Cretaceous Research 150 (2023) 105590

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

A well preserved pan-pleurodiran (Dortokidae) turtle from the English Lower Cretaceous and the first radiometric date for the Wessex Formation (Hauterivian–Barremian) of the Isle of Wight, United Kingdom

Megan L. Jacobs [a,*], Adán Pérez-García [b], Marcos Martín-Jiménez [b], Catherine M. Mottram [a], David M. Martill [a], Andrew S. Gale [a], Oliver L. Mattsson [c], Charles Wood [d]

[a] *School of the Environment, Geography and Geosciences, University of Portsmouth, Portsmouth, PO1 3QL, UK*
[b] *Grupo de Biología Evolutiva, Facultad de Ciencias, UNED, 28232, Las Rozas, Madrid, Spain*
[c] *Dinosaur Expeditions C.I.C., Military Road, Brighstone, Isle of Wight, PO30 4PG, UK*
[d] *Future Technology Centre, School of Mechanical Design and Engineering, University of Portsmouth, Portsmouth, PO1 3HE, UK*

A R T I C L E I N F O

Article history:
Received 26 February 2023
Received in revised form
7 May 2023
Accepted in revised form 22 May 2023
Available online 27 May 2023

Keywords:
Pan-Pleurodira
Dortokid
Isle of Wight
Wessex Formation
Barremian
Lower Cretaceous

A B S T R A C T

The oldest record of a dortokid turtle (Testudines, Pan-Pleurodira) and the first occurrence of the group in the UK is reported. This find corresponds to the oldest pan-pleurodiran turtle in the country, and the only one from the Mesozoic of the UK. The new specimen, from the Lower Cretaceous (Barremian) Wessex Formation of the Isle of Wight, comprises a relatively complete shell with post cranial elements within a calcite-filled shell vacuity. Micro CT scanning has revealed these tiny bones to include cervical, dorsal and caudal vertebrae, scapulae, pelvic girdle and appendicular elements. In addition, aspects of the internal morphology of the carapace and plastron are revealed. No features allow the new specimen to be distinguished from the coeval *Eodortoka morellana* of Spain, and we therefore identify it as *Eodortoka* cf. *morellana*.

The specimen was found ex-situ, and due to questions raised regarding the provenance of the specimen, U–Pb geochronology of the diagenetic calcite filling was performed to establish the age of the specimen. Previously, it has been challenging to determine absolute timing constraints for the Wessex Formation fossil material due to lack of minerals dateable with radiometric techniques. This analysis has thus provided the first radiometric date for the Wessex Formation of 127.3 ± 2.7 Ma.

1. Introduction

The Dortokidae are a group of poorly known basal pan-pleurodiran turtles, endemic to Europe with a temporal range from the Early Cretaceous to the Paleogene (Lapparent de Broin and Murelaga, 1999; Lapparent de Broin et al., 2004; Pérez-García et al., 2012, 2017; Pérez-García, 2014, 2017; Cadena and Joyce, 2015; Tong et al., 2022). Examples of dortokid turtles have previously been recorded from the Lower Cretaceous (late Barremian) of Spain, and the Upper Cretaceous (Campanian and Maastrichtian) of France, Spain and Romania. They have also been reported from the Paleogene of Romania. Four taxa have been described: *Eodortoka morellana* (Pérez-García et al., 2014), *Dortoka vasconica* (Lapparent de Broin and Murelaga, 1999), *Dortoka vremiri* (Augustin et al., 2021) and *Ronella botanica* (Gheerbrant et al., 1999).

The Wessex Formation of the Isle of Wight has become well known for its diverse vertebrate remains (Batten, 2011; Sweetman 2011a; Austen and Batten, 2018) especially its dinosaur assemblage (Martill and Naish, 2001; Barker et al., 2021; Lockwood et al., 2021; Longrich et al., 2022). The vertebrate remains, both isolated bones and teeth and partially articulated skeletons, occur frequently within thin (0.3 m–~1 m) so-called plant debris beds (PDBs). Besides dinosaurs,

* Corresponding author.
E-mail address: megan.jacobs@port.ac.uk (M.L. Jacobs).

https://doi.org/10.1016/j.cretres.2023.105590

the fossil assemblage includes amphibians, (Sweetman and Evans, 2011a) crocodiles (Buffetaut and Hutt, 1980; Buffetaut, 1983; Sweetman et al., 2014a; Ristevski et al., 2018), pterosaurs (Steel et al., 2005; Sweetman and Martill, 2010; Martill et al., 2020), turtles (see below), squamates (Sweetman and Evans, 2011b) and even mammals (Sweetman, 2006, 2011b, 2016) occurring less frequently. Fish remains can also be common and include both actinopterygians and freshwater chondrichthyans (Sweetman et al., 2014b).

Turtle remains occur frequently in the Wessex Formation strata of the Isle of Wight, UK, but they remain poorly known as most occur as fragmentary and indeterminate material and have only infrequently been studied (Milner, 2004; Joyce et al., 2011). There are currently only three turtle taxa reported from the Wessex Formation: the terrestrial *Helochelydra nopcsai* (Lapparent de Broin and Murelaga, 1999), the freshwater *Brodiechelys brodiei* (Lydekker, 1889) and *Pleurosternon* sp. (Owen, 1853). In addition, from mainland Wealden Group strata the genus *Hylaeochelys* has been reported, but it has yet to be recorded from the Isle of Wight outcrops (Milner, 2004).

Absolute timing constraints can be acquired for important fossil-bearing stratigraphic layers by dating key beds such as zircon-bearing tuffs (e.g. Bowring and Schmitz, 2003), however absence of such materials in many locations can make dating important stratigraphic layers challenging. In-situ U—Pb carbonate geochronology is a novel, but established method that provides absolute timing constraints for carbonate crystallisation in a range of geological settings (as summarised by Roberts et al., 2020), including diagenetic cements (e.g. Godeau et al., 2018). This method has successfully been used to provide timing constraints for diagenetic infills in fossil remains including Toarcian ammonites (Li et al., 2014)and Pliocene bivalves (Rochín-Bañaga et al., 2021). Therefore this can be a useful tool for providing absolutely timing constraints for important stratigraphic horizons in the fossil record (e.g. Kurumada et al., 2020).

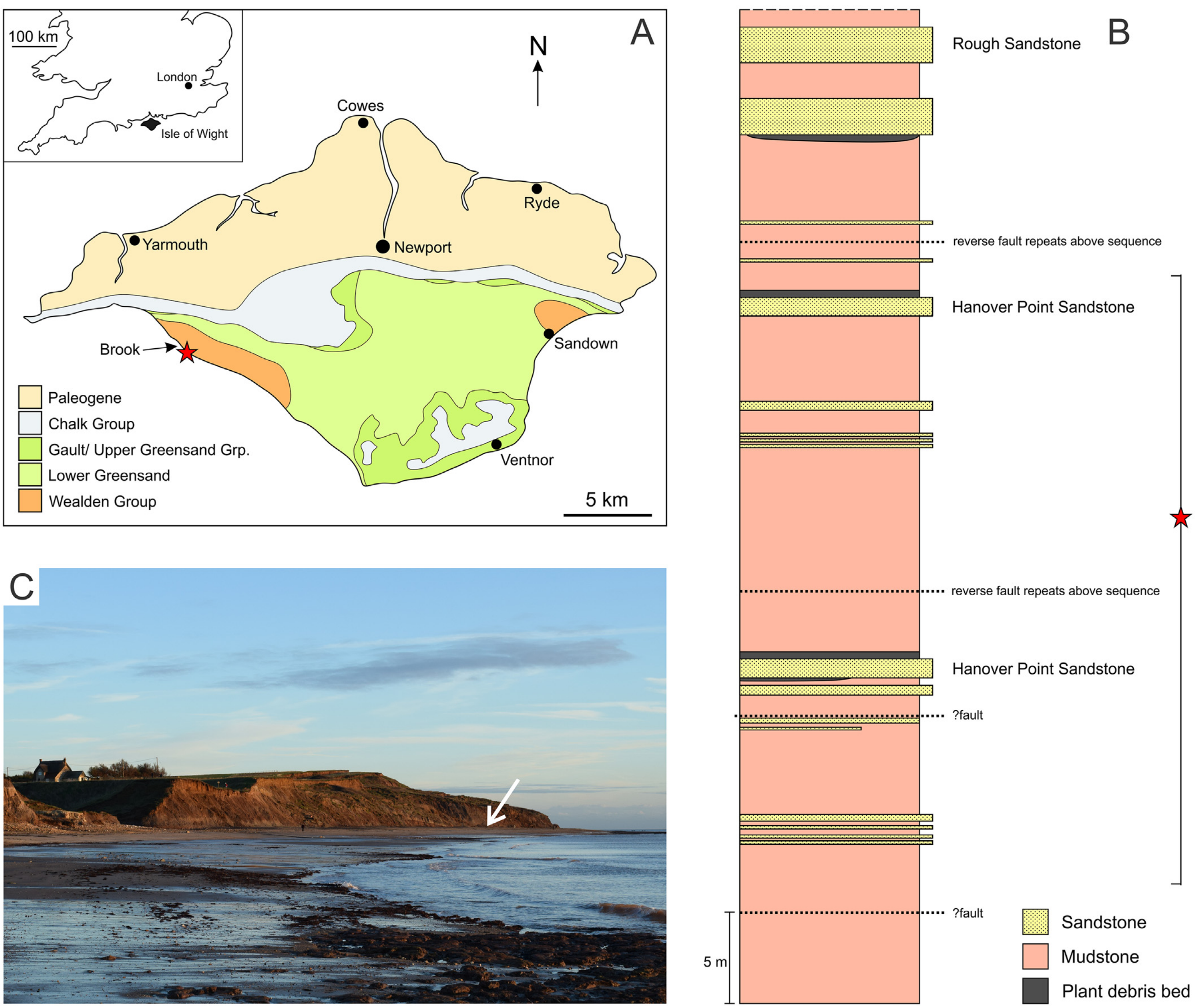

Fig. 1. Geology of the Isle of Wight showing the discovery site of *Eodortoka* cf. *morellana* IWCMS.2018.44 from the Wessex Formation. A, Map of the Isle of Wight with the locality indicated by a red star, modified from Gale (2019). B, Simplified stratigraphic column of the Wessex Formation of Compton and Brook Bays, with range of original horizon shown. C, Photo of Brook Bay showing the exposed Wessex Formation, with an arrow indicating where the specimen was found.

Here we report the oldest record of a pan-pleurodiran turtle in the United Kingdom, as well as the first and only occurrence of a dortokid in the UK represented by an almost complete shell with associated cervical, dorsal and caudal vertebrae, scapulae, pelvic girdle and appendicular bones. This specimen has been affectionately named 'Burby', after Mr Burbridge who found the specimen and kindly donated it to Dinosaur Isle Museum, Sandown. Due to the specimen's occurrence ex-situ and questions raised over provenance (the preservation superficially resembles that found in fossil turtles from the Eocene London Clay Formation of Kent, also in southern England), we used U–Pb geochronology to produce the first radiometric date for the Wessex Formation and confirm the specimens stratigraphic origin.

2. Locality and geological context

The new specimen (IWCMS 2018.44) was collected from the foreshore at Brook Bay on the southwest coast of the Isle of Wight, United Kingdom, National Grid reference SZ 385 836 in 2015 by Mr Steve Burbridge of Romsey (Fig. 1). This part of the coast is well-known for fossil vertebrates that come from the cliff and foreshore exposures of the upper part of the Wessex Formation (Sweetman, 2011a; Gale, 2019). The exposed sequence at Brook Bay comprises the lower part of the Wessex Formation consisting of high sinuosity fluvial red and variegated mudstones with fine to medium sandstones (Stewart, 1978, 1981; Sweetman, 2011b) (Fig. 1). Within the sequence are several thin (~30 cm) plant debris beds (PDBs) consisting of jumbled plant remains (lignite logs, fine plant debris and some charcoal) and coarser sediment, often with concretionary siderite (Sweetman and Insole, 2010) (Fig. 1). Preservation of the specimen described here is consistent with having been derived from one of these plant debris beds. The Wessex Formation at Brook Bay has been dated as late Hauterivian to lower Barremian by Robinson and Hesselbo (2004).

3. Analytical methods and results

3.1. Calcite U–Pb geochronology methods and results

Diagenetic calcite fragments from within the turtle specimen were disaggregated from the turtle, mounted in a 1-inch epoxy mount and polished. The calcite is enriched in U (~4.5–81.6 ppm) and contains low common Pb values (~0.019–11.560 ppm) making the material ideal for U–Pb geochronology.

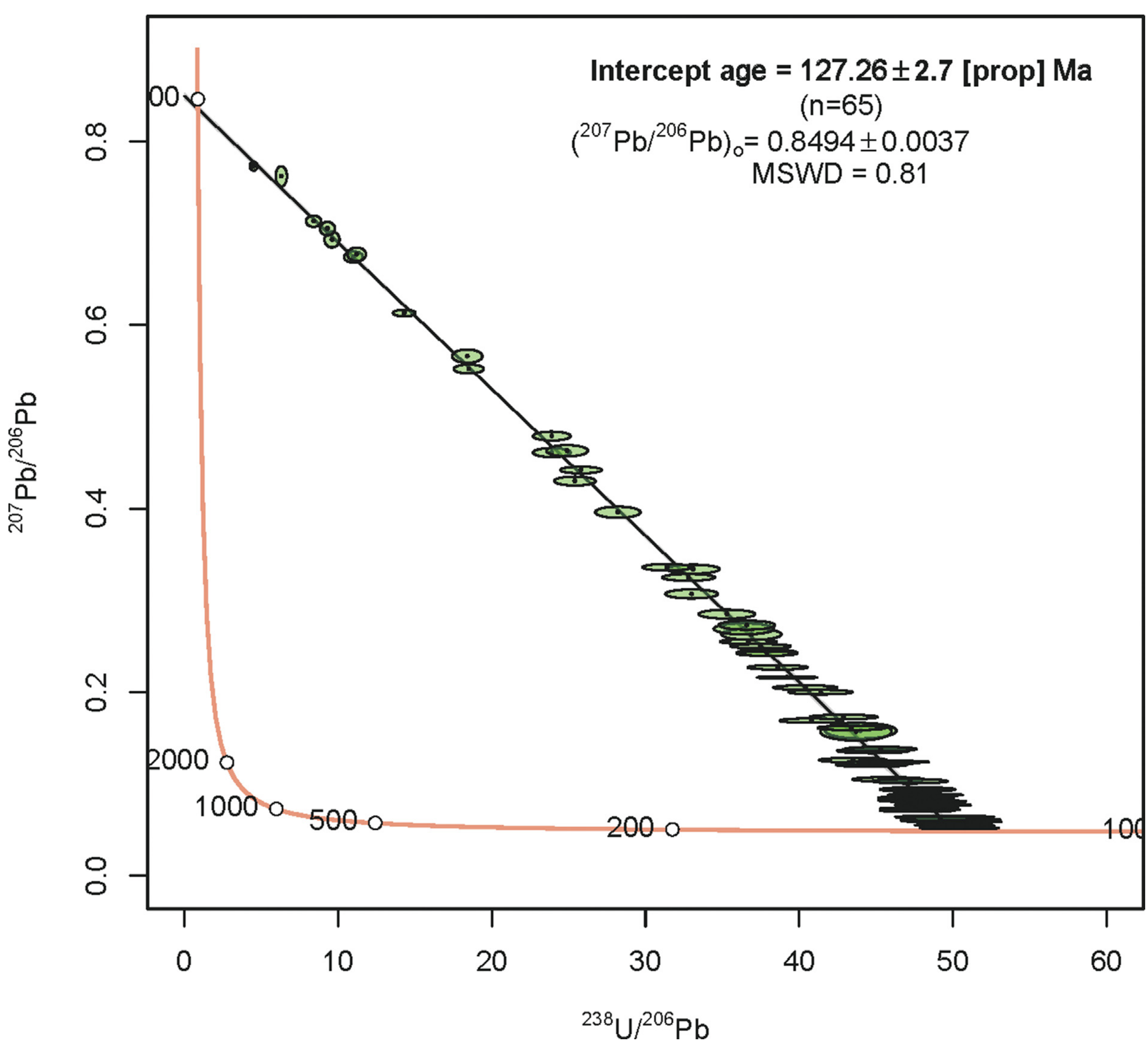

Fig. 2. Tera Wasserburg plot of turtle calcite $^{206}Pb/^{238}U$ intercept age. Quoted ages include propagated 2% long-term reproducibility of secondary reference material.

U–Pb calcite dating was performed at the University of Portsmouth, UK, using an ASI RESOlution© 193 nm ArF excimer laser coupled to a high sensitivity Jena Analytic PlasmaQuant Elite© LA-ICP-MS instrument. Calcite was analysed using 90 μm spot size, laser fluence of ≈2.6 J/cm^2, and a repetition rate of 8 Hz. SRM612 glass (NIST612; 38 ppb U and Pb; Pearce et al., 1997) and WC-1 carbonate (254.4 ± 6.4 Ma; Roberts et al., 2017) were used as primary reference materials and Mudtank zircon (732 ± 5 Ma; Black and Gulson, 1978; Jackson et al., 2004) and Duff Brown Limestone (64 ± 2 Ma; Hill et al., 2016) were used as a secondary reference material to test long-term reproducibility. Analyses of Mudtank during the analytical period yielded a ^{206}Pb/^{238}U intercept age of

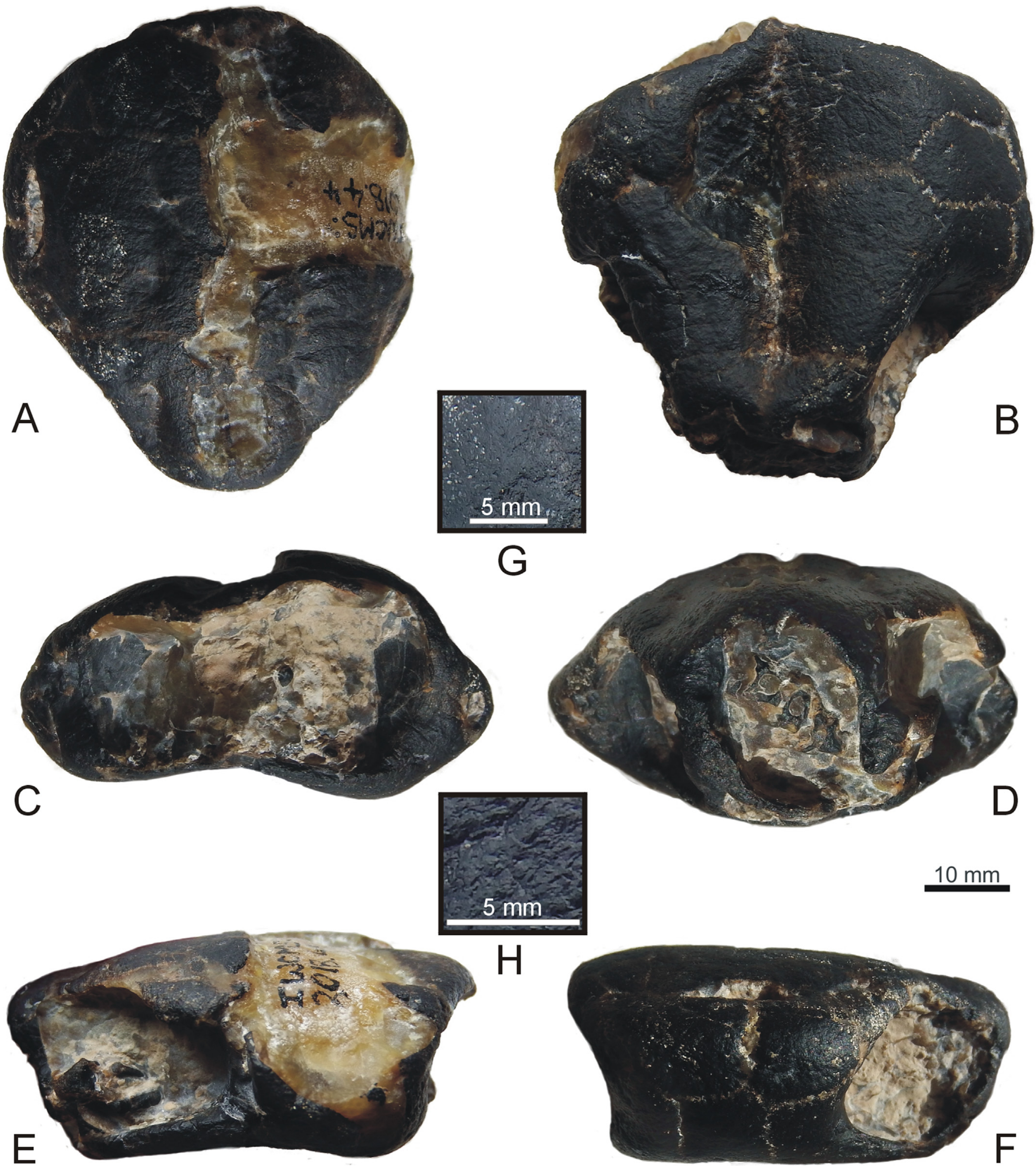

Fig. 3. IWCMS 2018.44, partial skeleton of *Eodortoka* cf. *morellana*. A, dorsal view, B, ventral view, C, anterior view, D, posterior view, E, left lateral view, F, right lateral view. G-H, details of the ornamental pattern on the outer surface of the shell, at the level of the left first costal (G) and of the left hypoplastron (H).

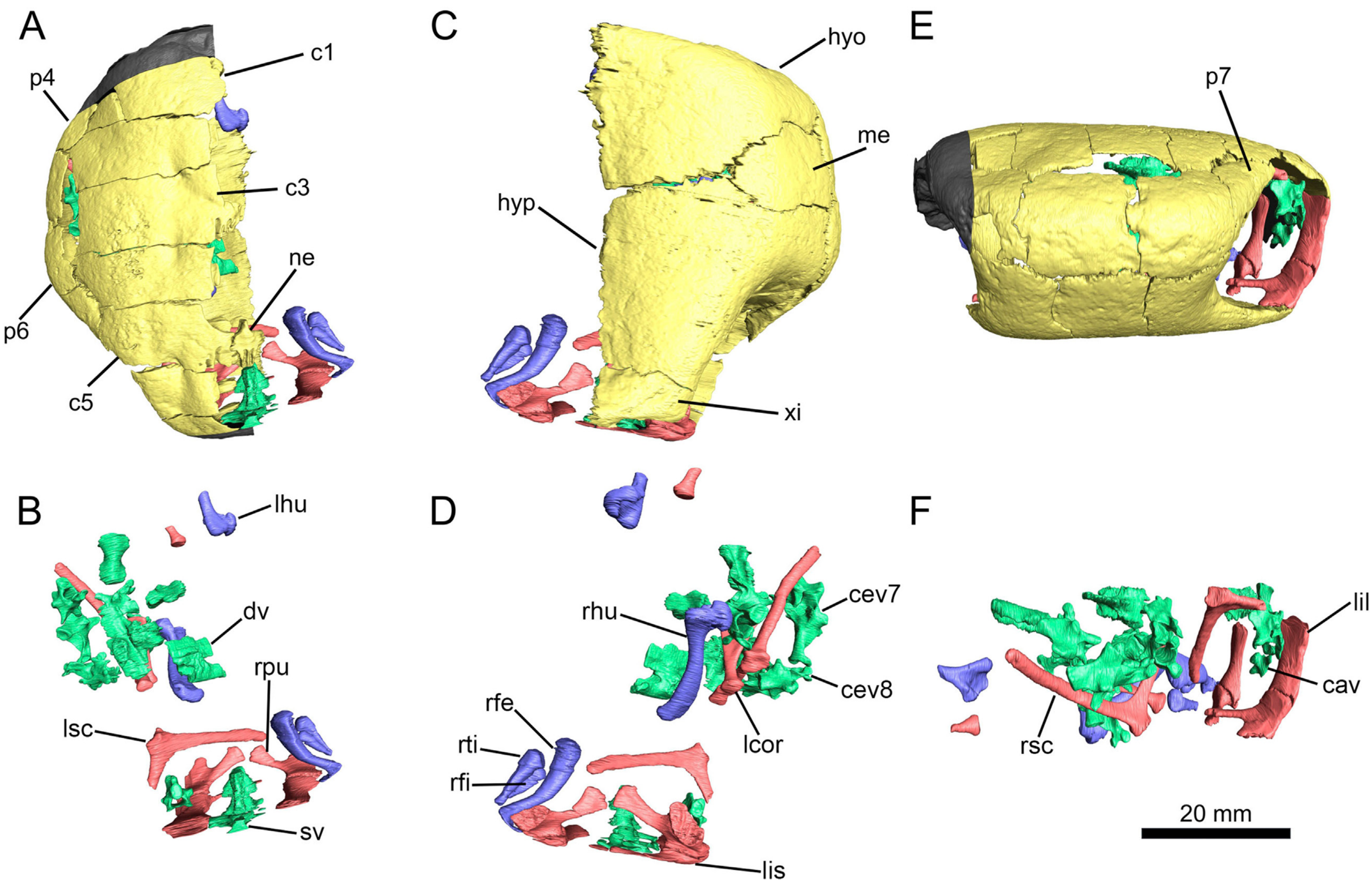

Fig. 4. IWCMS 2018.44, partial skeleton of *Eodortoka* cf. *morellana*. A,C,E, virtual three-dimensional reconstruction of the left shell plates and of the bones preserved inside the specimen; B,D,F, virtual three-dimensional reconstruction of the bones virtually removing the shell, in dorsal (A,B), ventral (C,D), and left lateral (E,F) views. The anterior and posterior ends of the shell cannot be reconstructed because they were not accurately scanned (black in A, E). The plates of the shell and the bones were reconstructed independently (shell plates in yellow, vertebrae in green, appendicular bones in blue, and girdles in pink). Abbreviations: c, costal; cav, caudal vertebra; cev7, seventh cervical vertebra; cev8, eighth cervical vertebra; dv, dorsal vertebra; hyo, hyoplastron; hyp, hypoplastron; lcor, left coracoid; lhu, left humerus; lil, left illium; lis; left ischium; lsc, left scapula; me, mesoplastron; ne, neural; p, peripheral; rfe, right femur; rfi, right fibula; rhu; right humerus; rpu, right pubis; rsc, right scapula; rti, right tibia; sv, sacral vertebra; xi, xiphiplastron.

711.5 ± 8.6 Ma (2.8% reproducibility). Duff Brown yielded a $^{206}Pb/^{238}U$ intercept age of 65.3 ± 2 Ma (2% reproducibility). U–Pb data are presented on Tera Wasserburg plots using IsoplotR (Vermeesch, 2018) and are uncorrected for common Pb. Quoted 2σ uncertainties include fully propagated analytical uncertainties (see Supplementary material for full details). Full analytical methods can be found in Parrish et al. (2018) and Mottram et al. (2020) and in the supplementary information.

Sixty-five laser spot analyses of 39 calcite fragments (~0.2–2 mm in size) yielded a combined $^{206}Pb/^{238}U$ Tera Wasserburg intercept age of 127.3 ± 2.7 Ma (MSWD = 0.81, n = 65; Fig. 2).

3.2. Micro CT scanning

The specimen IWCMS 2018.44, was scanned at the Future Technology Centre, University of Portsmouth, UK. A Zeiss Versa 520 X-ray Microscope was used with the following parameters: voltage 160 kV, current 63 μA, flat panel exposure 0.41 s, frame averaging 1, camera binning 1, source filter HE18, secondary reference filter tungsten, and 4501 projections, over 360°. To reduce voxel sizes to 20 μm, a vertical stitch scan was performed over a period of 34 h using a Flat Panel Detector, merging three datasets. To make the three-dimensional dataset (approx. 27.5 GB) manageable for post

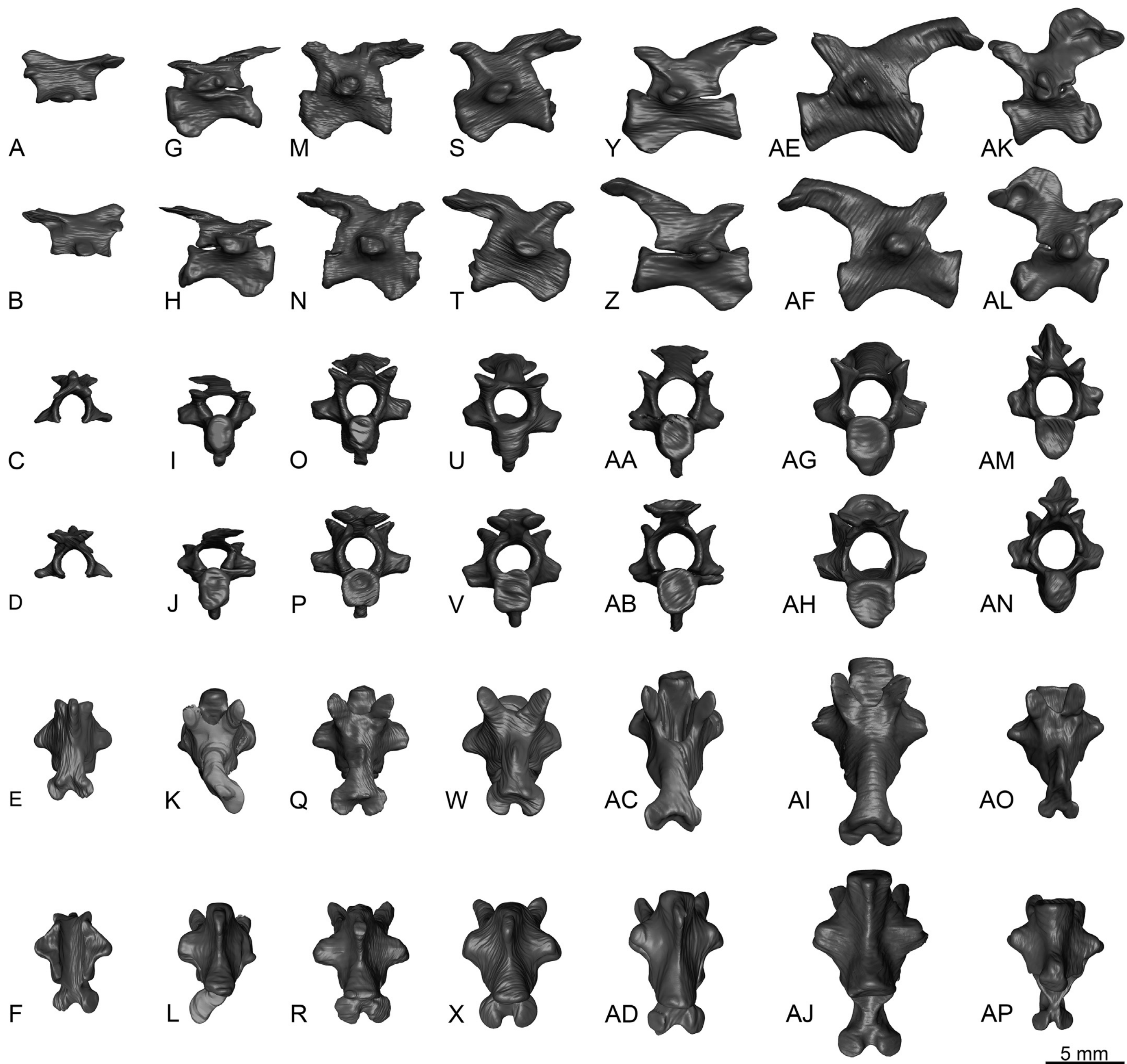

Fig. 5. Cervical vertebrae of IWCMS 2018.44. A-F, neural arch of the axis (cervical vertebra 2); G-L, cervical vertebra 3; M-R, cervical vertebra 4; S-X, cervical vertebra 5; Y-AD, cervical vertebra 6; AE-AJ, cervical vertebra 7; AK-AP, cervical vertebra 8. All of them are shown in left lateral (A,G,M,S,Y,AE,AK), right lateral (B,H,N,T,Z,AF,AL), anterior (C,I,O,U,AA,AG,AM), posterior (D,J,P,V,AB,AH,AN), dorsal (E,K,Q,W,AC,AI,AO), and ventral (F,L,R,X,AD,AJ,AP) views.

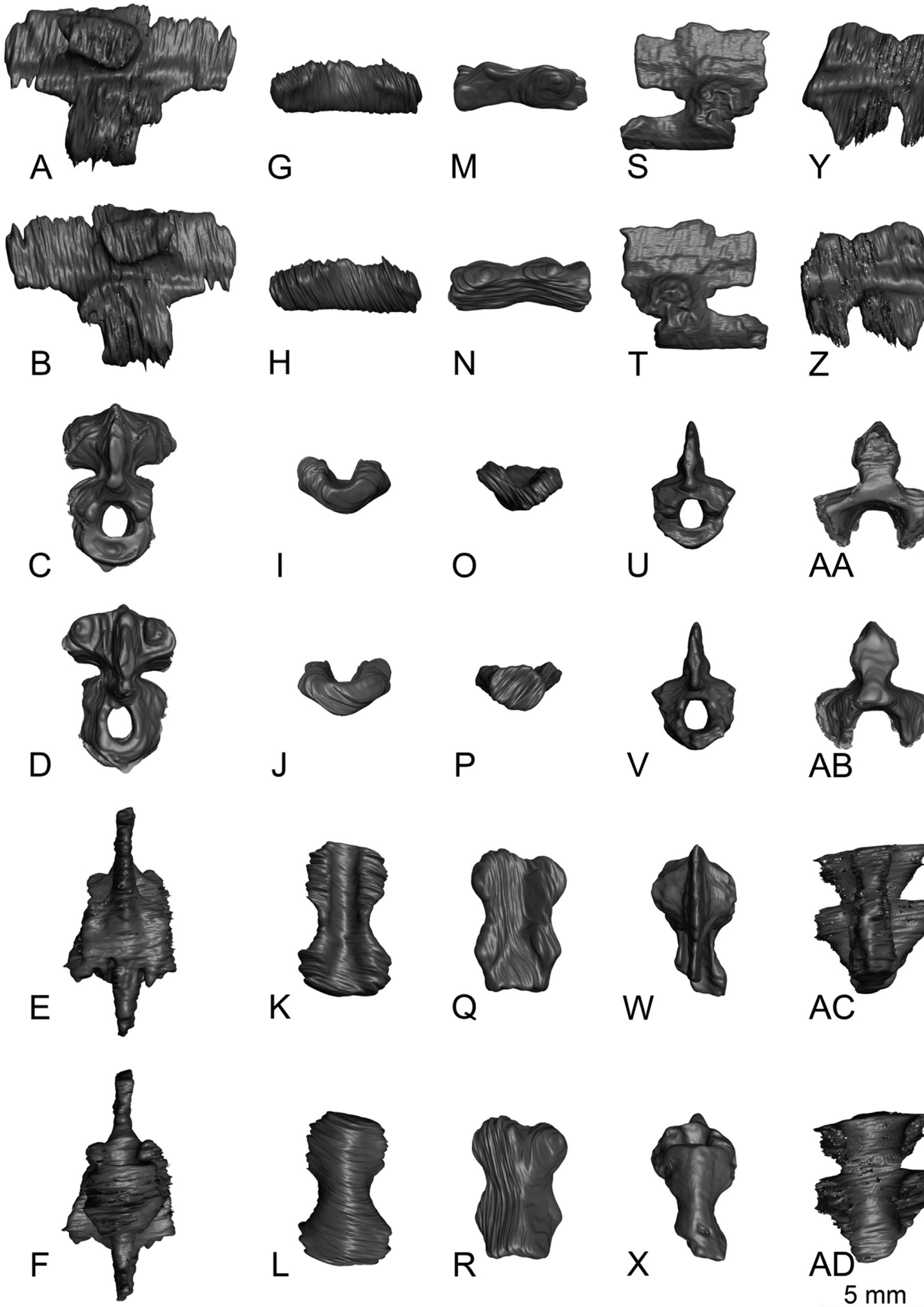

Fig. 6. Dorsal vertebrae of IWCMS 2018.44. A-F, complete dorsal vertebra with fused neural; G-L, dorsal vertebra centrum; M-R, dorsal vertebra centrum; S-X, complete dorsal vertebra; Y-AD, neural arch of a posterior dorsal vertebra. All of them are shown in left lateral (A,G,M,S,Y), right lateral (B,H,N,T,Z), anterior (C,I,O,U,AA), posterior (D,J,P,V,AB), dorsal (E,K,Q,W,AC), and ventral (F,L,R,X,AD) views.

processing the image stack was down sampled to 8 bit .tif and processed using the open-source software ImageJ 1.50i.

3.3. Rendering of CT imaging

The image file obtained from the CT corresponds to an archive in .tif format with a resolution of 20 μm voxel size. Due to its size (almost 27.5 GB), it was processed using ImageJ 1.50i to reduce the weight of the images and facilitate their subsequent analysis. In addition, for the processing of these files, they had to be subdivided into three packages of 1050, 1000, and 535 images, which were subsequently joined and merged. The segmentation of the elements on the left side of the shell and the bones located inside were made manually using the software Avizo 7.1 (VSG). The three-dimensional reconstructions obtained were subsequently fused using Geomagic Studio 2014.3.0 software. Each of the left plates and bones had been reconstructed independently. Bidimensional images were renderized using the snapshot tools of Avizo 7.1. Finally, the figures were composed using the software Adobe Photoshop CS6.

3.4. Abbreviations used

The specimen described here is accessioned to the collection of Dinosaur Isle Museum, Isle of Wight, UK, prefixed IWCMS.

4. Description

4.1. Systematic palaeontology

Testudines Batsch, 1788
Pan-Pleurodira Joyce, Parham and Gauthier, 2004
Pleurodira Cope, 1864
Dortokidae Lapparent De Broin and Murelaga, 1996
Eodortoka Pérez-García, Gasulla and Ortega, 2014

Eodortoka cf. ***morellana*** Pérez-García, Gasulla and Ortega, 2014 (Figs. 3–9)

Material. IWCMS 2018.44 is a partial skeleton of a probably juvenile individual (Fig. 3), comprising a relatively complete shell (maximum preserved length 49.6 mm and maximum preserved width 47.6 mm; Figs 3, 4), whose external surface has been partially eroded, obscuring most boundaries of the scutes; as well as several vertebrae (most cervicals, Fig. 5; some dorsals, Fig. 6; and scarce caudals, Fig. 7), partial pectoral and pelvic girdles (Figs. 4, 8), and several appendicular bones including both humeri, right femur, fibula and tibia (Fig. 9).
Locality. Brook Bay, Isle of Wight, United Kingdom, National Grid Reference SZ 385 836.
Horizon. Wessex Formation, Early Cretaceous, Barremian.

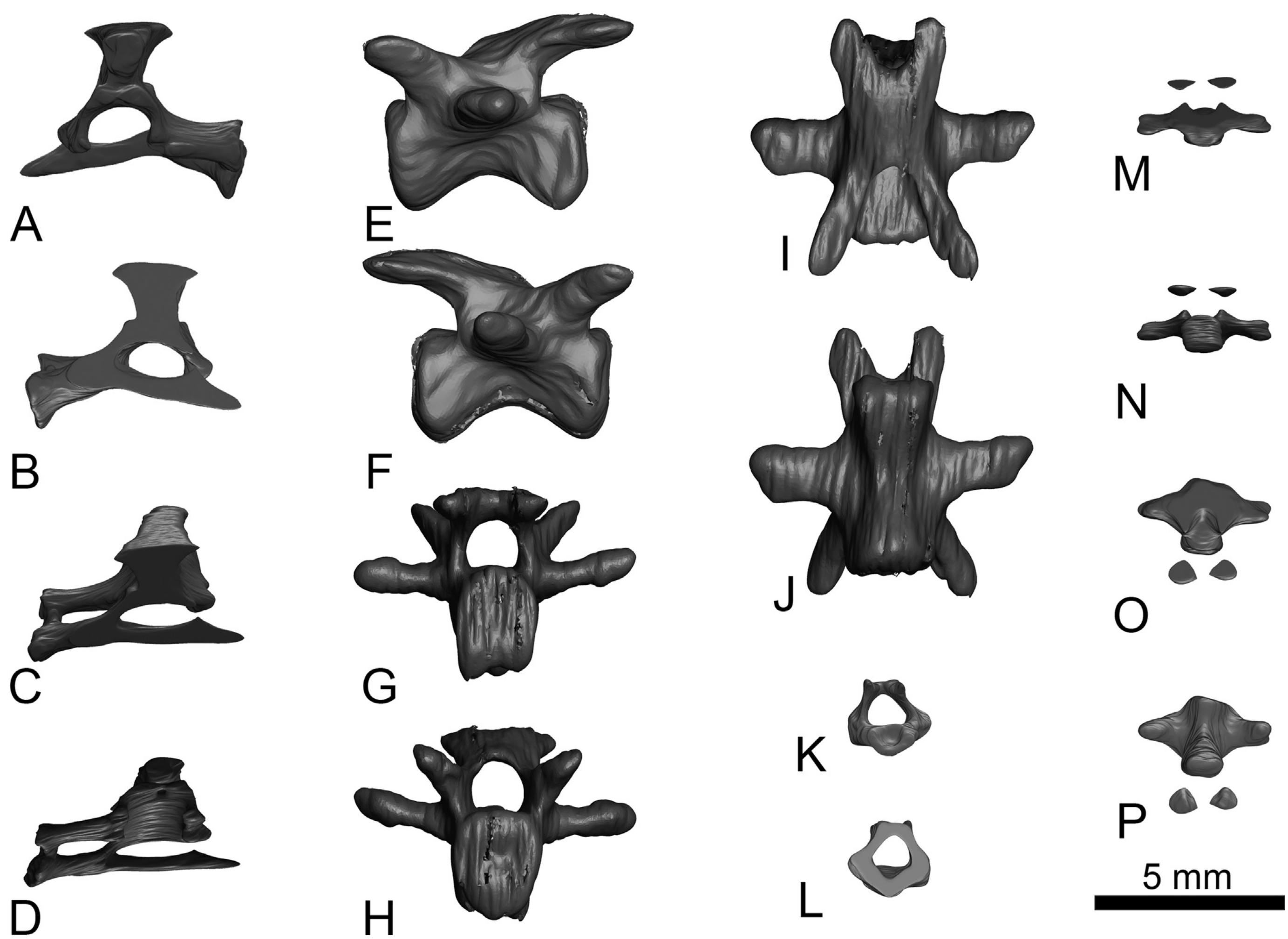

Fig. 7. Sacral and caudal vertebrae of IWCMS 2018.44. A-D, sacral vertebrae; E-J, anterior caudal vertebra; K-L, posterior caudal vertebra; M-P posterior caudal vertebra. These elements are shown in anterior (A,G,K,M), posterior (B,H,L,N), dorsal (C,I,O), ventral (D,J,P), left lateral (E), and right lateral (F) views.

4.2. Description

4.2.1. Shell

Carapace. The shell of IWCMS.2018.44 has a high degree of erosion, the nuchal plate, most elements of the neural series, most peripherals and the pygal plate are missing, as are some costal plates of the right side in the central third of the carapace (Figs. 3, 4). It is relatively low, and oval. The maximum width is at the level of the mesoplastron. Seven of the left costal plates are identified (all of them except the posterior one). Only the left bridge peripherals (4–7) are preserved. No fontanelles are recognized.

Plastron. The plastron is slightly crushed, seemingly having been depressed into the body cavity. The left side of the plastron is better preserved than the right (Figs. 3, 4). No remains of the epiplastra or entoplastron are preserved. The hyoplastron is almost fully preserved, except for its anterior margin. The specimen displays a laterally located pair of mesoplastra, being slightly wider than long. The anterior end of the xiphiplastron is present. At its thickest point, the plastron is 2.3 mm thick.

4.2.2. Vertebral column

Cervical vertebrae. There are seven cervical vertebrae preserved inside the shell of IWCMS 2018.44. 6 with a fused neural arch and centrum and one isolated neural arch of the axis (Fig. 5A-AP). These are not in articulation within the carapace. The centra are ventrally keeled with the keel becoming less prominent through the series, and almost non-existent in cervical 8 (Fig. 5). Centra 3–5 are opisthocoelus, centra 6–7 are amphicoelous and centra 8 is procoelus (Fig. 5). The anterior end of the centra have an oval cross section, becoming more triangular through the series. Posterior end of the centum have a square cross section to triangular through the series. All vertebrae have a large circular neural canal, increasing in diameter through the vertebral series. From vertebrae 5–8, the neural canal is larger in diameter than the diameter of the centrum (Fig. 5). The diapophyses are anteriorly placed in vertebrae 2–4 and become more posteriorly placed through 5 to 8. Vertebrae 8 has a small, rounded neural spine.

Thoracic vertebrae. Five thoracic vertebrae are preserved, two with a fused neural arch (a neural plate being also preserved as a fused element to one of them), two isolated centra, and an isolated neural arch (Fig. 6A-AD). The centra are shallow and are laterally pinched. This is more evident mid series, with the centra becoming wider posteriorly. They possess a large neural canal, at least twice the depth of the centrum. The neural spines are tall and elongate, extending over the posterior and anterior portion of the centrum anteriorly in the series, and only posteriorly towards the posterior portion of the series.

Sacral vertebrae. A portion of sacrum is preserved, with two right lateral processes (Fig. 7A-D). A small portion of centrum is preserved posteriorly. The neural arch is wide, with a T -shaped cross section.

Caudal vertebrae. Three caudal vertebrae are preserved, with fused neural arches (Fig. 7E-P). The most anterior caudal has a complete centrum and neural arch preserved. It lacks a neural spine but possesses large pre- and postzygopophyses. The centrum is oval in cross section. Posterior caudals have a short centrum.

4.2.3. Appendicular skeleton

Shoulder girdle. Both scapulae are preserved (Fig. 8A-L). The right one is complete. The acromion process is slightly oval in cross section. Both coracoids are preserved (Fig. 8M-X). The left coracoid is complete, the right coracoid is only presented by the proximal end. The coracoid is dorsoventrally thin and considerably expanded distally.

Pelvic girdle. The pelvic girdle is almost complete, preserved in their natural anatomical position (Fig. 9). The sutures between the ilium, ischium and pubis are visible, and the pubic scar is visible on the xiphiplastron. The ilium is fused to the carapace, and the

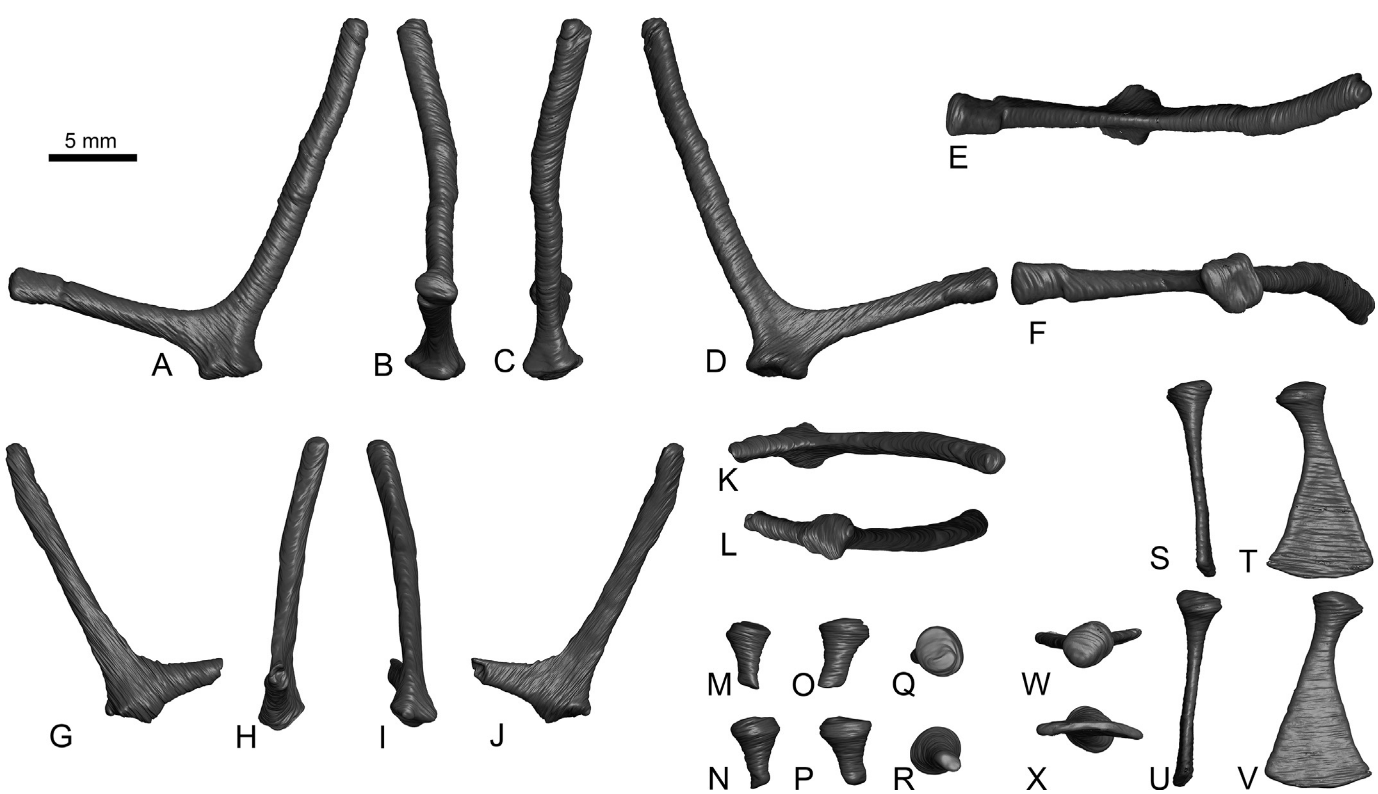

Fig. 8. Elements of the girdles of IWCMS 2018.44. A-F, right scapula; G-L, left scapula; M-R, proximal end of the right coracoid; S-X, left coracoid. These elements are shown in posterior (A,G,M,S), ventral (B,H,O,V), dorsal (C,I,P,T), anterior (D,J,N,U), proximal (E,K,Q,W), and distal (F,L,R,X) views.

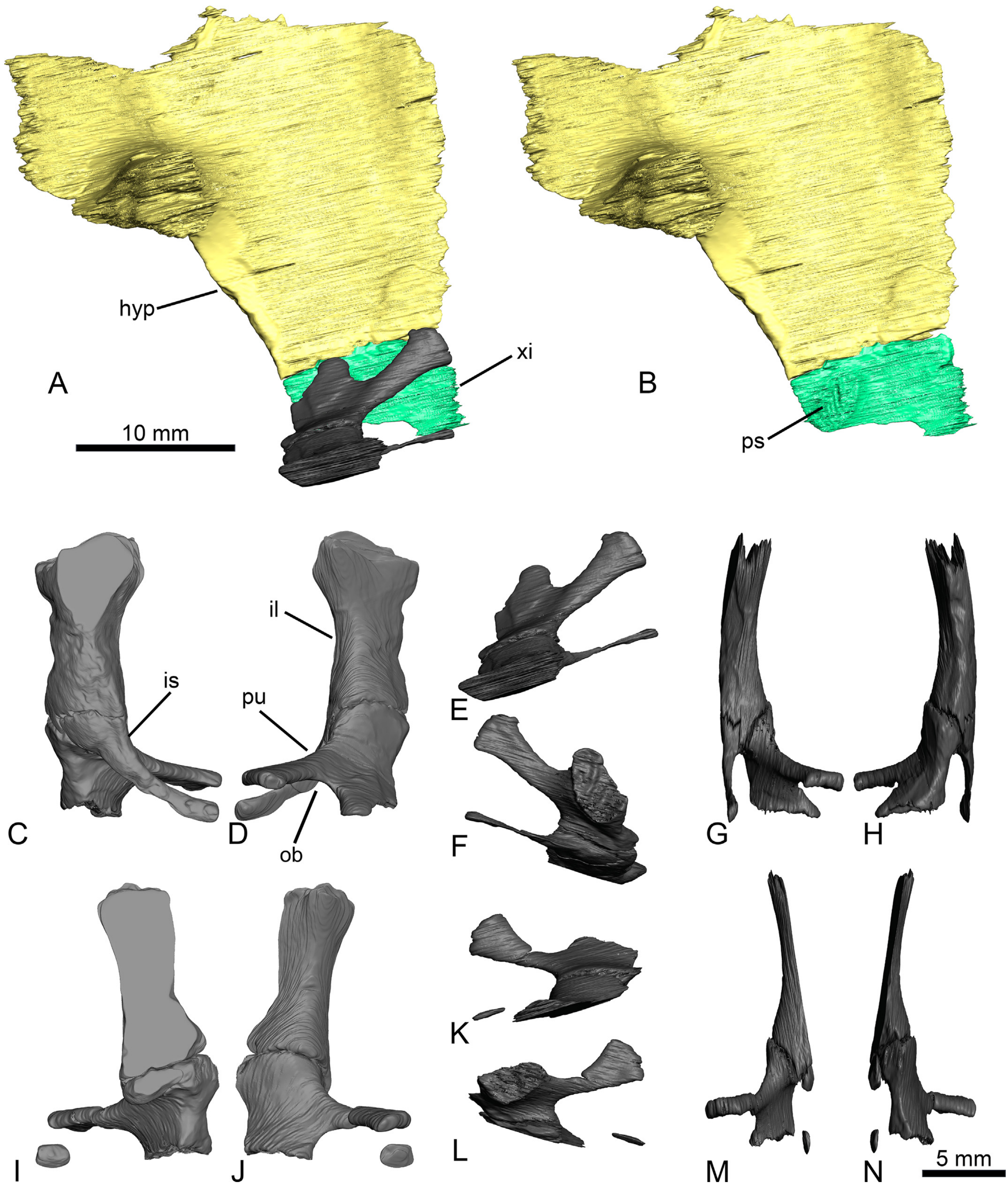

Fig. 9. Visceral view of the left hypoplastron and xiphiplastron with the left pelvis (A), and virtually removing the pelvis (B) to show the pubic scar of IWCMS 2018.44. C-N, Left (C-H) and right (I-N) pelvis in posterior (C,I), anterior (D,J), dorsal (E,K), ventral (F,L), medial (G,M), and lateral (H,N) views. Abbreviations: hyp, hypoplastron; il, illium; is, ischium; ob, obturator foramen; ps, pubic scar; pu, pubis; xi, xiphiplastron.

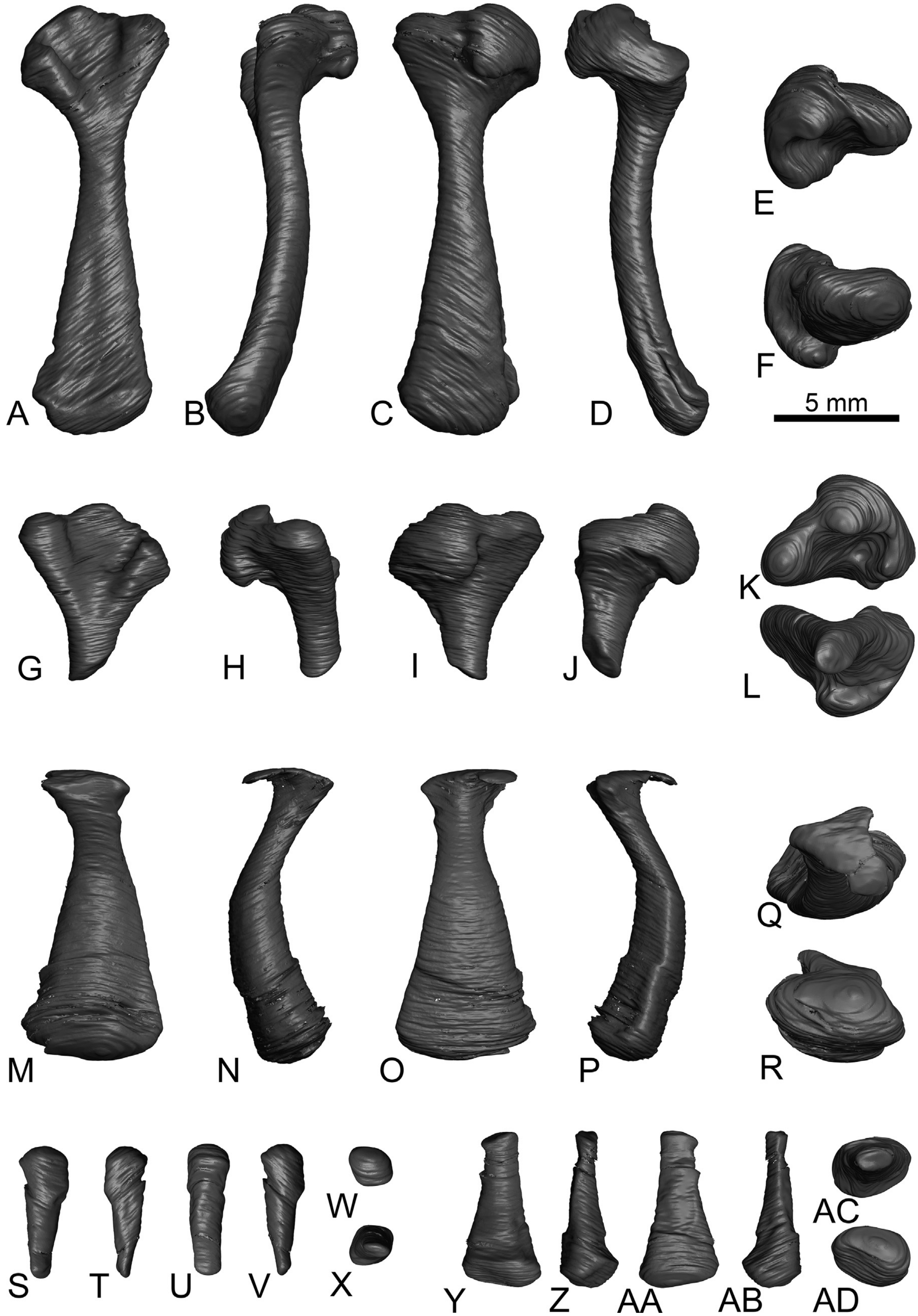

Fig. 10. Appendicular elements of IWCMS 2018.44. A-F, Right humerus; G-L, proximal end of the left humerus; M-R, right femur; S-X, proximal end of the right fibula; Y-AD, distal end of the right tibia; in ventral (A,G,M,S,Y), posterior (B,H,N,T,Z), dorsal (C,I,O,U,AA), anterior (D,J,P,V,AB), medial (E,K,Q,W,AC), and distal (F,L,R,X,AD) views.

ischium and pubis are fused to the plastron. The ilium is robust and mediolaterally narrow. The ischium is rod-like, with a distally expanded head where it contacts the ilium. The pubis has a large obturator foramen.

Forelimbs. Only the complete right humerus and part of the left are preserved (Fig. 10A-R). The diaphysis has a mediolateral curve, with an oval articular head. The distal end is wide, with a deep intertubercular fossa between a large medial process and a large lateral process.

Hindlimbs. The partial right femur, tibia and fibula are preserved. The right femur has its proximal end missing (Fig. 10M-R). The diaphysis is laterally curved and is distally expanded forming a large tibial condyle. Only distal portion of the right tibia is preserved (Fig. 10Y-AD). The shaft has an oval cross section. The distal end is expanded with a broad articular surface. Only the proximal end of the right fibula is preserved (Fig. 10S-X). It has a proximally expanded head with an oval cross section. The medial surface is straight, and the lateral surface is convex.

5. Discussion

5.1. Systematic discussion

The presence of a pelvis sutured with both the carapace and the plastron allow the attribution of IWCMS 2018.44 to Pan-Pleurodira (Gaffney et al., 2006; Pérez-García, 2019). It is recognized as a member of Dortokidae considering the presence of and exclusive ornamental pattern of the outer surface of the plates, comprising well-developed microreticulation, combined with crests and ridges in the carapacial medial area (Lapparent de Broin and Murelaga, 1996; Pérez-García et al., 2014).

The specimen shares exclusively with *Eodortoka morellana* (i.e., the only representative of Dortokidae so far recognized for the Upper Cretaceous, from the late Barremian (Lower Cretaceous) of Morella (Castellón, Eastern Spain)): the presence of mesoplastra (Pérez-García et al., 2014; Pérez-García, 2017). In addition, characters shared with *Eodortoka morellana* and *Ronella botanica*, but not with *Dortoka vasconica*: relatively short scars of the axillary

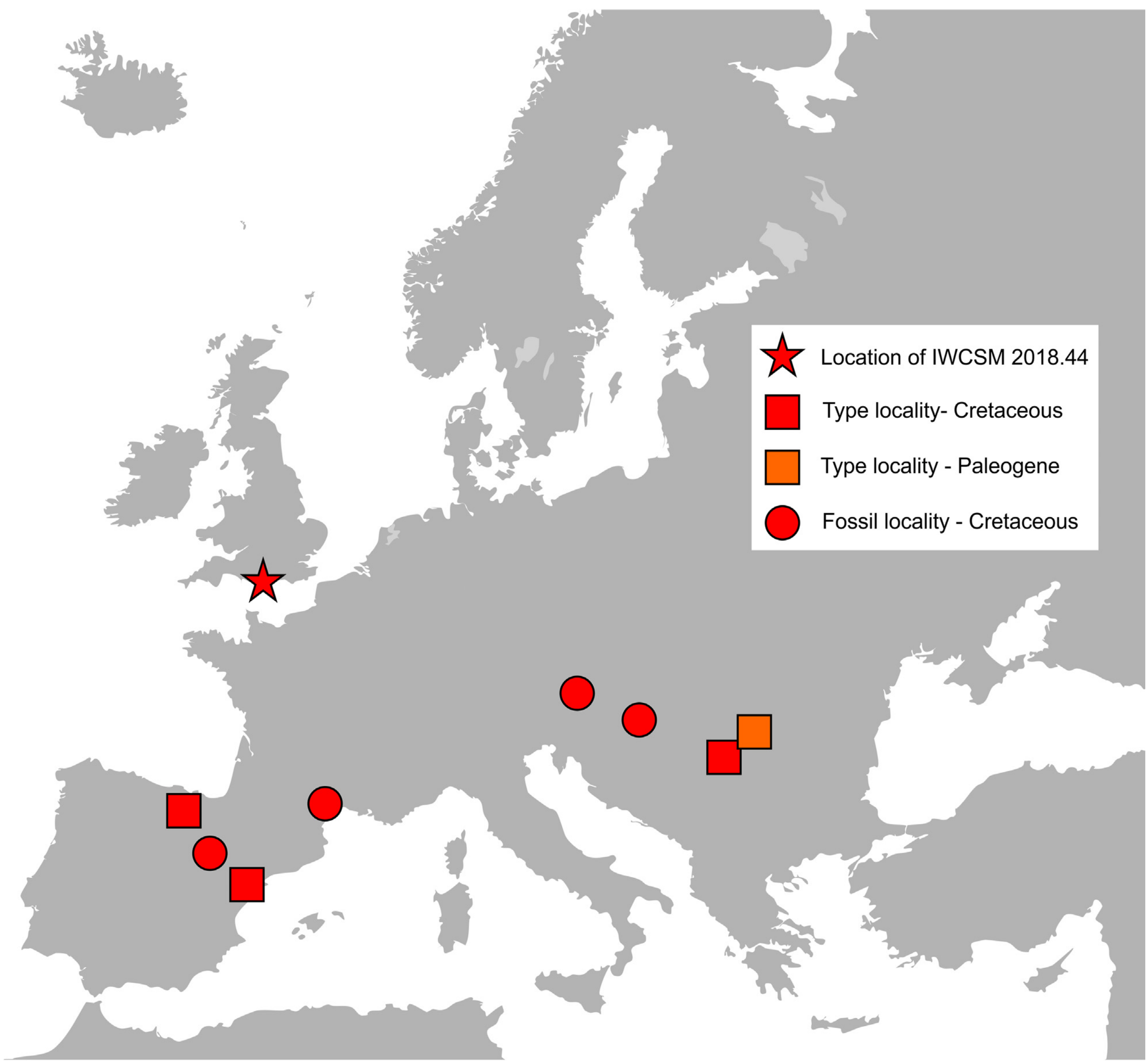

Fig. 11. Biogeographic distribution of dortokid turtles during the Early Cretaceous modified from Cadena and Joyce (2015), Pérez-García et al. (2017) and Augustin et al. (2021).

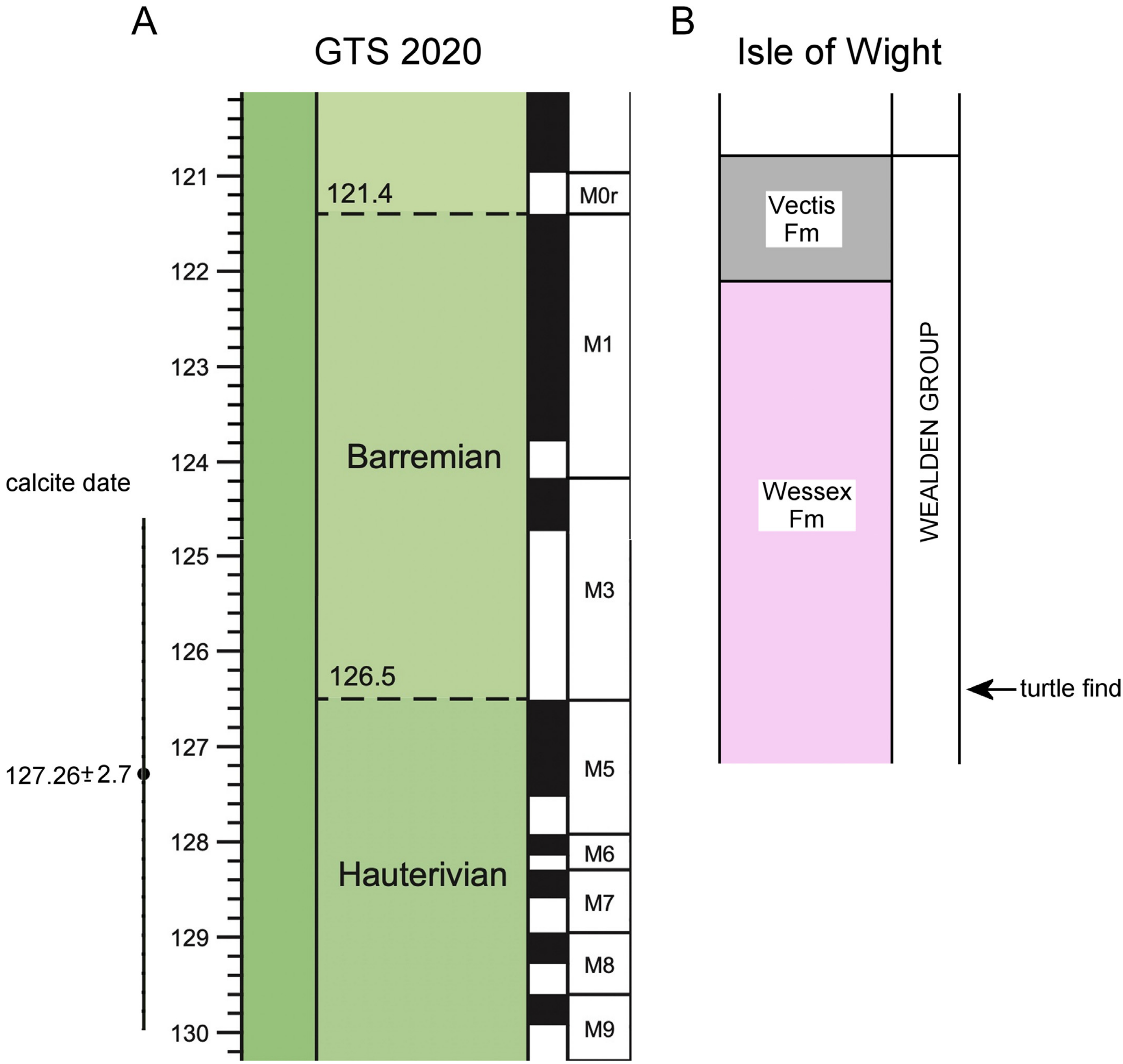

Fig. 12. Diagram showing the radiometric date in context with the Wessex Formation. A, time scale modified from Gradstein et al. (2020) with calcite date range. B, simplified stratigraphic log of the Wealden showing the age of the turtle.

processes, not contacting the second pair of costals; pubic scars exclusively located on the xiphiplastra, not contacting the hypoplastra (both characters are presently unknown for *Dortoka vremiri*). Therefore, IWCMS 2018.44 lacks autapomorphic characters needed to be recognised as a taxon distinct from the coeval *Eodortoka morellana*.

The relatively small *Eodortoka morellana* (being the smallest dortokid so far described, with a shell length closer to 150 mm) is exclusively recognized by shell remains (Pérez-García et al., 2014; Pérez-García, 2017). Due to the poor preservation of parts of the shell of the specimen analysed here, two autapomorphies of the Spanish *Eodortoka morellana* cannot be recognized: absence of the anterior region of the second pair of pleural scutes overlapping costals 1, and presence of a cervical scute with a distinctive (autapomorphic) morphology and arrangement. Consequently, we refer to IWCMS 2018.44 as *Eodortoka* cf. *morellana*.

The specimen analysed here constitutes not only the first evidence of Dortokidae in the UK but is also the only material attributable to this lineage identified outside southwestern and central Europe (Fig. 11). Material of this lineage is almost entirely restricted to elements of the carapace and plastron. Thus, the only other elements indisputably attributed to it have been several disarticulated and isolated bones of the pelvic girdle (see Lapparent de Broin and Murelaga, 1996; Lapparent de Broin et al., 2004). A few cervical and caudal vertebrae from the *Dortoka vasconica* type locality were tentatively referred to *D. vasconica* (only known by schematic drawings, see Lapparent de Broin and Murelaga, 1996, figs. 5,6), although they were identified as isolated remains at the discovery site, so this attribution could not be confirmed (Lapparent de Broin and Murelaga, 1996). Therefore, IWCMS 2018.44 corresponds to the first partial skeleton of this lineage, and considerably improves our knowledge of this enigmatic turtle family. For the position of Dortokidae within Crown Pleurodira see Pérez-García et al. 2012, and references therein. The presence of postzygapophyses of the cervical vertebrae elevated on to the neural spine, as they are in specimen IWCMS 2018.44, is considered synapomorphic for Pleurodira (Ferreira et al., 2018).

5.2. Implications of calcite U–Pb geochronology for the Wessex Formation

It has been recognised for some time that the bulk of the Wessex Formation exposed on the Isle of Wight is of Barremian age (Batten 2011). The presence of the normal magnetozone M0 was identified by Kerth and Hailwood (1988) in the upper part of the Vectis Formation, the base of which is provisionally used to define the base of the Aptian Stage (Gale et al., 2020). The Hauterivian–Barremian boundary was identified close to the base of the exposed Wessex Formation using palynology (Hughes and McDougall, 1990); subsequently, Robinson and Hesselbo (2004) used carbon isotope data from fossil wood to tentatively suggest that the boundary was higher, approximately 70 m above the base of the exposed Wessex Formation on the Isle of Wight. Recent palaeomagnetic studies demonstrate that the boundary between chrons CM3n and CM5r, coincident with the Hauterivian–Barremian boundary, fall a short distance above the Sudmoor Point Sandstone (Conall Mc Niocaill pers comm. 2021). The yielded U–Pb age of 127.3 ± 2.7 Ma suggests that the turtle specimen is of youngest Hauterivian or oldest in Barremian age (Gradstein et al., 2020) (Fig. 12). This confirms that the Hauterivian–Barremian boundary falls below the Hanover Point Sandstone and above the Sudmoor Point Sandstone.

6. Conclusions

The new specimen of turtle described here is identified as a pan-pleurodiran and is the oldest record of this lineage in the UK, corresponding to the only find in Mesozoic levels of this country. It can be referred to the family Dortokidae and shares many similarities with the Spanish Lower Cretaceous dortokid *Eodortoka morellana*. Consequently, it is identified as *E.* cf. *morellana*. It is the first occurrence of Dortokidae in the United Kingdom. Thus, the new specimen adds to the diversity of turtles reported from the Wessex Formation and extends the range of Dortokidae into northwest Europe. In addition, elements if the postcranial anatomy preserved within the body cavity are the first reported for *Eodortoka*, the postcranial material not corresponding to the shell being barely known for this lineage. The presence of postzygapophyses of the cervical vertebrae elevated on to the neural spine could support the attribution of Dortokidae to the crown Pleurodira. The Calcite U–Pb geochronology confirms the Wessex Formation of the Isle of Wight is late Hauterivian/early Barremian in age.

Data availability

The data is provided within the supplementary information.

Acknowledgements

We are greatly indebted to Mr Steve Burbridge of Romsey who discovered the new specimen and kindly donated it to Dinosaur Isle Museum. We also thank the staff at Dinosaur Isle Museum for access to their collections. We thank Gary Blackwell for his excellent preparation work. We thank Dr Stephan Voight, Amanda Shaw and Graeham Mann, of St Mary's Isle of Wight Hospital radiography department for assistant with initial CT scanning. Our good friend Stu Pond is thanked for rendering the initial CT images and videos. We thank Geoff Long for extracting and preparing the calcite samples for the U–Pb dating. We also thank the anonymous reviewer whose comments improved the manuscript. This research has been partially funded by the Spanish Ministerio de Ciencia e Innovación (PID2019-111488RB-I00).

References

Augustin, F.J., Csiki-Sava, Z., Matzke, A.T., Botfalvai, G., Rabi, M., 2021. A new latest Cretaceous pleurodiran turtle (Testudinata: Dortokidae) from the Haţeg Basin (Romania) documents end-Cretaceous faunal provinciality and selective survival during the K-Pg extinction. Journal of Systematic Palaeontology 19, 1059–1081.
Austen, P.A., Batten, D.J., 2018. English Wealden fossils: an update. Proceedings of the Geologists' Association 129, 171–201.
Batsch, G.C., 1788. Versuch einer Anleitung, zur Kenntniß und Geschichte der Thiere und Mineralien. Akad: Buchhand, Jena, p. 528.
Barker, C.T., Hone, D.W.E., Naish, D., Cau, A., Lockwood, J.A.F., Foster, B., Clarkin, C.E., Schneider, P., Gostling, N.J., 2021. New spinosaurids from the Wessex Formation (Early Cretaceous, UK) and the European origins of Spinosauridae. Scientific Reports 11, 1–15.
Batten, D.J., 2011. English Wealden Fossils. In: Palaeontological Association Field Guides to Fossils Series, vol. 14. Palaeontological Association, London, p. 769.
Black, L.P., Gulson, B.L., 1978. The age of the Mud Tank carbonatite, Strangways Range, Northern Territory. BMR Journal of Australian Geology and Geophysics 3, 227–232.
Bowring, S.A., Schmitz, M.D., 2003. High-precision U-Pb zircon geochronology and the stratigraphic record. Reviews in Mineralogy and Geochemistry 53, 305–326.
Buffetaut, E., 1983. The crocodilian Theriosuchus Owen, 1879 in the Wealden of England. Bulletin of the British Museum, Natural History. Geology 37, 93–97.
Buffetaut, E., Hutt, S., 1980. *Vectisuchus leptognathus*, n.g.n sp., a slender-snouted goniopholid crocodilian from the Wealden of the Isle of Wight. Neues Jahrbuch für Geologie und Paläontologie-Monatshefte 385–390.
Cadena, E., Joyce, W.G., 2015. A review of the fossil record of turtles of the clades Platychelyidae and Dortokidae. Bulletin of the Peabody Museum of Natural History 56 (1), 3–20.
Cope, E.D., 1864. On the limits and relations of the Raniformes. Proceedings of the Academy of Natural Sciences, Philadelphia 16, 181–183.
Ferreira, G.S., Bronzati, M., Langer, M.C., Sterli, J., 2018. Phylogeny, biogeography and diversification patterns of side-necked turtles (Testudines: Pleurodira). Royal Society Open Science 5, 171773. https://doi.org/10.1098/rsos.171773.
Gaffney, E.S., Tong, H., Meylan, P.A., 2006. Evolution of the side-necked turtles: the families Bothremydidae, Euraxemydidae, and Araripemydidae. Bulletin of the American Museum of Natural History 300, 1–700.
Gale, A., 2019. The Isle of Wight. In: Geologists Association Guide No. 60, p. 174.
Gale, A.S., Mutterlose, J., Batenburg, S.F., 2020. Chapter 27. The Cretaceous Period. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), Geologic Time Scale 2020. Elsevier, pp. 1023–1086.
Gheerbrant, E., Codrea, V., Hosu, A., Sen, S., Guernet, C., Lapparent de Broin, F., Riveline, J., 1999. Découverte de vertébrés dans les Calcaires de Rona (Thanétien ou Sparnacien), Transylvanie, Roumanie: les plus anciens mammifères cénozoïques d'Europe Orientale. Eclogae Geologicae Helvetiae 92, 517–535.
Godeau, N., Deschamps, P., Guihou, A., Leonide, P., Tendil, A., Gerdes, A., Hamelin, B., Girard, J.P., 2018. U-Pb dating of calcite cement and diagenetic history in microporous carbonate reservoirs: case of the Urgonian Limestone, France. Geology 46, 247–250.
Gradstein, F.M., Ogg, J.G., Schmitz, M.B., Ogg, G.M., 2020. The Geological Time Scale 2020, second ed. Elsevier, Amsterdam, The Netherlands, p. 1176.
Hill, C.A., Polyak, V.J., Asmerom, Y.P., Provencio, P., 2016. Constraints on a Late Cretaceous uplift, denudation, and incision of the Grand Canyon region, southwestern Colorado Plateau, USA, from U-Pb dating of lacustrine limestone. Tectonics 35, 896–906.
Hughes, N.F., McDougall, A.B., 1990. New Wealden correlation for the Wessex Basin. Proceedings of the Geologists' Association 100, 85–90.
Jackson, S.E., Pearson, N.J., Griffin, W.L., Belousova, E.A., 2004. The application of laser ablation-inductively coupled plasma-mass spectrometry to in situ U–Pb zircon geochronology. Chemical Geology 211, 47–69.
Joyce, W.G., Parham, J.F., Gauthier, J.A., 2004. Developing a protocol for the conversion of rank-based taxon names to phylogenetically defined clade names, as exemplified by turtles. Journal of Paleontology 78, 989–1013.
Joyce, W.G., Chapman, S.D., Moody, R.T.J., Walker, C.A., 2011. The skull of the solemydid turtle *Helochelydra nopcsai* from the Early Cretaceous of the Isle of Wight (UK) and a review of Solemydidae. Special Papers in Palaeontology 86, 75–97.
Kerth, M., Hailwood, E.A., 1988. Magnetostratigraphy of the Vectis Formation (Wealden Group) on the Isle of Wight, Southern England. Journal of the Geological Society, London 145, 351–360.

Kurumada, Y., Aoki, S., Aoki, K., Kato, D., Saneyoshi, M., Tsogtbaatar, K., Windley, B.F., Ishigaki, S., 2020. Calcite U–Pb age of the Cretaceous vertebrate-bearing Bayn Shire Formation in the Eastern Gobi Desert of Mongolia: usefulness of caliche for age determination. Terra Nova 32, 246–252.

Lapparent de Broin, F., Murelaga, X., 1996. Une nouvelle faune de chéloniens dans le Crétacé supérieur européen. Comptes rendus de l'Académie des sciences. Série 2. Sciences de la terre et des planètes 323, 729–735.

Lapparent de Broin, F., Murelaga, X., 1999. Turtles from the Upper Cretaceous of Lanõ (Iberian Peninsula). Estudios del Museo de Ciencias Naturales de Alava 14, 135–211.

Lapparent de Broin, F. de, Murelaga, B.X., Codrea, V., 2004. Presence of Dortokidae (Chelonii, Pleurodira) in the earliest Tertiary of the Jibou Formation, Romania: paleobiogeographical implications. Acta Palaeontologica Romaniae 4, 203–215.

Li, Q., Parrish, R.R., Horstwood, M.S.A., McArthur, J.M., 2014. U–Pb dating of cements in Mesozoic ammonites. Chemical Geology 376, 76–83.

Lockwood, J.A., Martill, D.M., Maidment, S.C., 2021. A new hadrosauriform dinosaur from the Wessex Formation, Wealden Group (Early Cretaceous), of the Isle of Wight, southern England. Journal of Systematic Palaeontology 19 (12), 847–888.

Longrich, N.R., Martill, D.M., Jacobs, M.L., 2022. A new dromaeosaurid dinosaur from the Wessex Formation (Lower Cretaceous, Barremian) of the Isle of Wight, and implications for European palaeobiogeography. Cretaceous Research 134, 105123.

Lydekker, R., 1889. On remains of Eocene and Mesozoic Chelonia and a tooth of (?) *Ornithopsis*. Quarterly Journal of the Geological Society 45 (1–4), 227–246.

Martill, D.M., Green, M., Smith, R.E., Jacobs, M.L., Winch, J., 2020. First tapejarid pterosaur from the Wessex Formation (Wealden Group: Lower Cretaceous, Barremian) of the United Kingdom. Cretaceous Research 113, 104487.

Martill, D.M., Naish, D., 2001. Dinosaurs of the Isle of Wight. In: Palaeontological Association Field Guides to Fossils Series, 10. Palaeontological Association, London, p. 440.

Milner, A.R., 2004. The turtles of the Purbeck Limestone Group of Dorset, southern England. Palaeontology 47, 1441–1467.

Mottram, C.M., Kellett, D.A., Barresi, T., Zwingmann, H., Friend, M., Todd, A., Percival, J.B., 2020. Syncing fault rock clocks: direct comparison of U-Pb carbonate and K-Ar illite fault dating methods. Geology 48, 1179–1183.

Owen, R., 1853. Monograph on the fossil Reptilia of the Wealden and Purbeck formations. Part 1, Chelonia. Palaeontographical Society Monograph 7, 1–12.

Parrish, R.R., Parrish, C.M., Lasalle, S., 2018. Vein calcite dating reveals Pyrenean orogen as cause of Paleogene deformation in southern England. Journal of the Geological Society 175, 425–442.

Pearce, N.J., Perkins, W.T., Westgate, J.A., Gorton, M.P., Jackson, S.E., Neal, C.R., Chenery, S.P., 1997. A compilation of new and published major and trace element data for NIST SRM 610 and NIST SRM 612 glass reference materials. Geostandards Newsletter 21, 115–144.

Pérez-García, A., 2014. Revision of the poorly known *Dorsetochelys typocardium*, a relatively abundant pleurosternid turtle (Paracryptodira) in the Early Cretaceous of Europe. Cretaceous Research 49, 152–162.

Pérez-García, A., 2017. The Iberian fossil record of turtles: an update. Journal of Iberian Geology 43, 155–191.

Pérez-García, A., 2019. The African Aptian *Francemys gadoufaouaensis* gen. et sp. nov.: new data on the early diversification of Pelomedusoides (Testudines, Pleurodira) in northern Gondwana. Cretaceous Research 102, 112–126.

Pérez-García, A., Scheyer, T.M., Murelaga, X., 2012. New interpretations of *Dortoka vasconica* Lapparent de Broin and *Murelaga*, a freshwater turtle with an unusual carapace. Cretaceous Research 36, 151–161.

Pérez-García, A., Gasulla, J.M., Ortega, F., 2014. *Eodortoka morellana* gen. et sp. nov., the first pan-pleurodiran turtle (Dortokidae) defined in the Early Cretaceous of Europe. Cretaceous Research 48, 130–138.

Pérez-García, A., Cobos, A., Royo-Torres, R., 2017. The oldest evidence of a dortokid turtle (stem Pleurodira) from the uppermost Hauterivian-basal Barremian El Castellar Formation (Teruel, Spain). Journal of Iberian Geology 43, 139–146.

Ristevski, J., Young, M.T., De Andrade, M.B., Hastings, A.K., 2018. A new species of *Anteophthalmosuchus* (Crocodylomorpha, Goniopholididae) from the Lower Cretaceous of the Isle of Wight, United Kingdom, and a review of the genus. Cretaceous Research 84, 340–383.

Roberts, N.M., Rasbury, E.T., Parrish, R.R., Smith, C.J., Horstwood, M.S., Condon, D.J., 2017. A calcite reference material for LA-ICP-MS U-Pb geochronology. Geochemistry, Geophysics, Geosystems 18, 2807–2814.

Roberts, N.M., Drost, K., Horstwood, M.S., Condon, D.J., Chew, D., Drake, H., Milodowski, A.E., McLean, N.M., Smye, A.J., Walker, R.J., Haslam, R., 2020. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) U–Pb carbonate geochronology: strategies, progress, and limitations. Geochronology 2, 33–61.

Robinson, S.A., Hesselbo, S.P., 2004. Fossil-wood carbon-isotope stratigraphy of the non-marine Wealden Group (Lower Cretaceous, southern England). Journal of the Geological Society, London 161, 133–145.

Rochín-Bañaga, H., Davis, D.W., Schwennicke, T., 2021. First U-Pb dating of fossilized soft tissue using a new approach to paleontological chronometry. Geology 49, 1027–1031.

Steel, L., Martill, D.M., Unwin, D.M., Winch, J.D., 2005. A new pterodactyloid pterosaur from the Wessex Formation (Lower Cretaceous) of the Isle of Wight, England. Cretaceous Research 26, 686–698.

Stewart, D.J., 1978. The sedimentology and palaeoenvironment of the Wealden Group of the Isle of Wight, Southern England (Unpublished Ph.D. thesis). Portsmouth Polytechnic, 346 pp + appendices.

Stewart, D.J., 1981. A meander belt sandstone from the Lower Cretaceous Wealden Group of southern England. Sedimentology 28, 1–20.

Sweetman, S.C., 2006. A gobiconodontid (Mammalia, Eutriconodonta) from the Early Cretaceous (Barremian) Wessex Formation of the Isle of Wight, southern Britain. Palaeontology 49, 889–897.

Sweetman, S.C., 2011a. The Wealden of the Isle of Wight, 52–78. In: Batten, D.J. (Ed.), English Wealden Fossils, The Palaeontological Association, Field Guides to Fossils 14. Palaeontological Association, London, p. 769.

Sweetman, S.C., 2011b. Vertebrate microfossils. In: Batten, D.J. (Ed.), English Wealden Fossils. Palaeontological Association Field Guide to Fossils, 14. The Palaeontological Association, London, pp. 192–204.

Sweetman, S.C., 2016. A comparison of Barremian–early Aptian vertebrate assemblages from the Jehol Group, north-east China and the Wealden Group, southern Britain: the value of microvertebrate studies in adverse preservational settings. Palaeobiodiversity and Palaeoenvironments 96, 149–167.

Sweetman, S.C., Evans, S.C., 2011a. Lissamphibians (frogs, salamanders and albanerpetontids). In: Batten, D.J. (Ed.), English Wealden Fossils (Palaeontological Association Field Guide to Fossils, 14. The Palaeontological Association, London, pp. 240–263.

Sweetman, S.C., Evans, S.E., 2011b. Lepidosaurs (lizards), 264–284. In: Batten, D.J. (Ed.), English Wealden Fossils, Palaeontological Association Field Guide to Fossils, 14. The Palaeontological Association, London, pp. 264–284.

Sweetman, S.C., Insole, A.N., 2010. The plant debris beds of the Early Cretaceous (Barremian) Wessex Formation of the Isle of Wight, southern England: their genesis and palaeontological significance. Palaeogeography, Palaeoclimatology, Palaeoecology 292, 409–424.

Sweetman, S.C., Martill, D.M., 2010. Pterosaurs of the Wessex Formation (Early Cretaceous, Barremian) of the Isle of Wight, southern England: a review with new data. Journal of Iberian Geology 36, 225–242.

Sweetman, S.C., Pedreira-Segade, U., Vidovic, S.U., 2014a. A new bernissartiid crocodyliform from the Lower Cretaceous Wessex Formation (Wealden Group, Barremian) of the Isle of Wight, southern England. Acta Palaeontologica Polonica 60, 257–268.

Sweetman, S.C., Goedert, J., Martill, D.M., 2014b. A preliminary account of the fishes of the Lower Cretaceous Wessex Formation (Wealden Group, Barremian) of the Isle of Wight, southern England. Biological Journal of the Linnean Society 113, 872–896.

Tong, H., Buffetaut, E., Claude, J., 2022. Dortokid turtle remains from the Upper Cretaceous of Cruzy (Hérault, southern France) and phylogenetic implications. Palaeo Vertebrata 45, 1–6.

Vermeesch, P., 2018. IsoplotR: a free and open toolbox for geochronology. Geoscience Frontiers 9, 1479–1493.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cretres.2023.105590.