In search of lost time: Recovering missing stratigraphical data from fossil marine reptile specimens using micropalaeontological analyses

by Nigel R. Larkin[1], Dean R. Lomax[2,3], Ian Boomer[4] and Phil Copestake[5]

[1]*University of Reading, School of Biological Sciences, Whiteknights, Reading RG6 6AH, UK; nrlarkin00@googlemail.com*
[2]*Palaeobiology Research Group, School of Earth Sciences, University of Bristol, Queens Road, Bristol, BS8 1RJ, UK;*
[3]*Department of Earth & Environmental Sciences, University of Manchester, Oxford Road, Manchester, M13 9PL, UK;*
[4]*School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, B15 2TT, UK;*
[5]*Merlin Energy Resources Ltd, Newberry House, New St, Ledbury HR8 2EJ, UK.*
Received September 2023, Accepted March 2024

Many museum and university collections contain fossil marine reptile specimens that have no provenance data associated with them, particularly those collected in the 19th and early 20th centuries. This may be because the information was never known to the museum or because the data have since been lost. Moreover, data that are associated with a specimen may have been assumed historically rather than verified and it is known that collectors, donors or sellers of specimens have sometimes been deliberately secretive or even misleading about the actual provenance of the fossils. If invertebrate macrofossils can be identified in the host matrix of the marine reptile specimen these can sometimes offer clues as to the stratigraphical origin of the specimen, but these instances are rare. Micropalaeontological analyses, however, can be undertaken on relatively small amounts of matrix associated with a specimen to attempt the recovery of lost data or confirm or reject assumed provenance details. Permission has been obtained to take small samples (as little as five grams) of host matrix from the rear of several ichthyosaur specimens during recent conservation projects where the provenance of the specimen was either totally unknown or was in doubt. These samples were analysed for their calcareous microfossil content, including ostracods and foraminifera. It was found that well-cemented limestones contained little or no recoverable material but softer mudstones have sometimes yielded very useful assemblages allowing specific biozones to be attributed to the host specimens, successfully recovering lost data and making the specimens much more useful scientifically. Even when the assemblage of microfauna is found to be poor or absent, some information about the sedimentary conditions of the preservational environment can often be ascertained from the micropalaeontological residues.

Larkin, N. R., Lomax, D. R., Boomer, I. and Copestake, P. 2024. In search of lost time: Recovering missing stratigraphical data from fossil marine reptile specimens using micropalaeontological analyses. *Geological Curator* **11** (9): 583-589. https://doi.org/10.55468/GC1472

Introduction

Large marine vertebrates of the Mesozoic Era (ichthyosaurs, plesiosaurs, pliosaurs, etc.) in museum collections often lack any provenance information, particularly those collected in the 19th and early 20th centuries. This may either because the information was never known to the museum or because the data have since been lost. This lack of data greatly reduces the usefulness of these fossils to taxonomic studies and other investigations. In addition, in the UK some specimens may be labelled with locations such as 'Lyme', 'Whitby' or 'Street' but not only are these sometimes assumptions added long after the fossil has been collected, rather than known facts, these localities cover a broad range of stratigraphical units. Also, collectors, donors or sellers of specimens can be secretive or even deliberately misleading about the actual provenance of a fossil (see Lomax *et al.* 2022). Whilst data such as the name of the collector or the date of collection may not be recoverable, information regarding the stratigraphical unit or biozone in which the specimen was found can sometimes be recovered by identifying invertebrate macrofossils (e.g. bivalves, ammonites, or belemnites, etc.), observable in the matrix on or around the specimen. They can sometimes be found during preparation and conservation work. However, stratigraphical information can be recovered more reliably and with greater precision by sampling very small amounts of the matrix (as little as five grams) for the purpose of micropalaeontological analyses. The resulting information might also suggest a geographical origin for the specimen.

Methods

In all instances where small samples of matrix (five to 15 g) have been taken from museum specimens, permission from the relevant curator has been obtained first. Samples have usually been taken from the rear of the specimen, or from matrix that was already loose and in the process of being repaired during a conservation project. More indurated samples were usually disaggregated using freeze-thaw methodologies or by soaking in ~1%

solution of H_2O_2 (hydrogen peroxide) for 30 minutes for softer sediments. All samples were then rinsed, dried and sorted under a binocular microscope. Microfauna such as ostracods and foraminifera were identified, then photographed using a Scanning Electron Microscope (SEM).

Invertebrate macrofossils proving useful in determining provenance

Example 1: Provenance inaccurately assigned historically to an ichthyosaur

A 180 cm long ichthyosaur skeleton (about 80% complete) in Jurassic matrix has been stored in the collections of the Royal Greenwich Heritage Trust for decades (M. Ross pers. Comm. 2021). This specimen recently required extensive conservation work. No data at all were associated with the specimen although it was assumed to have once been in the Borough Museum, London, England.

When dismantling the specimen to clean and conserve it an old envelope was found as a gap filler underneath the painted plaster in the abdomen. This helped to put a date to some repairs. The partial envelope was postmarked 14th March 1961 and was addressed (by typewriter) to: "The Curator, The Borough Museum, 232 Plumstead High Street, London, SE18". This has been crossed out and a handwritten note added: "Mr C. H. ?Turner, Woolwich". This in turn has been crossed-out and another name added, "Mr Rigden" (the curator of the Borough Museum used to be Reg Rigden). This means that the specimen is likely associated to the Borough Museum in southeast London c.1961. On the underside of the wooden frame the following number was found: 53.28. This was assumed to be an accession number of some sort e.g. 1953.28 or 1928.53. When the records for the collection were checked an entry was found for 1953.28 stating "Ichthyosaur, Skeleton of, Jurassic. Dorset". However, this may have been an assumption made at the time of entering the details rather than a statement of known fact, possibly because Lyme Regis is the most famous source of ichthyosaur specimens in the UK – even though to a marine reptile expert the matrix of this specimen does not look right for a Lyme Regis provenance.

A small sample of the matrix was analysed for microfossils but the dark fine-grained mudstone was likely dysaerobic and no microfossils were observed in the sample. However, during conservation work a distinctive bivalve mollusc was found preserved in pyrite on the underside of the abdomen. This was confirmed to be of the species *Pseudomytiloides dubius* (C. Little pers. Comm. 2020) and this dates only to the Toarcian Stage of the Early Jurassic in the UK (Caswell *et al*. 2009; Atkinson *et al*. 2023). This is not the right age for Lyme Regis, and this species simply does not occur there. Whilst the species does occur in Toarcian sections in SW England (e.g. Somerset), these facies are limestones, not shales like the matrix of the specimen in question (Boomer *et al.* 2009). Toarcian shale facies are present from the Midlands northwards, with the most likely provenance being the Yorkshire coast, north and south of Whitby. On the Yorkshire coast *P. dubius* first occurs in very low numbers in the Lower Sulphur Band in the lower Tenuicostatum Zone (Grey Shales Member of the Whitby Mudstone Formation), although this layer is only around 10 cm thick (Caswell *et al.* 2009; Atkinson *et al.* 2023). The ichthyosaur is more likely from rocks from the main range of abundant *P. dubius* specimens, from the Serpentinum Zone (encompassing the Mulgrave Shale Member of the Whitby Mudstone Formation) to the lowest part of the overlying Bifrons Zone (Alum Shale Member, Whitby Mudstone Formation) (C. Little pers. Comm. 2020).

Example 2: Provenance deliberately misassigned to an ichthyosaur by a collector

An ichthyosaur skeleton (DONMG:1983.98) with a preserved articulated length of 74.7 cm (and an estimated total body length of 1.4 m) in the palaeontology collection of Doncaster Museum and Art Gallery, UK, comprises a nearly complete skeleton (only missing one forefin, most of the hindfins and posterior portion of the vertebral column). Although the museum knowingly purchased the fossil as genuine in 1983 it was later mistaken for a plaster cast and used as such in the education department before being re-identified as an original specimen (Lomax 2010). Furthermore, it was subsequently recognised as a species new to science and is now the holotype of *Ichthyosaurus anningae* (Lomax and Massare 2015). To enable the taxonomic study of the specimen, a diverse range of work was required including checking its provenance (Larkin and Lomax 2015). An old index card relating to the specimen was found, recording the specimen as being found in Dorset, apparently from Upper Jurassic deposits at Kimmeridge, as detailed by the dealer Hilary Corke from whom it was bought, and a Dorset provenance looked likely from the appearance of the specimen. Usefully, fossils in the matrix surrounding the ichthyosaur included bivalves and belemnites, including a complete belemnite that lay next to the skull of the ichthyosaur, an example of *Bairstowius junceus* (Phillips 1867; see Lomax 2010). However, this species of belemnite has only ever been reported from a single horizon in the UK, the Lower Jurassic Stonebarrow Marl Member of the Charmouth Mudstone Formation, specifically Bed 110, the polymorphus subzone of the Jamesoni Zone (lower Pliensbachian). It is not known from Kimmeridge. The precise geographical location could not be determined from this, but the pos-

Figure 1. Specimen BU 5289 at the Lapworth Museum of Geology, University of Birmingham, UK, an almost complete neonate skeleton of Ichthyosaurus communis*. Scale 10 cm.*

sibilities were narrowed down. Bed 110 is found at three locations, all in the Charmouth area: Black Ven, Westhay Cliff, and on the foreshore west of Seatown. At the two latter locations, Bed 110 crops out nearer beach level so they are more likely spots for an articulated skeleton to be discovered. This does not match the record held by the museum. Significantly, the Pliensbachian age enabled the determination of the specimen as the most complete ichthyosaur ever recorded in the Pliensbachian worldwide, a stage of the Early Jurassic typically thought to be poor in ichthyosaur remains (Lomax 2010; Larkin and Lomax 2015; Lomax and Massare 2015).

Emma Corke, the daughter of the late Hilary Corke who sold the fossil, explained that her father had bought this ichthyosaur from collectors who were normally active along the coast at Charmouth and Seatown (Larkin and Lomax 2015). Her recollections fit perfectly with the evidence of the belemnite.

Both these projects described above demonstrate that even when fossils are labelled or registered as being from a particular location, it is worth checking this 'fact' with all means available. However, invertebrate macrofossils are not often observable in the associated matrix, or there may not be much matrix preserved. Even when such fossils are preserved, they are not usually particularly useful as zone fossils. Usefully, in such instances, the analysis of small amounts of matrix for microfossils can often yield not only data about the stratigraphic provenance of the fossil and therefore its age but also sometimes a likely geographical provenance can be suggested. Such analyses may also provide useful indications of water depth, salinity, etc. of the original depositional environment.

Microfossil analyses proving useful in determining provenance

Example 3: Neonate *Ichthyosaurus communis* skeleton (BU 5289) at the Lapworth Museum of Geology, University of Birmingham, UK

During conservation work this specimen (Figure 1), about 59 cm long, was identified as the only known neonate of the species *Ichthyosaurus communis* (Lomax *et al.* 2019). However, it had no provenance data associated with it at all. A ~12 g sample of matrix from the rear of the specimen yielded 110 microfossils: 13 species/subspecies of foraminifera (approximately 80 specimens) and 5 species (approximately 30 specimens) of ostracods. The most abundant species are shown in Figure 2.

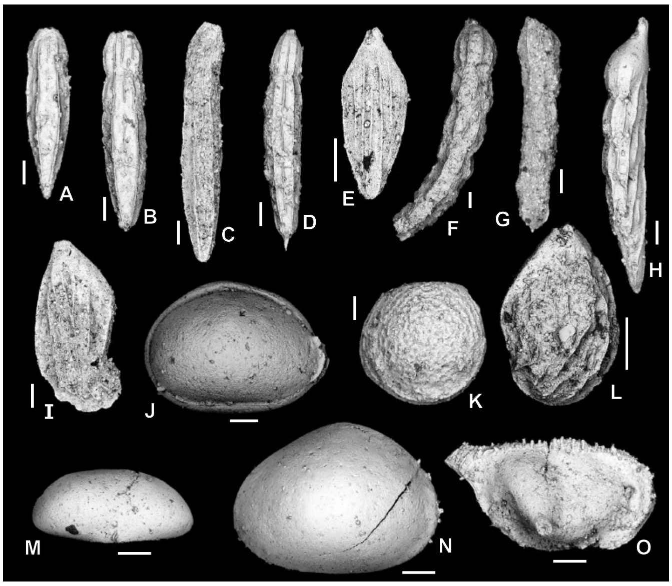

Figure 2 . Foraminifera (A–I, L) and Ostracoda (J–K, M–O), with specimen lengths along their longest axis given. A–C) Paralingulina tenera tenera*, 640 µm, 790 µm and 1075 µm respectively. D)* Nodosaria mitis*, 800 µm. E)* Ichthyolaria terquemi *(four-ribbed type), 390 µm. F)* Marginulina prima insignis*, 1290 µm. G)* Marginulina prima incisa*, 925 µm. H)* Mesodentlina matutina*, 1015 µm. I)* Planularia inaequistriata*, 790 µm. L)* Astacolus speciosus*, 660 µm. J)* Ogmoconchella nasuta *carapace, right lateral view. 510 µm. K)* Polycope pumicosa *carapace, left lateral view. 340 µm. M)* Paracypris sp. *right valve, external view. 440 µm. N)* Ogmoconcha hagenowi, *right valve, external. 590 µm. O)* Monoceratina frentzeni, *right valve, external. 600 µm. All scale bars 100 µm.*

Figure 3. Leptonectes ?tenuirostris *skeleton (SHEFM: H93.189) at Sheffield Museum and Galleries, UK. Length 169 cm including the frame.*

The occurrence of the foraminifera taxa strongly indicates the JF3 to basal JF4 Foraminifera Biozone (after Copestake and Johnson 2014) spanning a range from the base of the Complanata-Depressa ammonite Subchronozone to the top of the Conybeari ammonite Subchronozone (c). Furthermore, the co-occurrence of the foraminifera subspecies *Marginulina prima insignis* and *M. prima incisa* together with the ostracod species *Ogmoconcha hagenowi* and *Ogmoconchella nasuta*, indicates that the age of the specimen must be restricted from the very latest Hettangian to very earliest Sinemurian of the Lower Jurassic. Sediments of this age occur from southwest England and South Wales, through the English Midlands to the coasts of North Yorkshire and Humberside, and are generally assigned to the Blue Lias Formation of the Lias Group. Due to the relatively widespread occurrence of sediments that could be assigned to Foraminiferal Biozone JF3 across the UK, it is not possible to use the assemblage to provide any geographical control on the specimen.

Example 4: *Leptonectes ?tenuirostris* skeleton (SHEFM: H93.189) at Sheffield Museum and Galleries, UK

This ~160 cm long ichthyosaur skeleton (Figure 3) was known to have belonged to Thomas Bateman Jr (1821–1861), a well-known 'gentleman antiquarian' in Derbyshire. For a recent exhibition in Sheffield about his work and his collection, the specimen was extensively conserved. However, the fossil had no associated data regarding its original provenance. A sample of ~8 g of loose matrix yielded microfossils dominated by foraminifera. Although the species generally support a mid-Hettangian to early Sinemurian age, a single ostracod specimen proved crucial, refining the age to an interval from the Angulata to Bucklandi Ammonite Chronozone (latest Hettangian–earliest Sinemurian). Figure 4 shows selected calcareous microfossils recovered from this specimen. Based on this age and the nature of the matrix in which the skeleton is preserved, the original provenance of this specimen is likely to be Street in Somerset, UK (DRL pers. obs.).

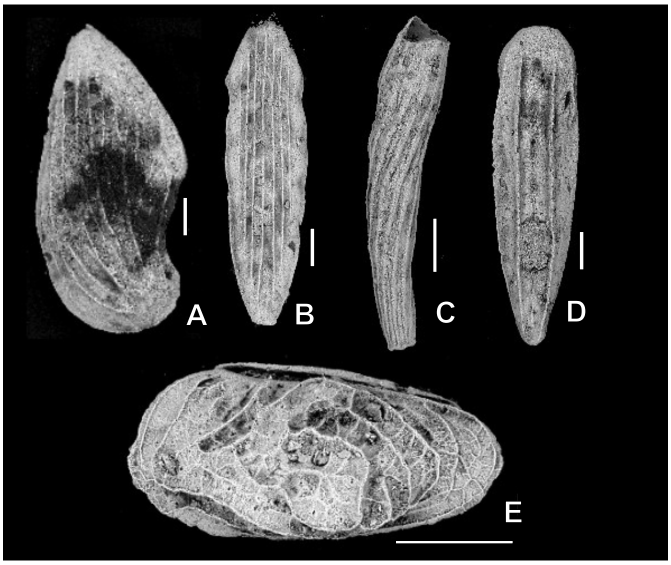

Figure 4 . Selected calcareous microfossils recovered from Leptonectes ?tenuirostris *specimen at Sheffield (SHEFM: H93.189) with specimen lengths along their longest axis given. A–D) foraminifera and E) ostracod. A)* Planularia inaequistriata*, 930 µm. B)* Ichthyolaria terquemi*, 750 µm. C)* Mesodentalina matutina*, 630 µm. D)* Paralingulina tenera tenera*, 800 µm. E)* Nanacythere elegans*, 320 µm. All scale bars 100 µm.*

Example 5: *Protoichthyosaurus prostaxalis* skeleton (BMT1955.G35.1) at the Thinktank, Birmingham Science Museum, UK

This 320 cm long ichthyosaur skeleton (Figure 5) is the largest known specimen of its species (Lomax *et al.* 2019). But of much greater importance, the skull was preserved in three dimensions with no hard sediment enclosing the bones, which is rare for a Lower Jurassic ichthyosaur (Lomax *et al.* 2019). However, the skull had been assembled from the individual bones soon after its excavation in 1955 and in 2015 the skull had to be disassembled and rebuilt to be more anatomically accurate. In the process,

Figure 5. Protoichthyosaurus prostaxalis *skeleton (BMT1955.G35.1) on display at the Thinktank, Birmingham Science Museum, UK. According to Lomax et al. (2019), the specimen has a total body length estimate of 3.2–4 m.*

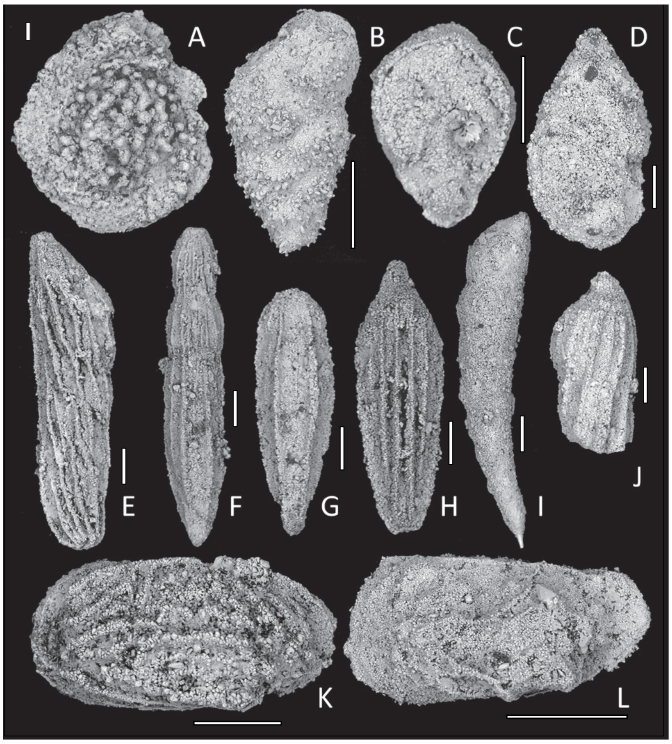

Figure 6. A–J) Foraminifera and K–L) ostracods, with specimen lengths along their longest axis given. A) Involutina liassica*, 1260 µm. B)* Neobulimina bangae*, 300 µm. C)* Berthelinella involuta involuta*, 220 µm. D)* Planularia protracta*, 480 µm. E)* Astacolus speciosus*, 960 µm. F)* Paralingulina tenera tenera*, 880 µm. G)* Paralingulina tenera substriata*, 570 µm. H)* Ichthyolaria terquemi sulcata*, 620 µm. I)* Prodentalina pseudocommunis*, 1080 µm. J)* Mesodentalina matutina*, 530 µm. K)* Nanacythere sp.*, 330 µm. L)* Eucytherura sp.*, 250 µm. All scale bars 100 µm.*

the postcranial skeleton was re-discovered in the museum collection and an investigation began into the origin of the specimen.

In contrast to the previous two examples, it was known where this ichthyosaur had been discovered but very little was known about the age of the sediments from which it had been excavated, nor the geology of the immediate local area and unfortunately all the matrix had been removed from the specimen. However, the exact location of the excavation within a specific field near Shipston-on-Stour, Warwickshire (UK), had been well recorded along with the depth at which the skeleton had been found. Therefore, permission was gained from the current landowner to use a mechanical digger to recover some sediment from the layer in which the specimen had been preserved.

A sample of ~20 g of matrix from this layer provided a diverse assemblage of foraminifera, although there were relatively few ostracods. Based on the species identified the specimen is suggested to date from a period of latest Hettangian to mid-Sinemurian, but the abundance of the foraminifera *Involutina liassica* suggests that an age equivalent to the latest Angulata to Bucklandi ammonite chronozones (latest Hettangian to earliest Sinemurian) seems most likely. Selected calcareous microfossils recovered are shown in Figure 6.

Discussion and Conclusions

Ostracods and foraminifera are microscopic organisms that mostly live on or within the seabed, whose evolutionary histories stretch far back into the Paleozoic. Their abundance, ubiquity, high species turnover rate and calcareous body parts that are relatively easily preserved make them interesting but also make them ideal for dating other fossils with which they are associated (such as vertebrates that are less easy to assign an age to). They are not always preserved in ancient marine sediments in a way that makes them recoverable (i.e. in well-cemented limestones), nor are they always preserved well enough to be identified. However, when they are recoverable and identifiable, these microfossils have provided very tightly constrained age ranges for fossil marine reptile specimens in museum collections that have lost some or all of the data associated with them. The stratigraphic ranges and interpreted ages for all three specimens discussed above are presented in Figure 7. This method should also work for dating other fossils preserved in marine sediments, not just marine reptiles.

Other microfossil groups could also be considered. Calcareous nannofossils are very small and require only a few milligrams of sediment. However, although they range from the latest Triassic to the present, they are not particularly strong biostratigraphic markers in the earliest Jurassic. They are probably of greatest value from the Cretaceous onwards where they achieve high abundance, high diversity and high turnover rates. Palynological remains of terrestrial spores and pollen as well as a range of single-celled marine organisms have also proven useful in biostratigraphic applications. These may require additional sample material, of a similar scale to the calcareous microfossils recorded above. Unfortunately, their stratigraphic resolution is restricted in the Early Jurassic. Where possible, multiproxy approaches could help to refine age determinations.

When matrix of a specific age has been identified and is known to be exposed in only a few outcrops, this can also help pinpoint the likely geographical source location of the specimen under study. It has to be considered of course that some outcrops that were available historically are no longer available, and some current outcrops may not have been accessible historically. Furthermore, in one instance during our research, an ostracod was found

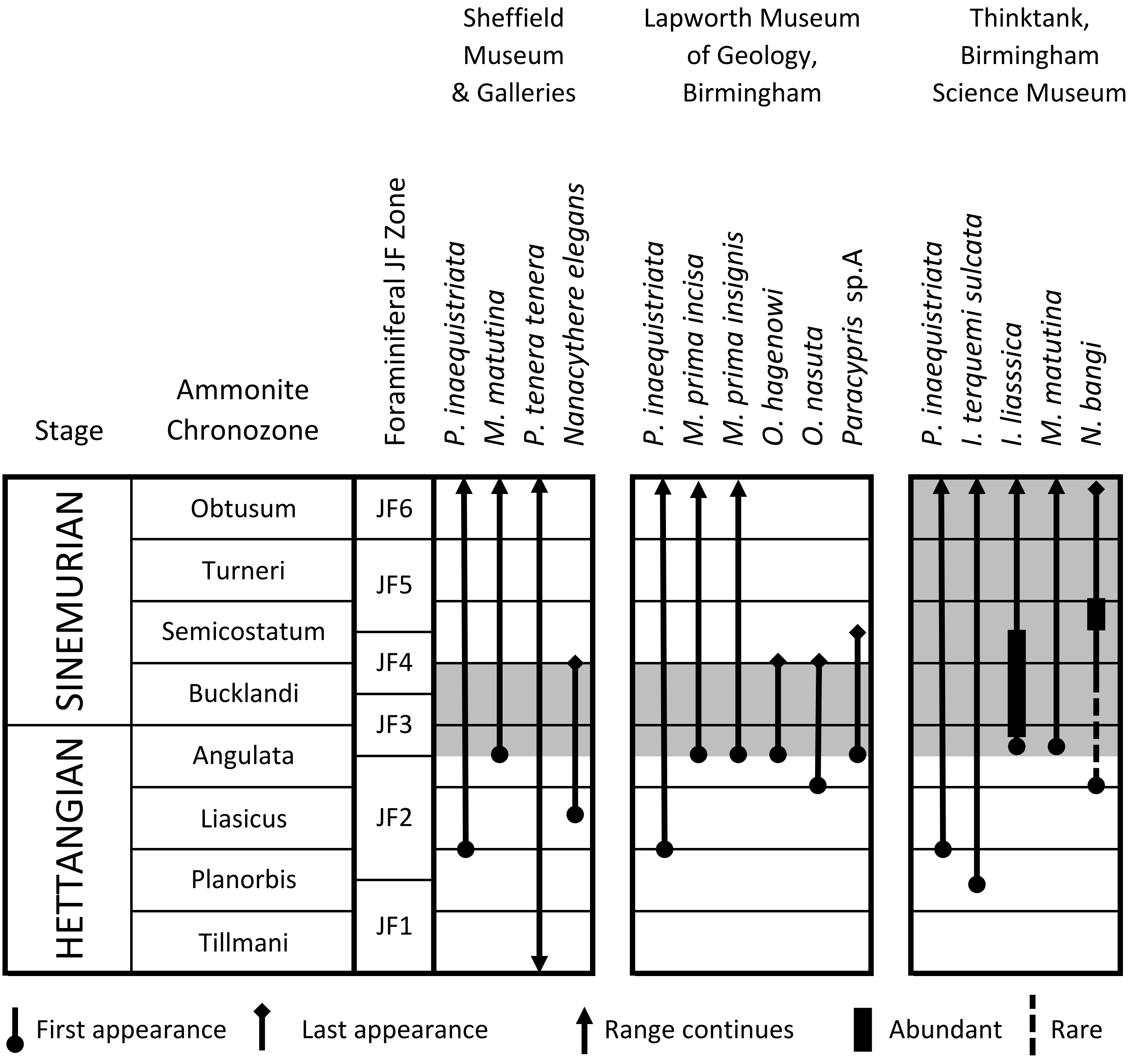

Figure 7. Range chart of key Lower Jurassic microfossil taxa recovered from the three vertebrate specimens discussed in the text. The shaded area indicates the most likely age assessment for each specimen based on overlapping ranges.

within the sample that was both modern and marine in habit – indicating that this fossil was likely to have been found at a coastal location.

One potential obstacle with this approach is that some museums may understandably be reluctant to allow the removal of matrix for study, especially if the specimen has some historic significance. However, only a fingernail-sized piece of matrix is usually required. The removal of such a small amount of matrix from the underside or rear of a specimen, or from a portion of the matrix situated some distance away from any bones, or especially if some small portion of matrix is loose anyway, would normally be justifiable considering the wealth of data that may be rediscovered about the specimen and how this information can aid further research. Such sampling could be undertaken during conservation work at no extra cost or inconvenience, as was the case with all the examples described above.

Acknowledgements

With thanks to staff at: the Lapworth Museum of Geology; Sheffield Museum and Galleries; the Thinktank (Birmingham Science Museum); Doncaster Museum and Art Gallery; and the Royal Greenwich Heritage Trust. Also: Crispin Little (University of Leeds); Jon Radley (Warwickshire County Council); and Malcolm Bryan (son of the finder of the Shipston-on-Stour specimen). DRL wishes to acknowledge The Royal Commission for the Exhibition of 1851 for generous support in the form of a Research Fellowship.

References

ATKINSON, J. W., LITTLE, C. T. S. and DUNHILL, A. M. 2023. Long duration of benthic ecological recovery from the early Toarcian (Lower Jurassic) mass extinction event in the Cleveland Basin, UK. *Journal of the Geological Society*, **180** (2), 1-14. doi: 10.1144/jgs2022-126

BOOMER, I. D., LORD, A. R., PAGE, K. N., BOWN, P. R., LOWRY, F. M. D. and RIDING, J. B. 2009. The biostratigraphy of the Upper Pliensbachian–Toarcian (Lower Jurassic) sequence at Ilminster, Somerset. *Journal of Micropalaeontology*, **28** (1), 67-85. doi: 10.1144/jm.28.1.67

CASWELL, B. A., COE, A. L. and COHEN, A. S. 2009. New range data for marine invertebrate species across the early Toarcian (Early Jurassic) mass extinction. *Journal of the Geological Society, London*. **166** (5), 859-872. doi: 10.1144/0016-76492008-0831

COPESTAKE, P. and JOHNSON, B. 2014. Lower Jurassic foraminifera from the Llanbedr (Mochras Farm) Borehole, North Wales, UK. *Monograph of the Palaeontographical Society*, **167** (641), 1-403. doi: 10.1080/02693445.2013.11963952

LARKIN, N. R. and LOMAX, D. R. 2015. An unexpected journey: the fall and rise of *Ichthyosaurus anningae*, from fossil to plaster cast to holotype. *Geological Curator,* **10** (3), 107-119.

LOMAX, D. R. 2010. An *Ichthyosaurus* (Reptilia, Ichthyosauria) with gastric contents from Charmouth, England: First report of the genus from the Pliensbachian. *Paludicola*, **8**, 22-36. doi: 10.1017/CBO9781107415324.004

LOMAX, D. R. and MASSARE, J. A., 2015. A new species of *Ichthyosaurus* from the Lower Jurassic of West Dorset, England, U.K. *Journal of Vertebrate Paleontology*, **35** (2), e903260. doi: 10.1080/02724634.2014.903260

LOMAX, D. R., LARKIN, N. R., BOOMER, I., DEY, S. and COPESTAKE, P. 2019. The first known neonate *Ichthyosaurus communis* skeleton: a rediscovered specimen from the Lower Jurassic, UK. *Historical Biology*, **31** (5), 600-609. doi: 10.1080/08912963.2017.1382488

LOMAX, D. R., PORRO, L. B. and LARKIN, N. R. 2019. Descriptive anatomy of the largest known specimen of *Protoichthyosaurus prostaxalis* (Reptilia: Ichthyosauria) including computed tomography and digital reconstruction of a three-dimensional skull. *PeerJ*, *7*, e6112. doi: 10.7717/peerj.6112

LOMAX, D. R., SACHS, S. and HALL, A. 2022. The ultimate 'iffyosaur' – An unusual ichthyosaur composite comprising British and German material of different geological stages. *Paludicola*, **14**, 32-41.