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A new exposure of the North Curry Sandstone Member (Dunscombe Mudstone Formation, Mercia Mudstone Group: Carnian, Triassic), near Taunton, Somerset (UK): The location of Charles Moore's vertebrate specimens resolved

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ABSTRACT

There is renewed interest in a series of Carnian-aged sandstone units across the UK because they represent a unique event in the Late Triassic, the Carnian Pluvial Episode (CPE), from 233 to 232 Ma. The North Curry Sandstone Member of the Mercia Mudstone Group in Somerset is of particular importance because it yielded a rich fauna of shark, bony fish and amphibian remains in coarse-grained sandstones to Charles Moore in the 1860s. However, the exact location and age of his important collection had not been identified. Here, we demonstrate that the Moore collection comes from the North Curry Sandstone Member in a location in the village of Ruishton, just east of Taunton, where a new road cutting reveals both the bone-rich units and a complete succession through the CPE, a time of major climatic and biotic upheaval. The 16 m section comprises several sandstones interbedded with red-green mudstones, representing a terrestrial environment with lacustrine, evaporitic mud flat and fluvial deposits.

1. Introduction

Sandstone units in the Upper Triassic mudstone-dominated Mercia Mudstone Group across central and southern England have long intrigued geologists. The Arden Sandstone of Warwickshire and Worcestershire, the Dane Hill Sandstone Member of Leicestershire, the North Curry Sandstone, Butcombe Sandstone, and Dunscombe Mudstone formations of Somerset and Devon all show similar features in terms of sedimentology and palaeontology and have been approximately equated in age, as Carnian, in the Late Triassic (Warrington et al., 1980). Their facies and stratigraphic position are comparable to the Schilfsandstein of the Stuttgart Group of northern Germany, and they yield fossils of fishes and amphibians as well as macroplants and palynomorphs that indicate a flora of hygrophilic (damp-loving) plants (Simms and Ruffell, 1989, 2018). These were the initial indicators of the Carnian Pluvial Episode, now dated from 233–232 Ma, in the early Carnian (Dal Corso et al., 2020), a time of global high levels of rainfall, associated with sharp floral and faunal changes, and followed by mass extinction as climatic conditions returned to highly arid (Dal Corso et al., 2020).

One of the earliest palaeontological descriptions of these beds was provided by Moore (1867), who reported a diverse vertebrate fauna from the foundations of a new house being built at Ruishton, near Taunton. Hitherto, the site of his collections has been mysterious, and it has also been unclear whether the fossils came from the North Curry Sandstone Member.

Here, in describing a new exposure of the North Curry Sandstone Member (Dunscombe Mudstone Formation, Mercia Mudstone Group) near Taunton, Somerset (United Kingdom), we identify a sequence likely close to or at Moore's 1867 locality. This resolves the unknown stratigraphic horizon from which Moore collected his specimens, as we document an analogous fauna, and match lithologies between the exposed fossiliferous beds we observed in the field with Moore's specimens. The interbedded succession of greenish-grey and red/brown calcareous mudstones/siltstones, sometimes with coarse-grained fossiliferous sandstones, is sandwiched between red-bed mudstones/siltstones of the Mercia Mudstone Group. Consequently, the age and facies of the unit were early pieces of evidence to be promulgated in the development of the Carnian Pluvial Episode theory (Dal Corso et al., 2022), elevating its

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hitherto local-scale status to that of an unusual member/formation of international significance.

2. Charles Moore's vertebrate collection

The Victorian geologist, Charles Moore (1814–1881), resided at Ilminster (1814–1837, 1844–1853) and Bath (1837–1844, 1853–1881) and made a large collection of fossils from the Mesozoic of Somerset (Duffin, 1978, 2019). He is most famous for the microvertebrate fauna that he collected from fissure fillings of latest Triassic age from Holwell, near Frome, amongst which are remains of some of the earliest mammaliamorphs (Whiteside and Duffin, 2017, 2020). We explore another of Moore's discoveries, an unpublished Late Triassic fauna from Ruishton, near Taunton. These, like many of the fossils he collected, form the Moore Collection in the museum of the Bath Royal Literary and Scientific Institution (BATGM).

In 1867, Moore reported that, "on proceeding by road from Taunton to Hatch, the Keuper Sandstones are exposed about midway at Ruishton" (Moore, 1867, p. 468). The road from Taunton to Hatch is now the A358, but the location of the house investigated by Moore is not known for certain.

Moore collected from the excavations being made for the house foundations, and gave a preliminary faunal list as follows, "teeth of *Labyrinthodon*, serrated teeth of *Belodon* (an aquatic phytosaur reptile, Duffin, 1978), *Acrodus keuperinus* etc., with *E. minuta* in the more indurated shales" (Moore, 1867, p. 468). In later papers, Moore (1880, 1881) added teeth of the sauropodomorph dinosaurs *Thecodontosaurus* and *Palaeosaurus*, as well as *Sphenonchus*, *Diplodus* (see below), and '*Triplodus*' to the list. The supposed dinosaur teeth require further study, but they might not now be given such firm attribution to the genera *Thecodontosaurus* and *Palaeosaurus* and would probably be described as simply archosaurian and could just as likely come from a rauisuchian as a dinosaur. *Sphenonchus* are cephalic spines; these were embedded in the dermal tissues just behind the orbit in male hybodont sharks, also represented by teeth in the Moore Collection (BATGM). '*Triplodus*' is an informal name for structures with three cusps, also in that collection, now believed also to be hybodont cephalic spines.

3. The North Curry Sandstone Member at Ruishton

The Ruishton fauna was found in the North Curry Sandstone Member (NCSM), a name introduced by Warrington et al. (1980, p. 60) for an arenaceous unit within the Dunscombe Mudstone Formation (Howard et al., 2008) in the upper part of the Mercia Mudstone Group succession of the Taunton district (previously termed 'Upper Keuper Sandstone'; Ussher, 1908) in the western part of the Wessex Basin. The NCSM is the lateral equivalent of the Somerset Halite Formation and is superseded by the Blue Anchor Formation (Gallois, 2003; Gallois and Porter, 2006). The Dunscombe Mudstone Formation is generally considered to be the time equivalent of the Arden Sandstone Formation in the English Midlands (Warrington et al., 1980) which forms a regional correlative marker separating the Sidmouth Mudstone Formation from the Branscombe Mudstone Formation of the Mercia Mudstone Group (Gallois and Porter, 2006; Milroy et al., 2019).

Warrington and Williams (1984) suggested that the NCSM was no older than early Carnian (Cordevolian), and more likely late Carnian (Julian or Tuvalian), on the basis of a palynomorph assemblage that includes *Vallasporites ignacii*, *Patinasporites densus*, *Duplicisporites* spp., *Camerosporites secatus* and *Ovalipollis pseudoalatus*. Furthermore, the miospore assemblages are comparable with those of the Arden Sandstone (Fisher, 1972; Old et al., 1991) and the lower part of the Dunscombe Mudstone Formation (Baranyi et al., 2019), divisions of the Mercia Mudstone Group in Warwickshire-Worcestershire and Devon respectively.

The depositional environments of the NCSM and sandstone units of the Dunscombe Mudstone Formation have been interpreted as fluviatile distributary channels with flow directions to the south or south-east, away from the Quantock uplands (Ruffell and Warrington, 1988; Ruffell, 1991; see also Porter and Gallois, 2008). The thicker channel successions in the NCSM comprise fining upwards beds in individual sets and bed-sets with basal rip-up mud clast conglomerates giving way to planar and trough cross-bedded fine-grained sandstones and siltstones. The exposures demonstrate the sandstones are laterally equivalent to calcareous nodular mudstones and siltstones that Warrington and Williams (1984) and Ruffell and Warrington (1988) considered represented channel overbank facies. On the south Devon coast, the Dunscombe Mudstone Formation includes a lenticular clastic unit of bioturbated, predominantly fine-grained sandstone up to 4 m thick, termed the Lincombe Member by Porter and Gallois (2008), deposited in a series of broad, shallow channels that crossed a low relief topography, around the margins of a lake. Laterally, along strike, these channel sands also either pass into or terminate against more argillaceous lacustrine deposits.

The NCSM/Dunscombe Mudstone Formation is one of the few mappable arenaceous/argillaceous units in the otherwise seemingly monotonous, dominantly red-bed succession of the Mercia Mudstone Group. The lower boundary of the NCSM/Dunscombe Mudstone Formation has been used as a correlatable sequence boundary, with some success, by Simms and Ruffell (1989) and Ruffell (1991). The age-equivalent Schilfsandstein (part of the Stuttgart Formation) stacked-channel sandstones (Hahn, 1984; Wurster, 1964) of Germany, Switzerland and Poland are comparable with the NCSM (Simms and Ruffell, 1990). Warrington and Williams (1984) mapped the NCSM westwards to Knapp, some 4.5 km east of the current exposure, whilst Ruffell (1990, fig. 4) indicated this exposure from geomorphological feature mapping.

The Dunscombe Mudstone Formation has a different clay mineral assemblage from the Mercia Mudstone Group formations above and below (Jeans, 1978): the clay mineral kaolinite, otherwise rare in the Mercia Mudstone Group, suggests a warm humid period in what was normally a hot arid climate (Simms and Ruffell, 1989; Lott et al., 1982). This observation (amongst others) led to the development of the Carnian Pluvial Episode theory (in some literature 'Event' or Humid Episode: Dal Corso et al., 2012), now linked to the early diversification of the dinosaurs (Benton et al., 2014; Bernardi et al., 2018).

The bulk of Moore's specimens from Ruishton (BATGM) are enclosed in associated sandy matrix. From these specimens, the matrix lithology varies from a greenish-grey siltstone to a fine-grained sandstone with white and grey pellets of dolomite, to a pebbly conglomerate with a variety of mudstone and siltstone intraclasts. This coarse-grained sandstone from which Moore collected his microvertebrate fauna is colloquially termed by us as 'Moore Facies'. Prior to the current exposure, the suggested environment of deposition for Moore's specimens was thought to be from either overbank deposits or channel lag conglomerates. This was in keeping with the observations of Simms and Ruffell (1990, p. 321) who found fossil fish debris in the basal rip-up mud clast conglomerates of the NCSM. The new exposure enables us to refine this interpretation, allowing us to consider in greater detail the likely sedimentary setting and stratigraphic position from which Moore extracted his specimens.

4. Geology of the new exposure: Taunton Gateway Park and Ride exit road

4.1. Introduction

In initiating road improvements, including connections from the M5 motorway to the new A358 road to the east of Taunton, Somerset (Fig. 1), the entrance and exit roads to an existing Park and Ride facility (adjacent to Junction 25 of the M5 Motorway), were expanded and substantially altered during late 2020. These works exposed faulted and steeply-dipping (up to 45°) Triassic strata, including the NCSM, of which a low (4–6 m high) steep (45–60° slope) excavation bank remains, with a parallel public footpath (Figs. 1 and 2; NGR 324864 124734).

With the kind permission of site owners, Somerset County Council, Estates Department, the newly exposed strata were logged and sampled by the authors during Spring and Summer 2021.

Fig. 1. Location of the Carnian (Triassic) North Curry Sandstone Member (Dunscombe Mudstone Formation) exposure described here. A: Location in the British Isles (Cosmographics©); B: location at the M5 Motorway–A358 road junction, Taunton (Somerset) with key locations in bold; C: road map of the site.
B and C base maps adapted from AppleMaps©, under terms of use: https://www.apple.com/uk/legal/internet-services/maps/terms-en.html.

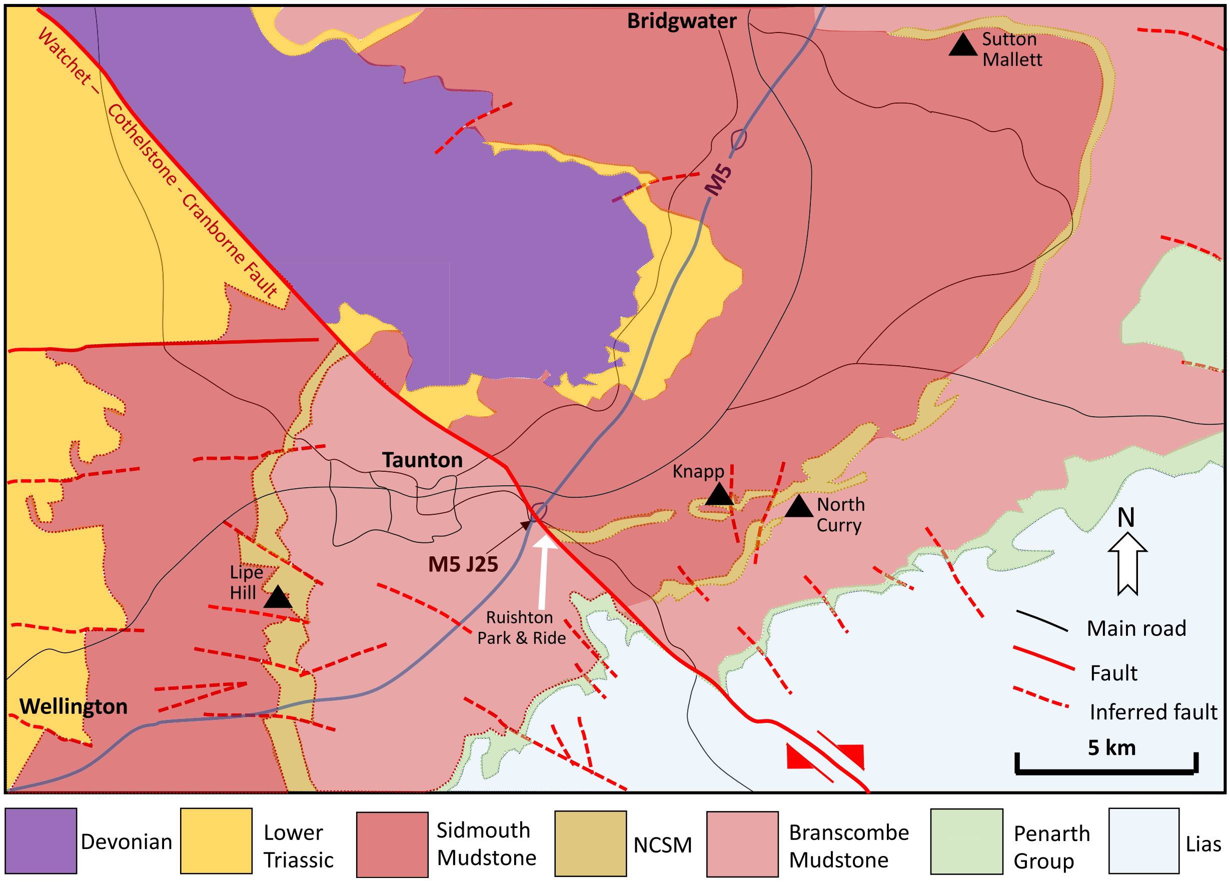

Fig. 2. Solid geology sketch map of the area showing the outcrop of the North Curry Sandstone Member (Dunscombe Mudstone Formation) based on the BGS 50 K digital sheets 295 and 311. NCSM = North Curry Sandstone Member. White arrow indicates area of Figure 1C.
Adapted from https://mapapps.bgs.ac.uk/geologyofbritain/ under terms of use, with amendments from Ruffell (1990) and Porter and Gallois (2008).

4.2. Stratigraphy

The exposure consists of several beds of predominantly fine-grained, pale grey to green sandstone interbedded with poorly bedded red and green coloured mudstones. The sandstone beds are less than 1 m in thickness and have sharp basal contacts with the underlying mudstone beds (Fig. 3) and display fining-upwards grain size profiles. Four of the sandstone beds have thin, coarse-grained basal sections with angular rip-up mudstone clasts and more rounded dolomite clasts. Mudstones associated with the coarser units are blocky and crumbly and are either red/brown or greenish-grey in colour. In places the green mudstone beds have sharp tops and are distinctly silty in grain size, and then merge downwards into red beds (Fig. 4). In total, the section is about 16 m thick, making it the thickest and best exposed North Curry Sandstone Member section known (Figs. 3 and 4).

The measured section (Fig. 4) includes *c.*, 2 m of poorly exposed red mudstones at the base and top of the section, and some 4.7 m of sandstone in up to seven discrete sand bodies. The NCSM at Taunton is thus a mud-dominated sequence, with 25 to 30% of sand being present.

4.3. Sedimentology

The sandstones are all characterised by a sharp, slightly erosive base, and fine upwards, indicating they were deposited by a waning current. The sandstones are thin, all being less than 1 m in thickness, so these were small depositional events. The dominant grain size is very fine- to fine-grained, but the bases of some units are very coarse-grained, containing elongate, angular clasts of dolomite and mudstone, identical to the intraformational conglomerate lithofacies of Porter and Gallois (2008). The dolomite clasts have a microcrystalline or aphanitic texture. These sediments cannot have been transported very far as the sedimentary lithoclasts would have fragmented and become more equant and rounded very quickly, so have been sourced locally to the depositional site. Rounded and abraded phosphatic bone material is common in these conglomerates (see Fig. 7).

The coarse-grained beds are invariably cross-bedded, with set heights of 0.2 m or less. Set tops are usually eroded and overlain by very fine to fine-grained sandstones with small trough shaped cross-beds and asymmetric climbing ripples, equivalent to the cross-bedded (S_x) and asymmetric ripple cross-laminated (S_r) sandstone lithofacies of Porter and Gallois (2008), the latter indicating a high sediment load (Picard and High, 1973). Other arenaceous beds are very fine-grained and grade into siltstones. These are equivalent to the interbedded symmetrical ripple and horizontally laminated fines lithofacies (F_r) of Porter and Gallois (2008) comprising lenticular ripples and mud drapes, similar to flaser bedding. As the proportion of sand or silt increases, ripples in these sediments climb. Current ripples and bed foresets indicate palaeocurrent directions to the east or south-east.

Two of the sandstones (Figs. 4 and 5) contain angular cavities with a cubic shape on bedding plane surfaces, likely formed by the dissolution of halite crystals.

The interbedded mudstones, despite being freshly exposed, reveal relatively few sedimentological features. They are poorly bedded, predominantly red coloured, and contain few silty horizons. Green-coloured layers have gradational bases and sharp tops, as the mud becomes siltier. In the lower part of the sequence red coloured mudstones grade upwards into discrete, greenish-grey coloured siltier mudstones which display faint nodular bedding with a vertical mottled fabric reminiscent of pedogenesis, although no definitive root or

Fig. 3. Outcrop photographs. (A) Panoramic view of the North Curry Sandstone Member (Dunscombe Mudstone Formation) exposure described here. Traffic light stand is ~3.5 m high, for scale. (B) Closer view of the middle part of the exposure, showing 'Moore Facies' (TPR5 on Fig. 4), (C) closer view of the 'Moore Facies' (TPR 5 on Fig. 4).

calcrete structures can be discerned. The silty mudstone at the base of the exposed section contains nodular, sometimes wrinkly, bedding in which pelleted horizons are interbedded with horizons containing abundant angular cavities (Fig. 5A). Bed colour varies from dark grey to purplish-red, but where silica and calcite cements are present, the nodular bed is white-coloured.

4.4. Petrography of the mudstones and sandstones

The nodular mudstone at the base of the section has a distinct pelleted texture in thin section (Fig. 7A). Large, irregularly shaped pellets of a dense, microcrystalline dolomite containing scattered silt quartz grains are set in a microporous microcrystalline dolomite matrix. Variations in the optical density of the dolomite pellets and silt content suggest that the pellets are not fully *in situ* but have undergone some transport or brecciation. The pelleted fabric does not have a strong preferred orientation, although the pellets are sometimes more elongated parallel to the direction of bedding. Former cavities in the pellets contain microcrystalline silica and non-ferroan calcite which are replacive with respect to the dolomite. The combined hand specimen and thin section appearance of this mudstone unit suggests *in situ* brecciation and dissolution, possibly associated with the dolomitization process, and indicative of the former presence of evaporite minerals.

Most of the NCSM sandstones are very fine-grained to fine-grained lithic quartz arenites. Rippled siltstones and fine-grained sandstones contain abundant clay drapes (Fig. 7B). Except for the clay drapes, these sandstones are free of detrital clay and contain excellent intergranular porosity. Oversized pores are common. In many cases angular oversized pores correspond to the hopper-shaped cavities visible in hand specimen, suggesting the former presence of halite crystals in the sandstones. In other cases, rounded oversized pores could represent dissolution of detrital feldspar or sulphate grains (Fig. 7E).

The 'Moore Facies' sandstones are characterised by coarse grains of red coloured mudstone, aphanitic silty dolomite, phosphatic bone fragments and very well-rounded quartz (Fig. 7C–F). Many of the mudstone clasts are elongate and thin, and therefore unlikely to have been transported long distances. The aphanitic dolomite clasts are identical to the dolomitic nodular mudstone at the base of the section, further indicating very local erosion of interbedded or underlying fine grained sediment. Phosphatic bone material is up to 2 mm in length and exhibits a consistent structure comprising

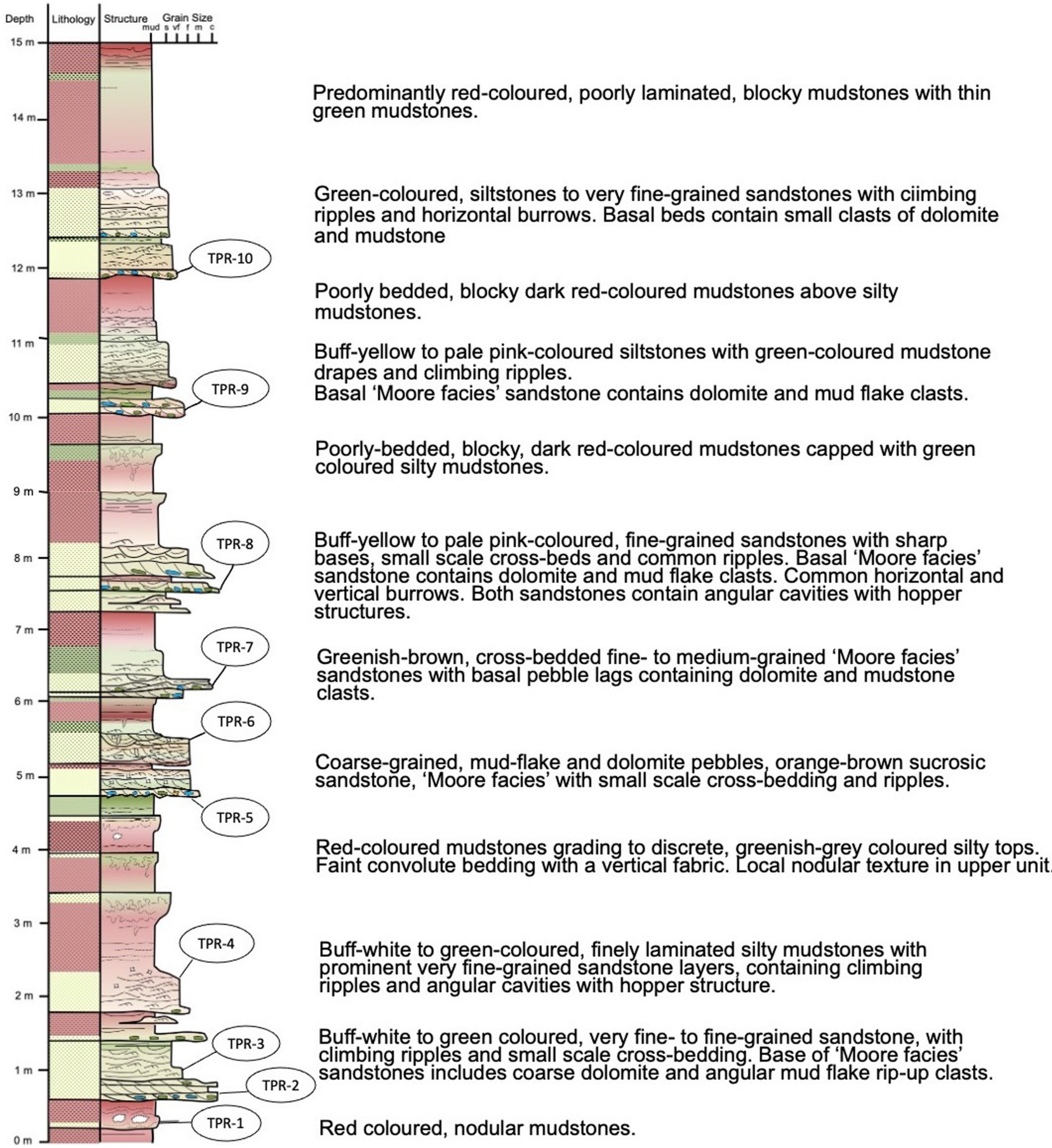

Fig. 4. Graphic sedimentary log of the exposed North Curry Sandstone Member from the Taunton Gateway Park and Ride outcrop showing lithology, colour, grain size and sedimentary structures, along with sample locations. Bed TPR5 is shown in detail on Figure 3.

radiating phosphate needles around open cavities but cannot be assigned to a specific vertebrate in thin section.

Large, very well-rounded detrital quartz grains are restricted to beds TPR5, -7 and -8. These are typically 0.5 to 1 mm in diameter. They impart a bimodal grain size to the detrital quartz fraction and comprise an even mixture of monocrystalline and polycrystalline grains. Their well-rounded shape strongly suggests that these quartz grains were derived from aeolian dune sands and not from interbedded sediments within the sequence. This indicates that in addition to a local intraclast source of detritus, at least some of the detrital material had travelled further.

4.5. Structure

The beds at the Taunton Gateway Park and Ride exposure dip steeply at approximately 45 degrees to the SW with at least one normal fault in

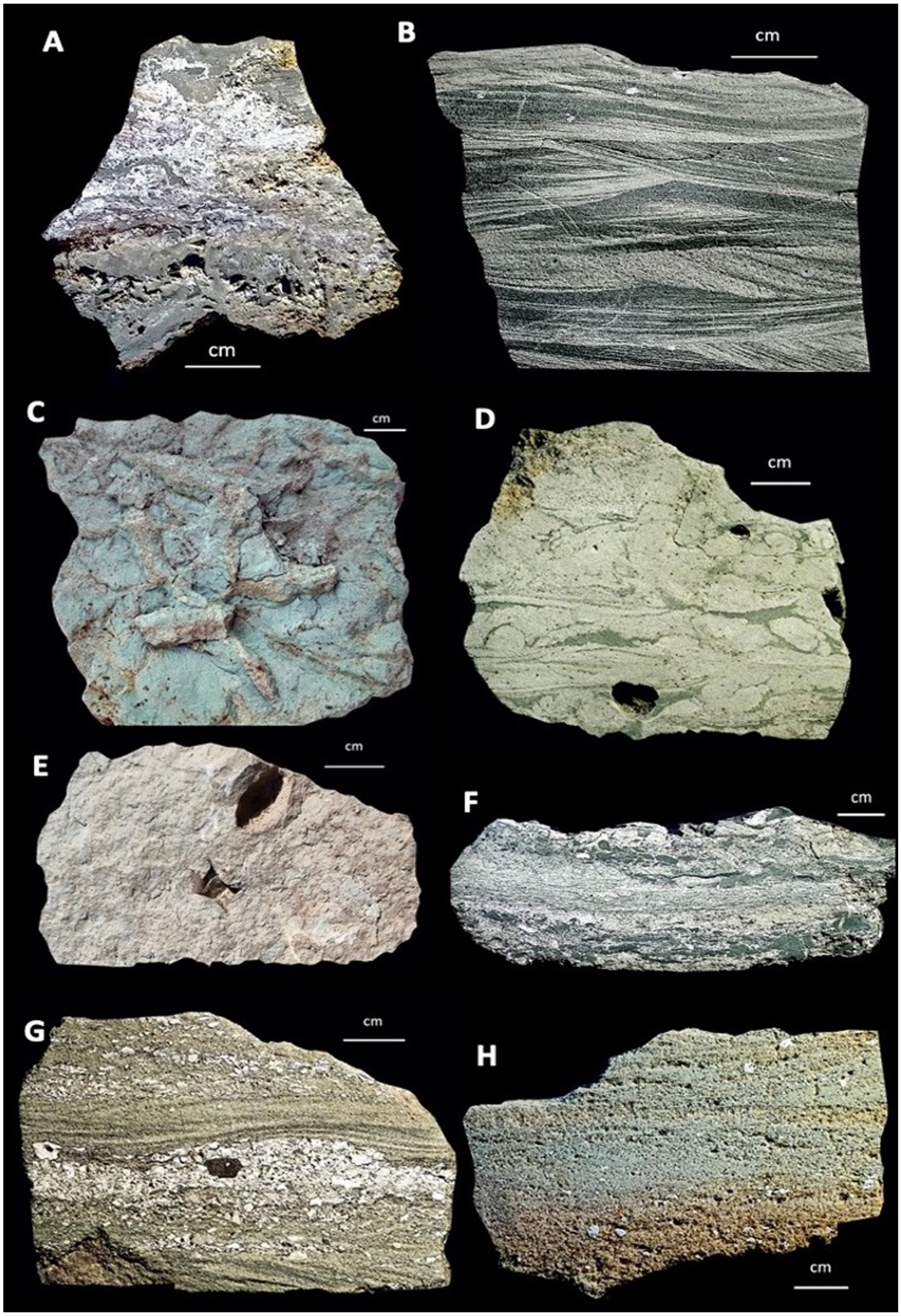

Fig. 5. Representative hand specimen examples from the Taunton Gateway Park and Ride outcrop. (A) Nodular bedded, silty dolomitic mudstone with abundant cavities probably after evaporite dissolution. Sample TPR-1. (B) Very fine-grained flaser bedded sandstone with mud drapes to current ripples. Sample TPR-3. Note the small dissolution voids. (C) Detail of *Fuersichnus*-type branching burrows on a bedding plane surface. Sample TPR-6. (D) Polished cross-section face on fine grained sandstone with horizontal branching *Fuersichnus*-type burrow at the interface between fine grained sandstone and mud drapes. (E) Angular 'hopper' voids after halite dissolution. Sample TPR-4. (F) 'Moore Facies' sandstone with abundant mudstone rip-up and dolomite clasts. Sample TPR-9. (G) Coarse grained 'Moore Facies' sandstone with large dolomite clasts. Sample TPR-2. (H) Coarse grained 'Moore Facies' quartz sandstone with dolomite clasts. Sample TPR-8.

the measured section (Fig. 3). In the surrounding area, NCSM beds dip at no more than 10–15°. The particularly steep dip was presumably caused by strike-slip movement along the regionally significant Watchet-Cothelstone-Cranborne Fault, located approximately 100 m SW of the outcrop (Fig. 2). Movement on the fault could also have contributed to the fractured appearance of the mudstones.

4.6. Palaeontology

Grey-green coloured mudstones and siltstones in the Taunton Gateway Park and Ride sequence, along with contiguous exposures to the north-east and south-west, contain abundant plant fragments and *Euestheria*. Partial moulds of bivalve shells are found in coarser siltstones and sandstones, some smooth and others ribbed, but unidentified.

Small, cylindrical, sand-filled horizontal burrows, *Planolites montanus*, are present in the mud drapes to ripples and are most easily observed from the contrast of the host green mudstone and sand fill (Fig. 5). Larger *Fuersichnus*-type sand-filled burrows locally form strongly bioturbated interfaces between clay drapes and the thin cross-bedded sandstones (Fig. 5). Two parallel probable burrows 7 cm long were observed on the base of the sandstone bed TPR-6 at 5.5 m from the base of the section (Fig. 6A).

Of especial interest here are bone fragments. Moore (1867) reported finding fish and vertebrate fossils in a coarse sandstone at Ruishton (see below). We have sampled the five coarse-grained sandstone beds (the beds described as ‘Moore Facies’ on Fig. 4) found and extracted fossils from two of the beds. One of the two other coarse beds contained plant fragments.

The samples we collected from the bonebeds were soaked in dilute acetic acid for several days, crushed and inspected. Several specimens of teeth which we believe are from *Palaeobates keuperinus* (Fig. 6C) and undetermined scale and fin material were found. Although not exclusively freshwater, the hybodont shark *Palaeobates keuperinus* is known from freshwater environments (Milner et al., 1990). Moore named some of the sharks' teeth from Ruishton as *Diplodus*, named *Diplodus moorei* by Woodward (1889), being later redescribed and placed in the genus *Xenacanthus* by Johnson (1980); finally, the teeth were allocated their own genus, *Mooreodontus*. The xenacanth shark, *Mooreodontus moorei* is known to be exclusively freshwater (Bhat et al., 2018).

Moore removed what he described as a “load” of rock from his location, which sounds considerably more than the 2 kg we removed. It is not surprising therefore that he found more fish and tetrapod remains that we did and it is quite possible that if we excavate further the scope of our finds could be much wider.

5. Discussion

5.1. Have we found Moore's location?

Moore (1867) described a section in the foundations of a house under construction. Considering the location of the beds at the surface and ages of buildings in the area (using old Ordnance Survey maps) there are a number of possible building locations. The distance to the nearest from the new outcrop is less than 100 m and the most distant is no more than 800 m. Moore described 6.4 m of exposed strata which, unless the bedding dips steeply, is considerably deeper than usual for the foundations of a house. Further, the matrix attached to Moore's fossils in the BRLSI is very similar to the matrix in the NCSM bone beds we have observed (Fig. 6).

5.2. Stratigraphy, cyclicity, and the CPE

We are confident that the new exposure represents the NCSM from mapping, lithological, and fossil evidence. The NCSM is mapped across the area on current BGS maps (Fig. 2) and forms a topographical escarpment which can be mapped across the Somerset levels between the Quantock and Mendip hills thence southwards towards Taunton, west to Lipe Hill (Ruffell and Warrington, 1988; Ruffell, 1990, 1991). The lithologies we describe are identical to those reported previously for the NCSM and very familiar to the current authors (Ruffell and Warrington, 1988; Ruffell, 1990, 1991; Porter and Gallois, 2008).

The NCSM and the Dunscombe Mudstone Formation are relatively fossiliferous (Ruffell and Warrington, 1988; Porter and Gallois, 2008), although age-diagnostic fossils are rare. The presence of *Camerosporites seccatus*, widely present throughout the equivalent units on the south Devon coast, indicates a Carnian age (Fisher, 1972; Kurschner and Herngreen, 2010; Kousis, 2015). The palynological assemblages from Lipe Hill and Sutton Mallet (Baranyi et al., 2019) suggest a Julian (probably late Julian) age but it cannot be defined more precisely based on the palynological assemblages alone.

It is interesting to note that at other locations, there is evidence of four or five discrete pulses of volcanic activity through the *c*., 1 Myr of the CPE (Dal Corso et al., 2020), each represented by a distinct sedimentary pulse in the Wiscombe Park boreholes (Miller et al., 2017). Here, at the Ruishton site, we also identify five prominent grey-green-pale mudstone beds, with additional, interbedded thin sandstones and mudstones. The cause of this cyclicity is worthy of further characterisation and investigation. Some of the mottled, green-coloured mudstones, may have resulted from discrete wetting or lake expansion events (as described in Milroy et al., 2019). It is not possible at present to directly correlate these five beds with those in the Wiscombe Park borehole cores which were taken ~35 km to the south-east.

5.3. Sedimentological interpretation

The mixed mudstone-sandstone NCSM system at the Taunton Gateway Park and Ride site indicates terrestrial conditions of deposition, with hints of soil formation in some of the mudstones. The sharp bases, general fining-upwards grain size profiles and abundance of current ripples in sandstone interbeds indicate waning flows with high sediment loads, especially where current ripples climb.

The exposure is only two-dimensional and therefore not ideal for determining palaeocurrent directions, but both current ripples and bed foresets suggest an eastward or south-east direction of transport, consistent with that recorded on the North Curry outcrop (Warrington and Williams, 1984; Ruffell, 1991) and from Lipe Hill (Ruffell and Warrington, 1988; Ruffell, 1991).

The thin (>1 m) sandstone beds have sharp bases with coarse-grained, angular clasts of dolomite and mudstone, and fine upwards into climbing ripple-dominated sets, indicating episodic waning current activity with high sediment load (Picard and High, 1973; Lanier and Tessier, 1998). It is tempting to envisage these thin sandstone beds as individual flash flood events, comparable to those described by Burley et al. (2022) from the Arden Sandstone of the English Midlands, and representative of small, ephemeral rivers (Frostick and Reid., 1986; Martin, 2000; Plink-Bjorklund, 2015).

The stratigraphic and sedimentological evidence indicate a system of high sediment load small rivers flowing from the west across a low relief, evaporitic, desert mud plain. Dolomite and halite cements formed in the muds, although mature soils did not develop. The sandstones, especially those of the ‘Moore Facies,’ contain detritus derived from the mud plain flats adjacent or close to the rivers. This is refined in some respects from previous suggestions of channel and overbank facies (Warrington and Williams, 1984; Ruffell and Warrington, 1988; Simms and Ruffell, 1990) but not so different as to be incompatible with previous work.

Close by, contemporary freshwater lakes were present, or at least the deposits of lakes which had formed in the basin. Well-defined lake sediments are present in the Dunscombe Mudstone Formation in the Wiscombe Park boreholes and south Devon coastal section (Porter and Gallois, 2008) which include laminated dolomicritic mudstones and breccia beds, associated with thin deltaic sandstones. The NCSM sequence at the Taunton Gateway Park and Ride exposure appears to represent a more proximal, possibly lake margin setting, than present in south Dorset and the central Wessex Basin (Fig. 8). This alluvial plain was at times evaporitic as evidenced by the presence of dolomite clasts and halite dissolution textures in the sandstones and mudstones.

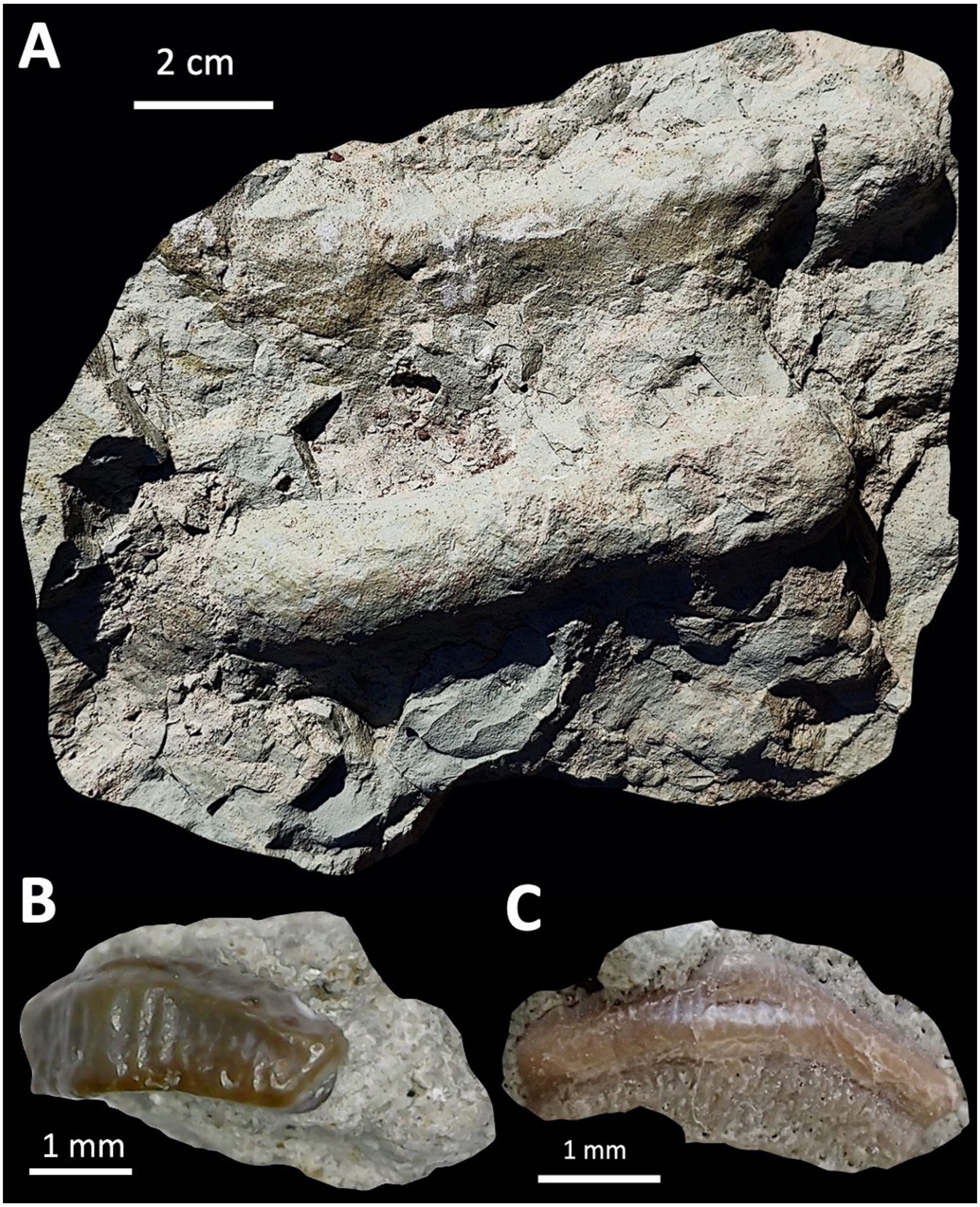

Fig. 6. Representative fossils from the Taunton Gateway Park and Ride outcrop. (A) Two parallel burrows from bed TPR-6, perhaps the bases of U-shaped burrows, approximately 7.0 cm long. (B) Tooth of *Palaeobates keuperinus* collected in 2021 from bed TPR-8. Similar also recovered from bed TPR-9. (C) Tooth of *Palaeobates keuperinus* collected by Charles Moore (M12g, BRLSI).

The salinity of this lake was, for at least some time, freshwater. The xenacanth shark, *Mooreodontus moorei* is exclusively freshwater (Bhat et al., 2018), as are the amphibians ("Labyrinthodon", Moore, 1867, p. 468) from the NCSM. Specimens of *Euestheria* from the NCSM (Moore, 1867; Ruffell and Warrington, 1988) confirm the habitat, as modern conchostracans thrive in ephemeral freshwater ponds and lakes. The ichnofauna includes common infaunal feeding traces of *Planolites*, *Treptichnus*, *Taenidium* and *Phycodes*-types, especially at sandstone-mudstone interfaces and vertical tubes of *Skolithos* and *Cylindrichnus*-types, in the dominantly sandstone lithofacies, all consistent with a fluvial and freshwater lake depositional environment. The abundant green algae (*Plaesiodictyon*) and a chlorophyceaen alga (*Botryococcus*), are taxa indicative of quiet, oxygenated, fresh or low-salinity water.

5.4. Regional palaeogeography

Across the Somerset-Devon basins the arenaceous beds of the NCSM and Dunscombe Mudstone Formation undergo dramatic thickness changes (1–20 m) and lateral lithofacies variations over short distances of as little as 1–5 km. Further afield, in its subcrop in the Wessex Basin, the NCSM reaches 24 m in thickness (Howard et al., 2008). The regional

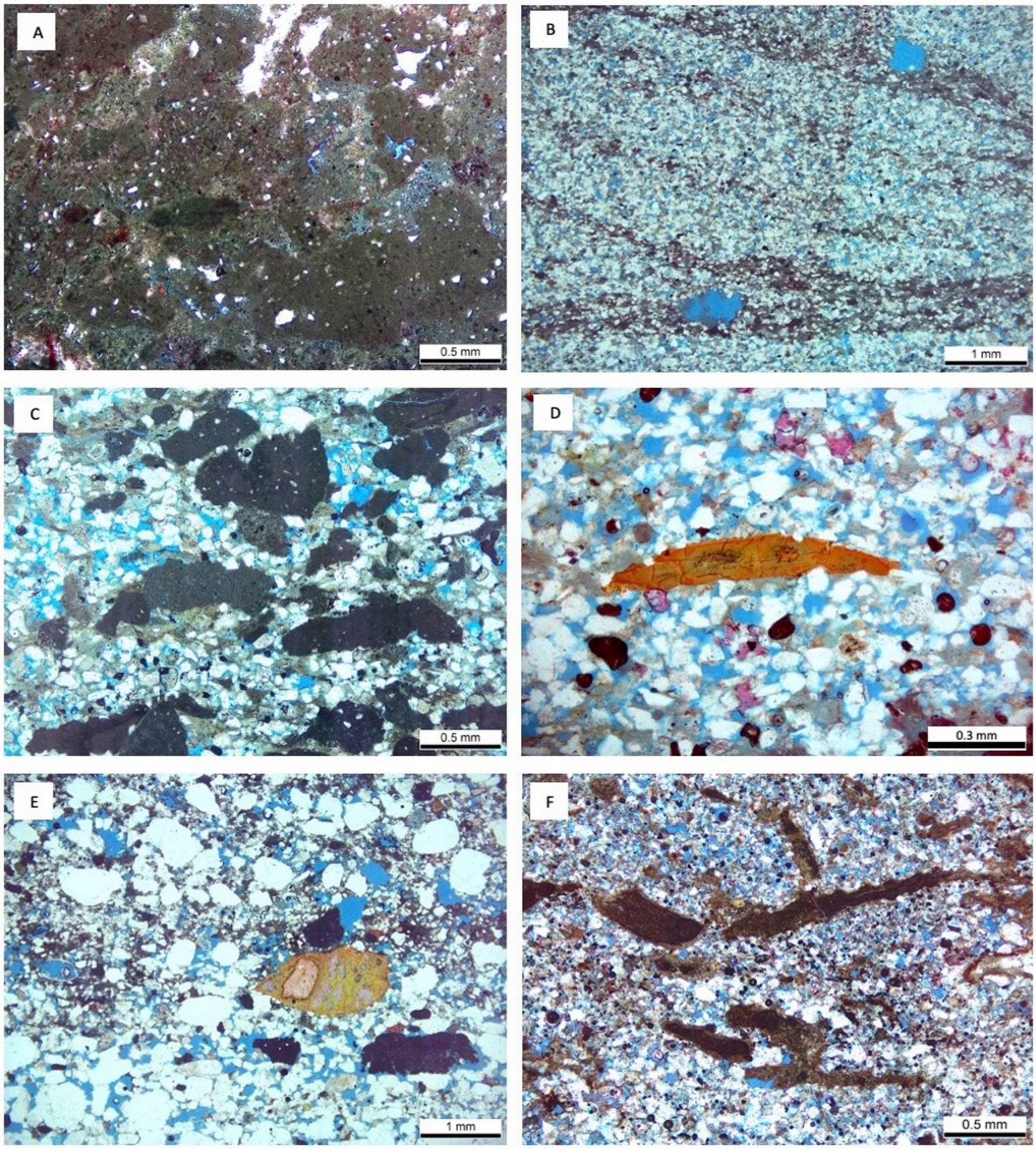

Fig. 7. Representative photomicrographs of samples from the Taunton Gateway Park and Ride outcrop illustrating the detrital mineralogy. Sample locations shown on the graphic sedimentological log; hand specimen appearance shown on Figure 5. All samples impregnated with blue epoxy to colour pore space. (A) Pelleted texture after evaporite dissolution in silty mudstone associated with nodular bedding. Sample TPR-1, PPL x 5. (B) Very fine-grained sandstone typical of many of the outcrop sandstones showing mud drapes to ripples and angular cavities after halite dissolution. Sample TPR-5, PPL x 2.5. (C) Typical coarse-grained 'Moore Facies' sandstone containing angular clasts of aphanitic dolomite in fine grained sandstone. Sample TPR-2 PPL x 5. (D) Detail of a small, abraded bone fragment from 'Moore Facies' sandstone. Sample TPR-2, PPL x 10. (E) Moore Facies sandstone with very well-rounded detrital quartz grains and angular aphanitic dolomite clasts. Note the large, well-rounded bone fragment. Sample TPR-8, PPL x 2.5. (F) Rip-up clasts of dolomitic mudstone in a basal lag from 'Moore Facies' sandstone. Sample TPR-9, PPL x5.

variation in thickness of the NCSM and Dunscombe Mudstone Formation is because they were deposited at a time of active tectonic subsidence and extension (Gallois, 2003). This is consistent with continued basin development (Whittaker, 1973) and a depositional system resulting from fluvial drainage from upstanding highs into a subsiding basin.

The angular mudstone and dolomite clasts in the coarse-grained 'Moore Facies' of the NCSM cannot have been transported very far (they would have fragmented and come more equant and rounded very quickly) so must have been sourced locally and may represent microbial mats (Hips et al., 2015). The small rivers supplying the Wessex Basin lake were of sufficient energy to erode and transport hardened mudflake rip-up clasts and dolomitic crusts from the immediately adjacent mud plain across which they flowed. This contrasts with the very well-rounded quartz pebbles in the 'Moore Facies' which strongly indicate derivation from aeolian sediments. These could be contemporary transient dunes in NCSM river system which are no longer preserved, or more likely, derived from older Sherwood Sandstone or Permian sandstones, which outcropped around the south-eastern margin of the Quantocks High during the Carnian (Fig. 8). Regional palaeo-current data from the area (Warrington and Williams, 1984; Ruffell and Warrington, 1988; Ruffell, 1990; Ruffell, 1991) indicate that current flow in the NCSM was generally away from the upstanding massifs of the west of England eastwards into the Wessex Basin, and radially arranged around the Quantocks High (Fig. 8). Comparable easterly to south-easterly palaeo-currents are reported from medium- to coarse-grained sands in the Sutton Mallet area north of Bridgwater in Somerset

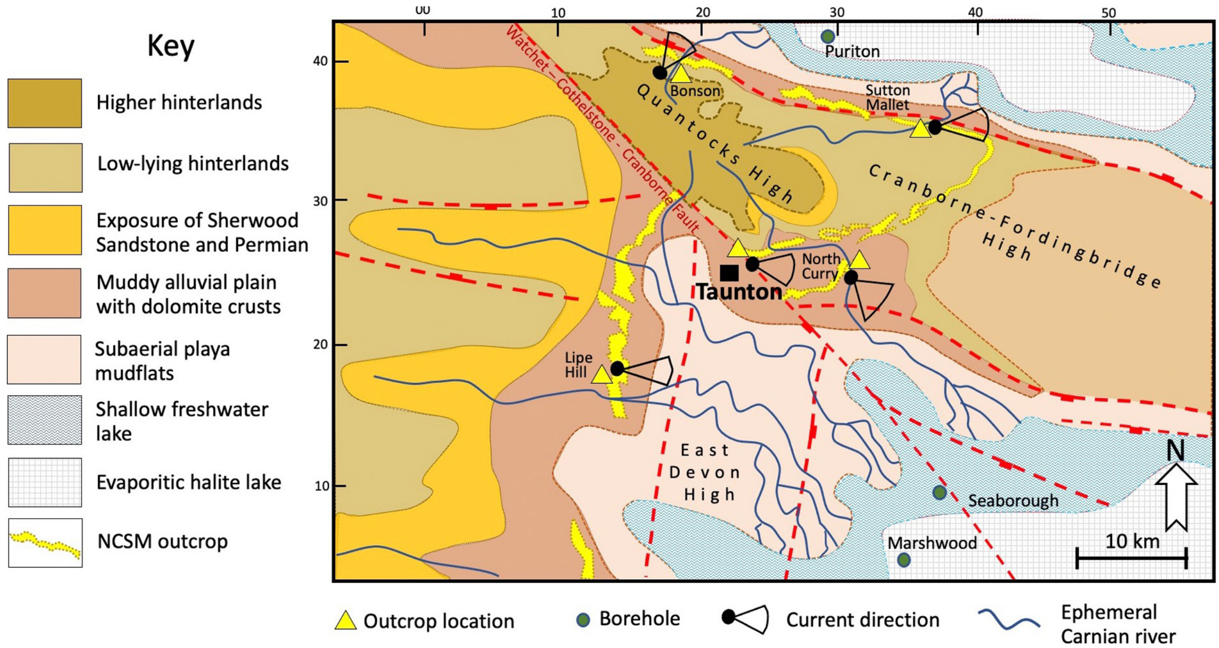

Fig. 8. Palaeogeographical sketch map of the greater Taunton area showing an interpretation of the depositional facies and their distribution around the Quantocks High and Cranborne-Fordingbridge High at a time in the Carnian of relatively low lake level stand. Note the radial, conjectured fluvial drainage off the Quantocks High and the presence of Triassic outcrops around the southern and eastern margins of the Quantocks High. Palaeocurrent directions compiled from Warrington and Williams (1984), Ruffell and Warrington (1988), and Ruffell (1991). The width of facies belts, although highly speculative, is based on concept that they are broadly concentric around higher hinterlands and with a lake in the basin centre.

(Ruffell, 1990) immediately east of the Quantock uplands that were likely exposed in Carnian times.

This palaeogeography fits well the isopach evidence of Whittaker (1973) and Ruffell (1991), wherein the Somerset Basin axis is orientated north-west to south-east and the east-flowing palaeo-currents of Sutton Mallet and North Curry flow towards the main depocentre of the Wessex Basin further to the south-east. The present-day Taunton occupied a marginal area in the Carnian, the 'East Devon High' of Gallois (2003), elevated from the Wessex Basin and separated from the Central Somerset Basin by the Quantocks-Cranborne-Fordingbridge High. This marginal location may explain why true lake facies are not recorded in the Taunton Gateway Park and Ride site at Ruishton. Whilst the presence of hopper crystal pseudomorphs after halite and other dissolution fabrics (and as reported from the NCSM at Lipe Hill and Knapp, Ruffell et al., 2018) indicate aridity, these can be precipitated by evaporation processes in soils (Benison et al., 2007) or transported as wind-blown (Mahowald et al., 2003) and do not require the direct local presence of a saline lake.

6. Conclusions

We demonstrate that the Moore (1867) microvertebrate collection most likely comes from the North Curry Sandstone Member in a location at Ruishton, just east of Taunton, where a new cutting reveals Moore's bone-rich units and the complete succession of the Carnian (late Triassic) North Curry Sandstone Member (partly equivalent to the Dunscombe Mudstone Formation, Mercia Mudstone Group). This resolves the unknown stratigraphic horizon that Moore likely collected his specimens from, as we document an analogous lithology and fauna. The interbedded succession of greenish-grey and red/brown calcareous mudstones/siltstones, associated with coarse-grained fossiliferous sandstones, is sandwiched between red-bed mudstones/siltstones of the Mercia Mudstone Group. The 16 m thick section comprises several sandstones interbedded with red-green mudstones, representing a terrestrial environment with lacustrine, evaporitic mud flat and fluvial deposits.

Our preliminary results suggest at the Taunton location in Carnian times, small 'flash-flood' rivers reworked sediment on alluvial mud flats on the East Devon High, west of and adjacent to the saline lake which occupied the deeper parts of the Wessex Basin. The environment as a whole is of varying salinity. The lake extent varied throughout the Carnian concomitant with ephemeral flash floods and at times extended onto the margins of the Quantocks-Cranborne-Fordingbridge High. Plant and animal life thrived in this environment of varying salinity as well as surrounding mudflats and uplands and dolomite crusts, potentially biogenically influenced, covered the muddy alluvial plain. The plant, xenacanth shark and amphibian ("Labyrinthodon") fossils all indicate freshwater and low salinity brackish waters nearby, whilst evidence of higher salinities enough to form halite as crystals (now the common hopper pseudomorphs) is equally abundant: no unequivocal evidence for continuous open marine nor *in situ* lacustrine freshwater occurs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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