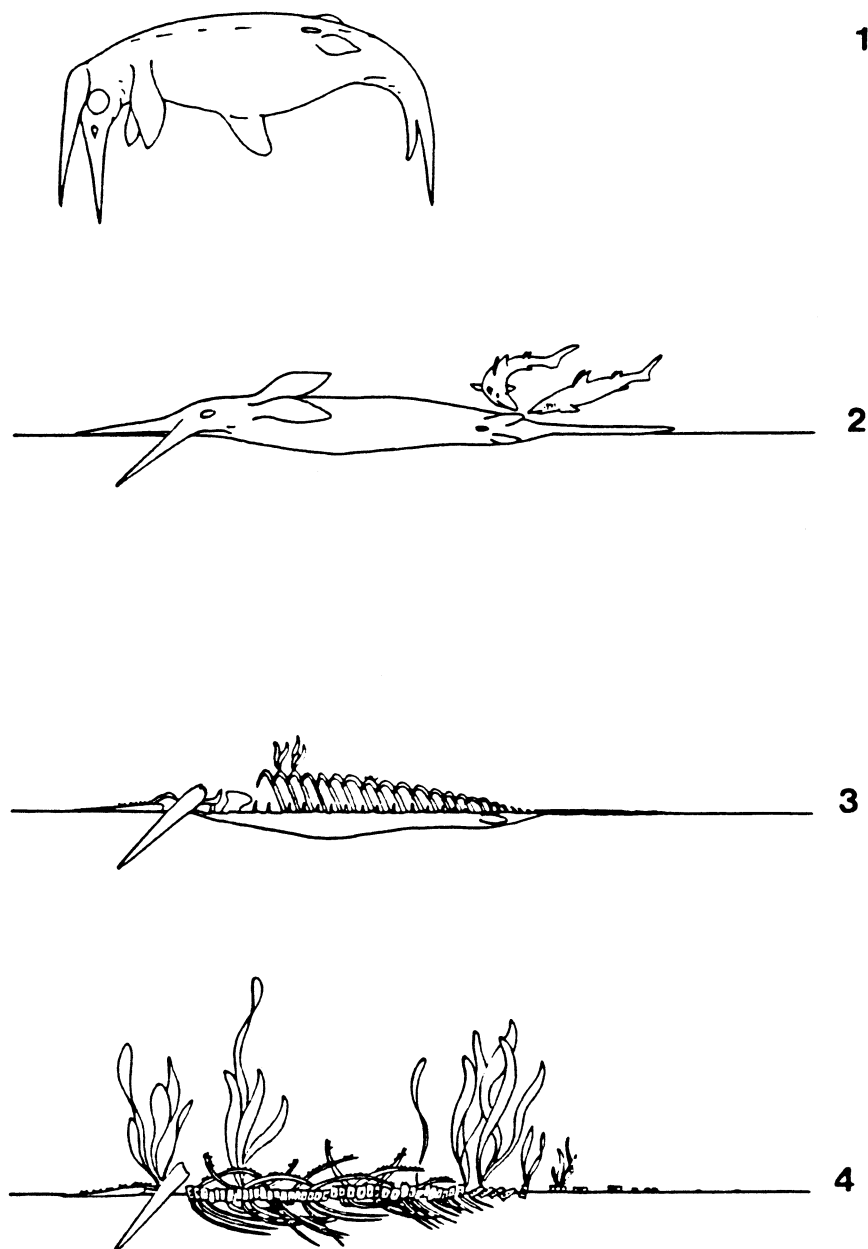


Fig. 16. Taphonomic history of ichthyosaurian BCM 1001, 1983. 1. post mortem drifting in water column. 2. descent to seafloor accompanied by scavenging. 3. rapid decay of integument in oxygenated water, slow decomposition of integument in contact with anoxic pore water. 4. Collapse of skeleton and encrustation by epibionts and seaweed.

## Epibionts

Many of the disarticulated elements of the skeleton are a pale buff colour and are frequently encrusted with oysters and serpulid worms. The epibionts are only found encrusting the buff coloured bones, and are restricted to the upper surfaces. No macro-epibionts have been found on the underside of the skeleton, or on the dark brown bones of the articulated portions of the skeleton. The oysters are preserved in dark grey calcite, and frequently reach a length of 4 cm. On flat bones they remain attached continuously during ontogeny; when attached to bones with strongly curving surfaces, e.g. ribs, they are only attached during early ontogeny, later stages of shell growth growing away from the bone surface with the oyster becoming curved. On very smooth bone surfaces the oyster may not secrete shell material, but lie in direct contact with the bone (Plate 9A).

Serpulid worms are less common than oysters, and are usually small, being generally less than one centimetre long. They are preserved as white aragonite conical tubes, approximately 2–3 mm diameter at the anterior end. No geotropism or phototropism has been established, but the distribution pattern on the skeleton is the same as that of the oysters.

The undersides of the articulated parts of the skeleton are dark brown, and lack epibionts. A black coating adheres to the underside of the articulated vertebrae that lie within the mudstone, and also to the underside of some of the ribs from the left side of the rib cage. The black coating, overlain by a slightly shiny white/buff coating was also found on a portion of the pre-maxilla.

These coatings are restricted to the dark brown bones. These bones have no encrustations suggesting that they were in contact with and partly buried in the sediment. The black and white coatings may be by-products of a decomposing integument (Fig. 17).

Scanning electron microscopy of the black coating from the underside of the vertebral column shows it to be composed of an amorphous mass, underneath which are numerous ovoids approximately 1  $\mu\text{m}$  long, and about 0.5  $\mu\text{m}$  diameter. These ovoids are interpreted as lithified bacteria, as have been reported from soft part outlines of Eocene Anura and Chiroptera by Wuttke (1983).

The light buff coloured bones encrusted with oysters have powdery surfaces that are very soft and easily scratched with a finger nail. These bones have been altered due to prolonged exposure on the sea floor. Encrusting oysters were able to grow to 2–4 cm diameter. This shows that sedimentation was slow, and that bottom waters were well oxygenated. An infauna of small scaphopods and foraminifera suggests that the pore water of the top 2–3 cm of the sediment was also oxygenated, although the low diversity of the infauna reflects lower than normal oxygen levels.

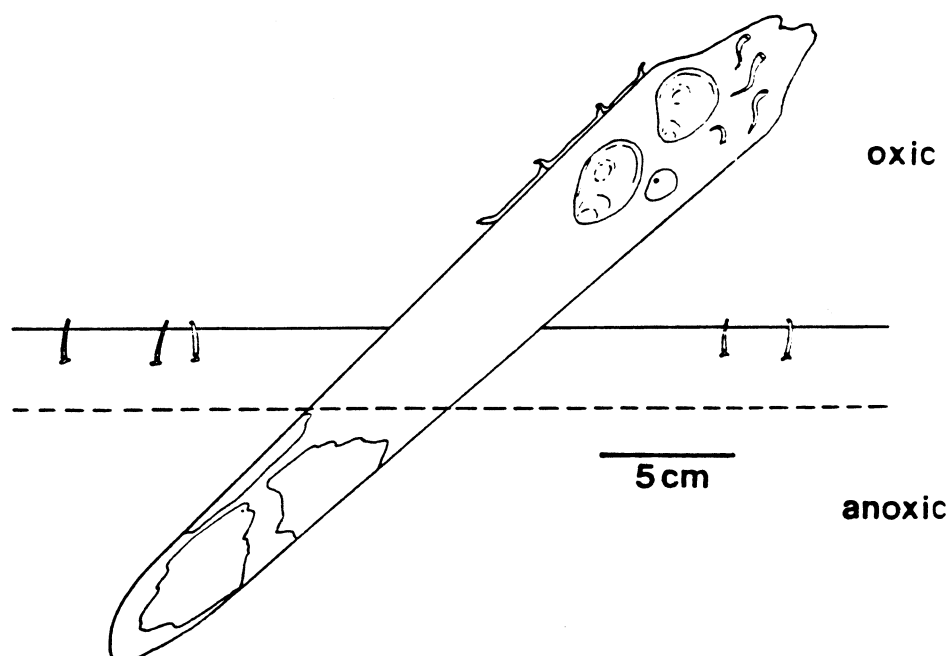


Fig. 17. Pre-maxilla of BCM 1008, 1983, showing epibionts on surface of bone within oxic sea water, and with patches of preserved "skin" on surface within anoxic pore water. Scaphopods live in top two or three centimetres of sediment.

The abundance of pyrite within the sediment and encrusting some of the bones shows that reducing conditions were present within the sediment. If the oxic/anoxic boundary was close to the sediment water interface, the penetration of the ichthyosaur carcass into the sediment may have introduced some of the soft tissues to reducing conditions, thus limiting the rate of decay.

### **Burial diagenesis**

Burial diagenesis and compaction have had deleterious effects on the ichthyosaur specimen, and have caused differential preservation of the skeleton. Those parts of the skeleton that were lying within the bituminous mudstone have been uniaxially flattened by compaction. Failure of the bones is of a brittle nature (Plate 11A), with the complete shattering of all the inner trabeculae. The more solid sides of bones have resisted compaction, as have those bones with shapes that can transmit the pressure around their surface.

Compaction of some of the vertebrae has been greater than 50% and has been unaffected by the position of the bone in the sediment. Vertebrae lying flat on the bedding planes have been flattened into thin discs, while the articulated row of seven vertebrae have been flattened dorso-ventrally (Plate 11B).

Early diagenesis of the septarian calcareous and pyrite concretions protected many of the bones from compactional damage, but brecciation of the septarian concretion, with adjustment of the brecciated fragments and subsequent re-cementing with coarse calcite, has resulted in the almost complete destruction of the gross morphology of the individual bones, and the formation of a bone breccia. The microstructure of the bones in the concretion has been unaffected.

Late ferroan calcite cements have filled cavities within the bones, and have cemented together the highly crushed bones in the bituminous mudstone.

Many of the bones in the bituminous mudstone are coated with fibrous calcite up to 2 mm thick, with a thin film of clay sandwiched in between. This fibrous coating causes problems for the preparator as it requires removal with a vibratool, although it will sometimes flake off the surface if the underlying clay film has prevented cementation.

## **Discussion**

### **General**

The several different styles of vertebrate preservation which occur in the Oxford Clay are lithologically constrained. This is to be expected where different lithologies are controlled by different physical and biological conditions. Perfect preservation of skeletons is only possible if a carcass arrives on the sea floor intact, and remains undisturbed by current activity and the effects of scavenging. Under such conditions, usually attributed to deep anoxic basins, well preserved vertebrate skeletons frequently occur, e.g. parts of the Posidonia Shales of Holzmaden, West Germany.

The Oxford Clay basin at Peterborough was, however, not deep, and there is little, if any, evidence to suggest that bottom waters were anoxic even for short periods. That the pore water in the bottom sediment was anoxic is well shown by the abundance of pyrite as minute grains found disseminated throughout the sediment, and as a replacement of calcareous fossils. It is not known, however, at what depth within the sediment the pore water became anoxic, although in Coronatum Zone times in the area around Milton Keynes, anoxic conditions were prevalent just 4 to 5 cm below the sediment water/interface. The same may have been the case for the whole of the Lower Oxford Clay basin. In such conditions it is possible to have a restricted infauna and a diverse epifauna, providing the substrate is sufficiently firm to support burrowing and crawling. These conditions would not appear to be conducive to the perfect preservation of vertebrate skeletons; yet at Peterborough perfect preservation of reptiles, and delicate fishes is not uncommon.

In areas where the sediment/water interface is hard to define (soupy bottom) the invertebrate fauna may be restricted to only a few bivalves that can tolerate soupy sediment. Duff (1975) has amply demonstrated the restricted nature of the invertebrate fauna of the Lower Oxford Clay. It is most likely that in shallow basins perfect preservation of skeletons can take place when the bottom sediment is soft enough to allow a carcass to sink into it sufficiently to reduce the amount of scavenging that can take place. Bioturbation in the vicinity of the carcass may be reduced due to the presence of an anoxic micro-environment building up around a decomposing corpse.

Two special cases deserve more detailed discussion, namely, preservation in paper shales (Bed 10, base Bed 12) at Peterborough and vertebrates in the *Gryphaea* shell beds.

#### **Preservation in the paper shales**

The observed facts are as follows:-

1. Vertebrate skeletons are frequently fully articulated, with teeth still in the jaws. Any missing parts of the skeleton can easily be attributed to scavenging during post-mortem drifting of the carcass.
2. Articulated skeletons in the paper shales lack an encrusting epifauna of oysters and serpulids, yet these organisms are common in the intervening shell beds and frequently occur encrusting ammonites, and logs within the paper shales themselves. In Seilacher's (1982) *Posidonia Shales* model this would be used as evidence for anoxic bottom conditions, however a restricted, but abundant infauna occurs in the paper shales, including *Trautscholdia* and the semi-infaunal *Pinna mitis*. The *Pinna mitis* found in the Lower Oxford Clay is rather smaller than *Pinna* from the Middle and Upper Oxford Clay, although Duff (1978) considers them to be the same species, such a size reduction is possibly a response to an environmental constraint.
3. Fish skeletons from the paper shales are often perfect on the lower surface, with all the scales intact, have coprolitic material in the gut region, and have even the finest fin ray segments in perfect articulation. The upper surface is however usually disrupted, with many scales distributed, but not widely scattered.
4. Ammonites, fossil wood and rarely belemnites are found with encrusting epibionts, usually small oysters and serpulid worms. A single log of 3 m length was found to be covered with *Parainoceramus* on its underside.
5. Belemnites are occasionally found "point down" in the sediment. This occurs when the guard drops from a floating corpse and falls to the sea floor like a bullet (Barthel, 1978). The sediment must be soft enough to allow the guard to enter, but firm enough to prevent it from toppling over.
6. No bivalves are found in life position. All lie flat on bedding planes, possibly because upward migrations of anoxic pore water drove them out of the sediment. If the oxic/anoxic boundary migrated to a position just 2 to 3 cm above the sediment/water interface, then the bivalves would be killed. This explanation seems more likely than reworking by currents since this would lead to bivalve disarticulation, and would also prevent belemnites occurring vertically.
7. All *Pinna* valves are flat lying, articulated, and frequently aligned.
8. Orientated belemnites and other elongate fossils suggest that there was some gentle current activity on the sea floor, but this was not strong enough to dislodge vertical belemnites.
9. Burrows are not found within the paper shales, except at the top of bed 10, where it can be demonstrated that the burrows emanate from the overlying *Gryphaea* shell bed.
10. Thin sections of early diagenetic concretions from within the paper shales show that the paper shales are a compacted mud of small "faecal" pellets. These pellets may have been formed not on the sea floor, but in the water column itself by the activities of copepods.
11. Many ammonite conchs display primary breakage, indicating intense predation (Aigner 1980).

The data presented above do not fit the typical anoxic basin model, neither do they fit the oxygenated clay basin model in which normal clays are formed. The perfection of vertebrate preservation, and the lack of encrusted bones shows that bottom conditions did not support an epifauna. Bones can only be encrusted after the animal has died, whereas ammonites can be encrusted during life and logs can be encrusted while floating in the water column. Vertebrate skeletons in the shales of the Coronatum Zone are frequently encrusted with oysters and serpulids, so the absence of encrustation, in the paper shales is due, not to substrate preference, but to environmental inhibition.

It is not easy to see what is the cause of this environmental inhibition. Bottom water was not anoxic, although the pore water probably was anoxic below 4–5 cm. Infaunal activity was limited to only a few species, but the species present were in super abundance, with patches of twenty to thirty *Pinna* being common. One possibility is sedimentation rate. If this were high, then any organisms that prefer clear water, as many epifaunal filter feeders do, would get their filters clogged by sediment. A low or reduced sedimentation rate is indicated by the high organic carbon content of the shales (up to 10%) and also by its geological setting, the Jason Zone at Peterborough being the most condensed sequence in the Lower Oxford Clay basin.

To try to explain the numerous paradoxical data it appears that the sea floor must have been periodically swept by gentle currents, and was at times well oxygenated. Reduced sedimentation with high organic input; due to high productivity in surface waters, maintained low oxygen levels at times when current activity was reduced. Bottom waters were soupy, probably due to intermittent stirring of the sediment by storms and gentle currents. Rapid environmental switching contributed to a reduction of infaunal diversity, and prohibited any continued colonisation of the sea floor by epifaunal elements. Current strength was insufficient to disarticulate the carcasses of the larger vertebrates, but was able to dislodge smaller fish carcasses. The underside of a fish carcass may have remained intact as it could have stuck to the seafloor by an algal/fungal film.

#### **Vertebrates of the *Gryphaea* shell beds**

Partially articulated skeletons occur within the *Gryphaea* shell beds in the Jason Zone at Peterborough. The skeletons are more numerous than in the paper shales, but are rarely complete and never as well articulated. The sedimentology of the *Gryphaea* shell beds is complex, and it is interesting to note how the shell beds were formed.

After the deposition of the paper shales, as a fairly soft substrate, sedimentation was further reduced and the soft sea floor compacted to a moderately firm substrate allowing burrowing to take place. Several tens of centimetres of sediment may also have been removed by increased current activity or storms. *Thalassinoides* and *Rhizocorallium* occur in the top of bed 10 where they emanate from the base of bed 11. A very thin layer of green clay low in organic carbon occurs at this level and is found infilling the burrows. During this period the sea floor became littered with broken ammonite tests, the result of intense predation by the hybodont shark *Asteracanthus* and the chimaeras *Pachymylus*, *Brachymylus* and *Ischyodus*, whose dental plates are common in bed 11. The accumulation of this ammonite debris produced a shell gravel covering many square kilometres of sea floor, and provided a firm substrate for the attachment of *Gryphaea* spat, shown by xenomorphic ornament of both valves of *Gryphaea*.

The reduced sedimentation rate produced an increase in the number of skeletons found at this level, but due to current activity and scavenging the skeletons are often partly disarticulated. Isolated bones can be considerably worn due to the abrasive nature of the shell hash. Many bones found at this horizon have small numbers of oysters and serpulids attached to their surface. Although some of the *Gryphaea* shells found at this level are in life position, many are overturned, but remain articulated, suggesting that the overturning may be due to storm activity turning over live shells. These same storms had the affect of disarticulating the skeletons, but not of distributing them very far.

#### **Conclusion**

The Lower Oxford Clay is rich in vertebrates throughout the sequence, but the remains are concentrated at certain horizons due to sedimentological criteria. The high organic carbon content of the shales suggest high productivity levels in the surface waters, which presumably fed a diverse pyramid of organisms. As productivity declined so did the number of vertebrates living in the surface waters. This is reflected in the fossil record with high vertebrate diversity and abundance in the organic rich Lower Oxford Clay, followed by extreme scarcity in the clays with low organic carbon of the Middle and Upper Oxford Clay.

#### **Acknowledgements**

Collecting an *in-situ* fossil reptile requires much work. I am indebted to all those who helped me in this task. In the field Alan Dawn, Rod Branson, Nick Laffoley, Arthur Meadows and Ian Fisher; all toiled hard in the bottom of the brick pits. In preparing material Lorraine Cornish and Nick Laffoley made specimens, thought to be unpreparable, worthy of exhibition. To produce the skeleton plans I am grateful to Rod Branson, and to Henry, Collin and Ian in the University of Leicester Central Photographic Unit.

Many people made specimens available in their museums and the following were especially helpful, Dr Collin Patterson and Dr Angela Milner at the British Museum, Mr John Martin, Leicester Museum, Dr Gordon Chancellor, Peterborough City Museum, and Phil Powell, Oxford University Museum.

Dr C. Forbes and Dr R.G. Clements were kind enough to let me use their unpublished data.

The London Brick Company, and especially their chief geologist Mr J. Horrell, made many facilities available in their pits. Without their kind cooperation this study could not have taken place. I must also thank the pit men who kept an eye open for bones and also for supplying me with cups of tea during the hot summer months.

Dr J.D. Hudson and Dr R.G. Clements along with Dr Mike Taylor provided useful discussions and criticisms. Dr Trevor Ford kindly read the manuscript.

I thank Leicester University for a research Scholarship awarded for a three year study on vertebrate bearing bituminous shales.

### References

- Aigner, T., 1980. Biofabrics and Stratigraphy of the Lower Kimmeridge Clay (U. Jurassic, Dorset, England). *N. Jb. Geol. Palaeont. Abh.* 3, 324–338.
- Andrews, C.W., 1910–13. *A descriptive catalogue of the marine reptiles of the Oxford Clay*, 1. 205pp., 10pls., (1910). 2. 206pp., 13pls., (1913). London British Museum (Natural History).
- Appleby, R.M., 1956. The osteology and taxonomy of the fossil reptile *Ophthalmosaurus*. *Proc. Zool. Soc. Lond.* 126, 403–447.
- 1979. Fossil aches and pains, *New Scientist*, 16th Aug. 516–7.
- Benton, M.J. & Taylor, M.A., 1984. Marine reptiles from the Upper Lias (Lower Toarcian, Lower Jurassic) of the Yorkshire coast. *Proc. Yorks. Geol. Soc.*, 44, 399–429.
- Brenner, K. 1976. Schwarzschiefer. Biostratigraphische, untersuchungen im Posidonienschiefer (Lias epsilon, Unteres Toarcium) von Holzmaden (Wurttemberg, Sud-Deutschland). In *Sondersforschungsbereich 53, Palokologie, Arbeitsbericht, 1970–1975, Zbl. F. Geol. u. Palaont.*, 2, S. 223–226.
- Brongersma-Sanders, M., 1949. On the occurrence of fish remains in fossil and recent marine deposits. *Bijdr. Dierk.*, 28, 65–76.
- Brown, D.S., 1981. The English Upper Jurassic Plesiosauroidea (Reptilia) and a review of the Phylogeny and classification of the Plesiosauria. *Bull. Br. Mus. Nat. Hist. (Geol.)*, 35, (4), 253–347.
- Calloman, J.H., 1968. The Kellaways beds and the Oxford Clay. In: *The geology of the East Midlands* (Eds. Sylvester Bradley, P.C. & Ford, T.D.), 264–290. University of Leicester Press.
- Camp, C.L., 1980. Large ichthyosaurs from the Upper Triassic of Nevada. *Palaeontographica. Abt. A*, 170, (4–6), 139–200.
- Charig, A.J., 1980. A diplodocid sauropod from the Lower Cretaceous of England. In: *Aspects of vertebrate history, essays in honour of Edwin Harris Colbert*. (Ed. Jacobs, L.L.). Museum of Northern Arizona press, Flagstaff, 231–244.
- & Horell, J., 1971. The Fletton plesiosaur, *Rep. Huntingdon Flora Fauna Soc.* 23: 37–40.
- Cope, J.C.W., Duff, K.L., Parsons, C.F., Torrens, H.S., Wimbledon, W.A., & Wright, J.K., 1980. A correlation of Jurassic rocks in the British Isles. Part Two: Middle and Upper Jurassic. *Spec. Rep. Geol. Soc. Lond.* 15, 1–109.
- Delair, J.B., 1974. Two deformed ichthyosaur forelimbs from the English Lower Lias. *Mercian Geologist*, 5, (2), 101–103.
- Duff, K.L., 1975. Palaeoecology of a bituminous shale—the Lower Oxford Clay of Central England, *Palaeontology*, 18, (3), 443–482.
- Fisher, I. st. J., 1983. *Studies on pyrite in shales*. Unpublished PhD. Thesis, University of Leicester.
- Fitch, J.E., & Brownell, R.L., 1968. Fish otoliths in cetacean stomachs and their importance in interpreting feeding habits. *J. Fish. Res. Bd. Can.*, 25, (12), 2561–2574.
- Galton, P.M., 1980. European Jurassic ornithomimid dinosaurs of the family Hypsilophodontidae and Camptosauridae. *N. Jb. Geol. Palaont. Abh.* 160, (1), 73–95.

- Hudson, J.D., 1978. Concretions, isotopes, and the diagenesis of the Oxford Clay (Jurassic) of central England. *Sedimentology*, 25, 339–370.
- 1982. Pyrite in ammonite bearing shales from the Jurassic of England and Germany. *Sedimentology*, 29, 639–667.
- Judd, J.W., 1875. The geology of Rutland. *Mem. Geol. Surv. England and Wales*, 320pp.
- Jukes-Browne, A.J., 1885. The geology of the south west part of Lincolnshire, *Mem. Geol. Surv. England and Wales*, 180pp.
- Kauffman, E.G., 1981. Ecological reappraisal of the German Posidonienschiefer (Toarcian) and the stagnant basin model, in: *Communities of the past*, (Ed. Gray, J., Boucot, A.J., & Berry, W.B.N.), Hutchinson Ross Publ. Comp., Stroudsburg, Penns.
- Keller, T., 1976. Magen-und Darminhalte von Ichthyosauriern des suddeutschen Posidonienschiefers, *N. Jb. Geol. Palaont. Mh.* 5, 266–283, Stuttgart.
- Leeds, A.N. & Woodward, A.S., 1897. Excursion to Peterborough, *Proc. Geol. Assoc.* 15, 188–193.
- Leeds, E.T., 1956. *The Leeds collection of fossil reptiles from the Oxford Clay of Peterborough*, 104pp., Oxford.
- Lydekker, R., 1889. *Catalogue of the fossil Reptilia and Amphibia in the British Museum ... Part II* 307pp., London, British Museum (Natural History).
- 1890. On ornithosaurian remains from the Oxford Clay of Huntingdonshire. *Q. J. Geol. Soc. London*, 46, 429–431.
- Milner, A.R., 1980. The tetrapod assemblage from Nyrany, Czechoslovakia, In: *The terrestrial environment and the origin of land vertebrates*. (Ed. Panchen, A.L.), 439–496. Academic Press, London & New York.
- Porter, H., 1861. *The geology of Peterborough and its vicinity*. Peterborough, 126pp.
- 1863. On the Occurrence of large quantities of fossil wood in the Oxford Clay near Peterborough. *Q. J. Geol. Soc. London*, 19, p.317.
- Seeley, H.G. 1889. Note on the pelvis of *Ornithopsis*. *Q. J. Geol. Soc. Lond.*, 45, 391–397.
- Seilacher, A., 1981. Posidonia shales (Toarcian, S. Germany)—stagnant basin model revalidated, *Proc. 1st international meeting on "Palaeontology, essentials of historical geology, Venice*, Ed. Gallitelli, E.M. 25–55.
- Schafer, W., 1972. *Ecology and palaeoecology of marine environments*, Oliver & Boyd, Edinburgh, 568pp.
- Tarlo, L.B., 1960. A review of the Upper Jurassic Pliosaurus, *Bull. Br. Mus. Nat. Hist. (Geol.)*, 4, (5), 147–189, pls. 20–28.
- Taylor, M.A., 1981. Plesiosaurs, rigging and ballasting. *Nature*, Lond. 290, 628–629.
- Thies, D., 1983. Jurazeitliche neoselachier aus Deutschland und S-England (Jurassic neoselachians from Germany and s. England), *Cour. Forsch. Inst. Senckenberg*, 58, 1–116, Frankfurt/M.
- Woodward, A.S., 1897. A contribution to the osteology of the Mesozoic amioid fishes *Caturus* and *Osteorachis*. *Ann. Mag. Nat. Hist.*, 19, 379–387, pls. 8–11.
- 1905. On parts of the skeleton of *Cetiosaurus leedsi*, a sauropodus dinosaur from the Oxford Clay of Peterborough, *Proc. Zool. Soc. London*, 232–243.
- Wuttke, M., 1983. a. "Weichteil-Erhaltung" durch lithifizierte Mikroorganismen bei mittel-eozanen Vertebraten aus den Olschiefern der "Grube Messel" bei Darmstadt. *Senckenbergians lethaea*, 64, (5/6), 509–527, Frankfurt/M.
- 1983. b. Aktuopalaontologische studien uber den zerfall von wirbeltieren. Tiel 1: Anura, *Senckenbergians lethaea*, 64 (5/6), 529–560, Frankfurt/M.

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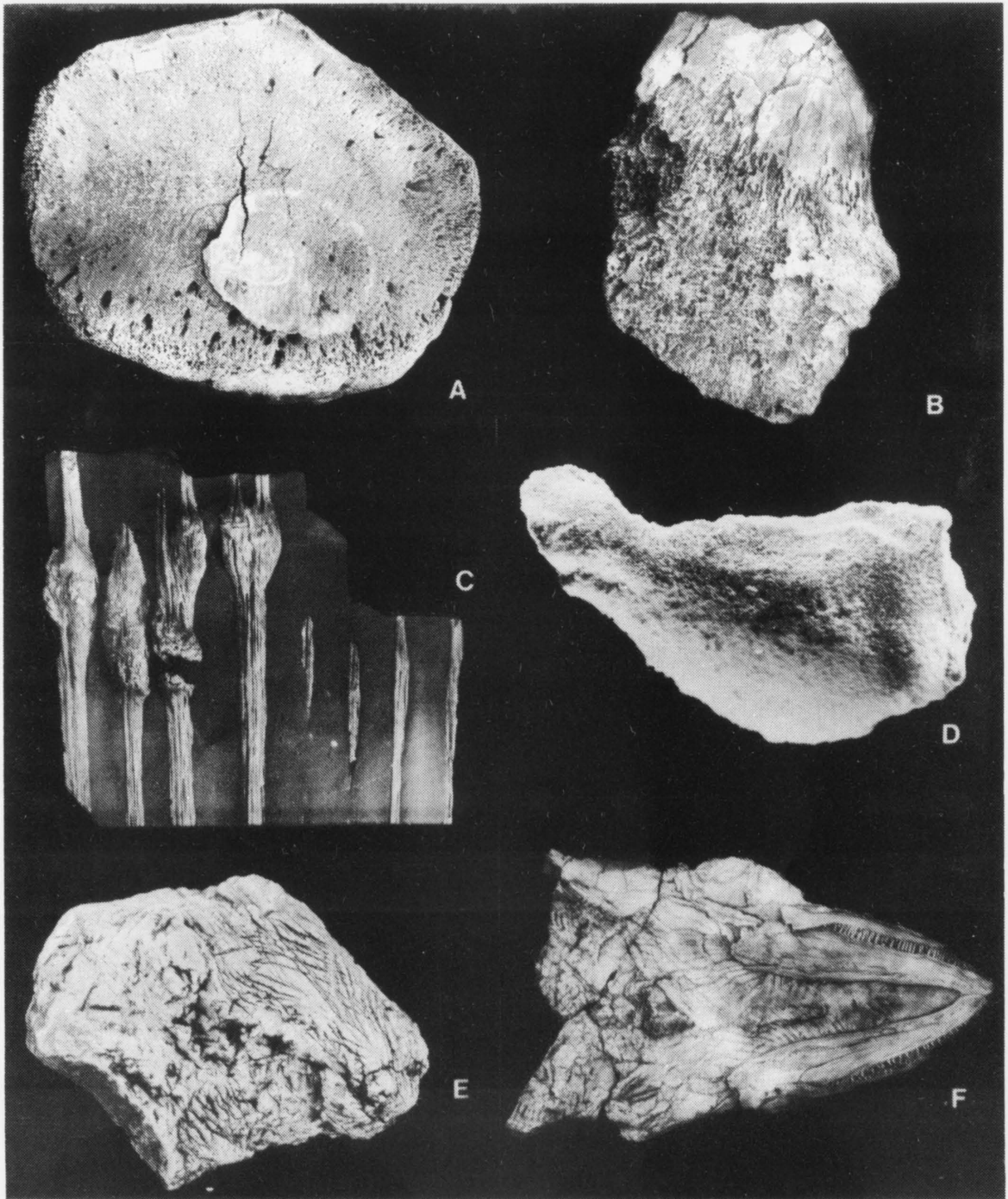


Plate 9A

Bone hardground. ?Ulna of *Ophthalmosaurus* sp. with encrusting oyster. Note late cracking of bone and oyster shell. Lower Oxford Clay. Milton Keynes, Bucks.  $\times \frac{1}{2}$

Plate 9B

Partially eroded saurian girdle bone. Smooth outer surface has been eroded away exposing inner trabecular bone. Lower Oxford Clay, Bed 13, Farcet barrow pit. Peterborough.  $\times \frac{1}{2}$

Plate 9C

Caudal fin rays of *Leedsichthys* sp. showing possible predation damage.  $\times \frac{1}{2}$

Plate 9D

Drop shaped otolith with etched surface.  $\times 30$

Plate 9E

Coprolite with feeding traces.  $\times 2$

Plate 9F

Dorso ventrally crushed skull of *Caturus porteri* Rayner.  $\times \frac{1}{2}$



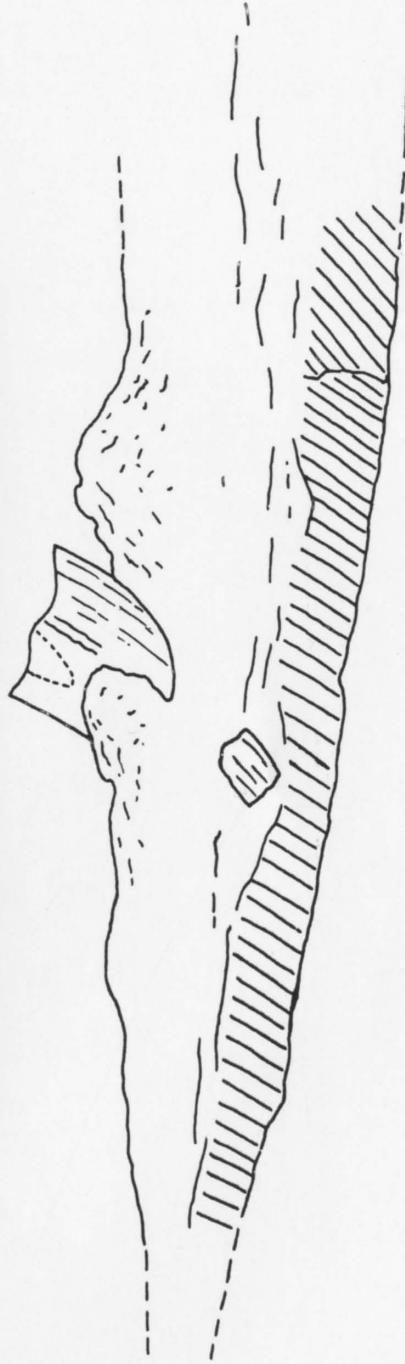
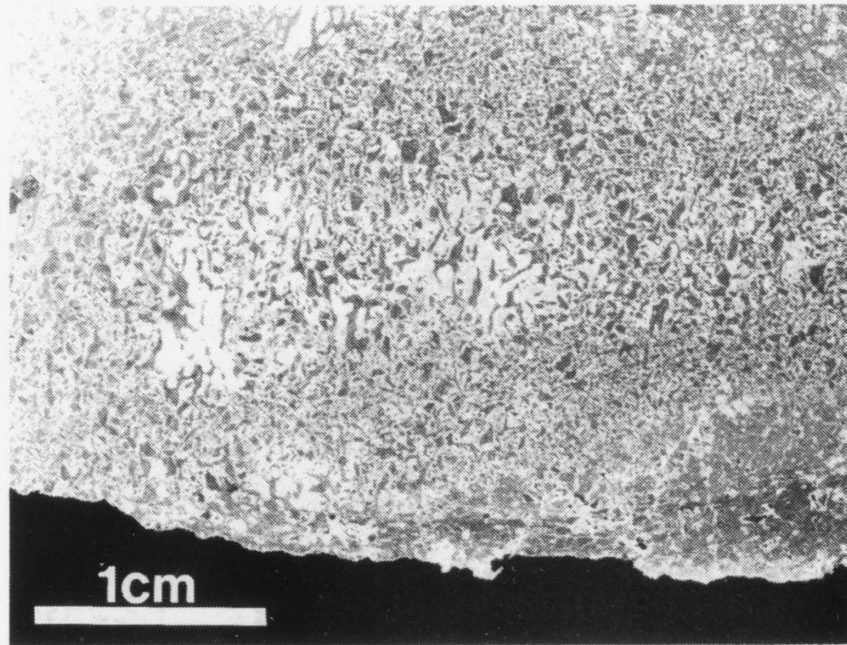


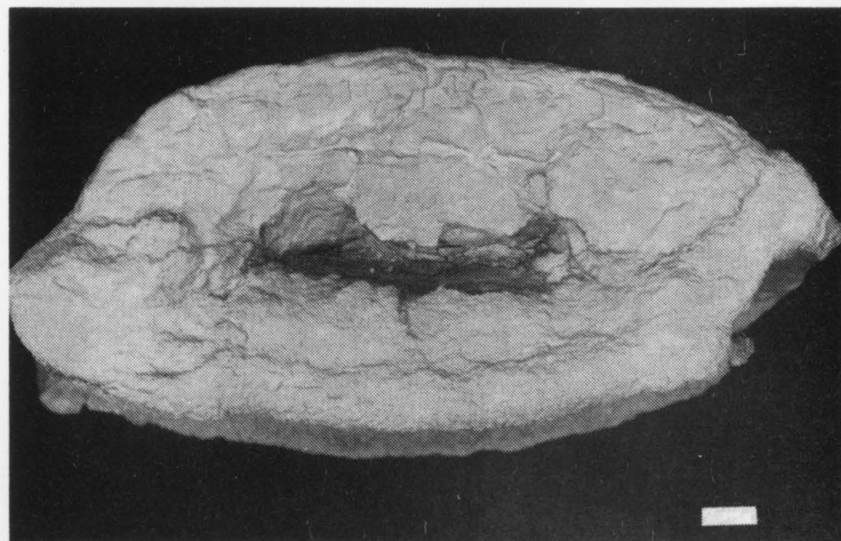
Plate 10  
Frontal bone of the giant pachycormid fish *Leedsichthys* sp. punctured by crocodilian tooth. New bone has grown around the tooth showing that not all crocodile attacks are fatal.  $\times 2$





**Plate 11A**

Thin section of ichthyosaur centrum showing high degree of brecciation due to compaction. There has been more than 50% volume reduction due to crushing.



**Plate 11B**

Dorso-ventrally crushed ichthyosaurian thoracic centrum. BCM 1008, 1983, Lower Oxford Clay, Milton Keynes, Buckinghamshire. Scale bar 1 mm.