Proceedings of the Geologists' Association 127 (2016) 478–505

Contents lists available at ScienceDirect

Proceedings of the Geologists' Association

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

The Rhaetian (Late Triassic) vertebrates of Hampstead Farm Quarry, Gloucestershire, UK

Ellen M. Mears [a,1,3], Valentina Rossi [b,2,3], Ellen MacDonald [b], Gareth Coleman [b], Thomas G. Davies [b], Caterine Arias-Riesgo [b], Claudia Hildebrandt [b], Heather Thiel [b], Christopher J. Duffin [b,c,d], David I. Whiteside [b], Michael J. Benton [b,*]

[a] School of Earth and Environment, University of Leeds, Maths/Earth and Environment Building, Leeds LS2 9JT, UK
[b] School of Earth Sciences, University of Bristol, Wills Memorial Building, Queens Road, Bristol BS8 1RJ, UK
[c] Palaeontology Section, Earth Science Department, The Natural History Museum, Cromwell Road, London SW7 5BD, UK
[d] 146, Church Hill Road, Sutton, Surrey SM3 8NF, UK

ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form 11 May 2016
Accepted 18 May 2016
Available online 14 June 2016

Keywords:
Late Triassic
Chondrichthyes
Actinopterygii
Marine reptiles
Bristol
Rhaetian
Rhaetian bone bed
Westbury Formation

ABSTRACT

The Rhaetian marine transgression, which occurred across Europe in the latest Triassic, 205.5 Ma, famously deposited one or more bone beds. Attention has generally focused on the basal bone bed alone, but here we explore this bed, and a stratigraphically higher bone bed at the top of the Westbury Formation, and compare the faunas. The Rhaetian at Hampstead Farm Quarry, Chipping Sodbury, Gloucestershire, UK, has produced more than 26,000 identifiable microvertebrate remains, including teeth and scales of chondrichthyan and osteichthyan fishes, as well as vertebrae of sharks, bony fishes, ichthyosaurs, and plesiosaurs. The higher bone bed ('bed 9') contains more small specimens than the basal bone bed, and they are also less abraded, suggesting less transport. Both bone beds yield largely the same taxa, but *Rhomphaiodon minor* and rare *Vallisia coppi* and *Sargodon tomicus* are found only in the basal bone bed. *Duffinselache* is reported only from units above the basal bone bed, but low in the Westbury Formation, and durophagous teeth only from two horizons. Four out of nine chondrichthyan species are common to both bone beds, whereas *Rhomphaiodon minor* and *Ceratodus* are absent, and hybodonts in general are rarer, in bed 9. Bed 9 is the richer source of marine reptile remains, including ichthyosaur teeth, jaw fragments, vertebrae, rare plesiosaur teeth and vertebrae, and a few *Pachystropheus* vertebrae and limb bones. Whereas the basal bone bed represents considerable transport and possible storm bed deposition associated with the onset of the Rhaetian Transgression, bed 9 was deposited under a lower energy regime.

1. Introduction

The Rhaetian was an important time in Earth history and in the evolution of life, leading up to the end-Triassic mass extinction, ETME (Schoene et al., 2010). After the devastating Permo-Triassic mass extinction, life recovered stepwise (Chen and Benton, 2012), with the appearance of major new groups both in the sea and on land, many of them characteristic of modern ecosystems. For example, on land, while dinosaurs were rising in importance, the precursors of many modern tetrapod groups had emerged, including the first lissamphibians (frogs and salamanders), turtles, lepidosaurs (basal rhynchocephalians), crocodylomorphs, and mammals (Sues and Fraser, 2010; Benton et al., 2014). On land, the ETME was an important trigger in the evolution of dinosaurs, marking the end of the large carnivorous phytosaurs, ornithosuchids, and rauisuchians, and enabling dinosaurs to expand to fill those niches (Brusatte et al., 2010; Benton et al., 2014). The other main terrestrial tetrapod clades, including crocodylomorphs, lepidosaurs, and mammals also diversified to some extent after the ETME. In the seas, there were major extinctions and turnovers among sharks (Cappetta, 1987, 2012) and marine reptiles (Thorne et al., 2011), whereas bony fishes were apparently unaffected by the ETME, with all families passing into the Jurassic (Friedman and Sallan, 2012). Many details of the ETME are still much debated, not

* Corresponding author. Tel.: +44 117 3941208; fax: +44 117 9253385.
E-mail address: mike.benton@bristol.ac.uk (M.J. Benton).
[1] Current address: School of Geosciences, University of Edinburgh, Grant Institute, James Hutton Road, Edinburgh EH9 3FE, UK.
[2] Current address: School of Biological, Earth and Environmental Sciences, Distillery Fields, North Mall, University College Cork, Cork, Ireland.
[3] These authors are equal first authors.

http://dx.doi.org/10.1016/j.pgeola.2016.05.003
0016-7878/

least the timing, duration, and magnitude of the event (e.g. Tanner et al., 2004; Mander et al., 2008; Deenen et al., 2010).

The Rhaetian as a stratigraphic stage has also had a chequered history, and its duration is currently debated, with estimates ranging from 7 to 8 Myr (Muttoni et al., 2010) to 4.4 Myr (Maron et al., 2015). In central Europe and the United Kingdom, the beginning of the Rhaetian is marked by the Rhaetian Transgression, dated at 205.7 Ma (Maron et al., 2015), when marine waters and sediments flooded over the underlying Mercia Mudstone Group. In Britain, the Mercia Mudstone Group red beds pass up into the Blue Anchor Formation, and these are overlain conformably, but with a very clear eroded surface, by black and dark grey, bedded marine beds of the Penarth Group, comprising the Westbury Formation and the overlying Lilstock Formation. There is a famous basal bone bed at the base of the Westbury Formation, although it is occasionally absent, and this may comprise microscopic, minimally abraded teeth, scales and bones in some localities, and large-sized abraded blocks of bone, mixed with phosphatized coprolites and inorganic nodules in others (Storrs, 1994; Swift and Martill, 1999; Suan et al., 2012). In places, the base of the Rhaetian is marked by abundant *Thalassinoides* burrows that penetrate the semi-consolidated sediments of the Blue Anchor Formation, and may be filled with gravity-borne bone bed sediments, which were even reworked and packed by the arthropods that produced the burrows (Korneisel et al., 2015). In most places, there may be one or more younger bone beds in the Westbury Formation, generally one, and sometimes several (Duffin, 1980; Swift and Martill, 1999).

The Rhaetian bone beds in England have been sampled at many localities along the outcrop of the Westbury Formation, from Devon in the south, through the Bristol area and South Wales, and across the Midlands of England (Swift and Martill, 1999), and these have been sampled in detail and reported especially from the southern end of the outcrop, around Bristol and Devon (Korneisel et al., 2015; Nordén et al., 2015; Allard et al., 2015; Lakin et al., 2016). Our aim here is to explore a rich locality, Hampstead Farm Quarry, near Chipping Sodbury, south Gloucestershire, in southwest England. The study is based on a unique and extensive fossil collection that was made over many years by Mike Curtis, a renowned local collector, and it is combined with fieldwork, logging, and sampling throughout the Westbury Formation. This allows us to provide one of the most extensive accounts to date of a classic Rhaetian-age marine microvertebrate locality, and to compare the basal and higher bone beds.

Institutional abbreviations: BRSUG, Bristol University, School of Earth Sciences Collection; BRSMG, Bristol City Museum and Art Gallery, Geology Collection.

2. Geological setting

Hampstead Farm Quarry (HFQ; grid reference: ST 726840) is one of a series of quarries, north of Chipping Sodbury, Gloucestershire, UK (Fig. 1). Quarrying began in the area in the Middle Ages, and was intensified in the nineteenth century. From 1844, men in the workhouse were conscripted to break stones for road building, and limestone was also burned in limekilns. When the direct railway route was built from Swindon to South Wales in 1903, a tunnel 4 km long had to be created at Chipping Sodbury, and this brought a railway connection close enough for quarried limestone to be carted down the hill, and quarrying then expanded enormously (Lakin et al., 2016).

Several quarries were excavated on both sides of the Wickwar Road, the B4060, that runs north from Chipping Sodbury, and these are now elongate pits, named Barnhill and Southfield quarries on the west side, and Hampstead Farm Quarry on the east side (Fig. 2). Initially, all the quarrying was close to Chipping Sodbury itself, and in 1929 three separate principal quarries (formerly called Arnolds, Limeridge, and Wilson and Turners quarries, from south to north) were amalgamated into the single, large Barnhill Quarry (ST725830), operated by the new British Quarrying Company, later ARC and now Hanson Aggregates. Barnhill Quarry is no longer worked, and Southfield Quarry (ST723842) houses the offices and rock crushing equipment of Hanson. In 1975, a tunnel was blasted

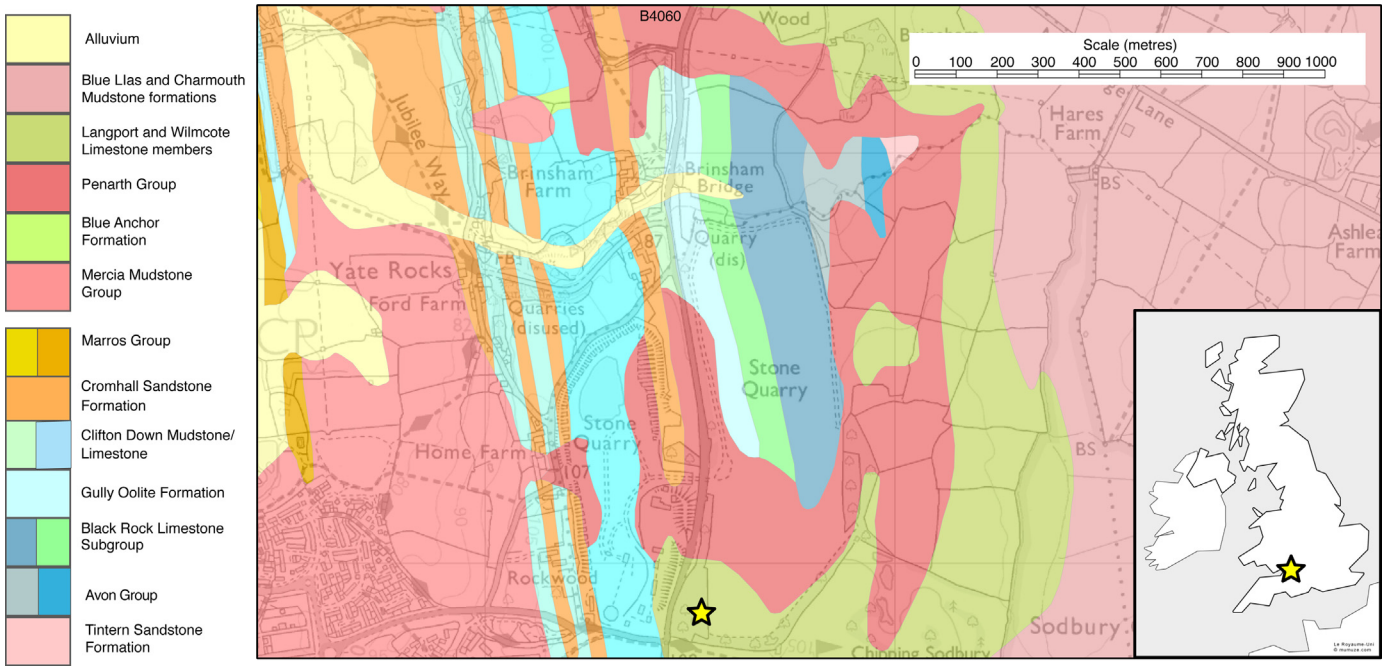

Fig. 1. Geological map of the quarries north of Chipping Sodbury, with Southfield Quarry to the west of the B4060 road, and Hampstead Farm Quarry to the east; the Rhaetic microvertebrate samples came mainly from the south-west corner of Hampstead Farm Quarry, marked with a yellow star. Key geological formations are indicated, separated into the Devonian and Carboniferous units (bottom of column) and the key Triassic–Jurassic units above. Note that there are many subdivisions in the Carboniferous Limestone, and part of the Cromhall Sandstone appears between the Clifton Down Mudstone and the Clifton Down Limestone. © Crown Copyright and Database Right 2015. Ordnance Survey (Digimap Licence).