REPLY

MICROFACIES OF THE COTHAM MARBLE: A TUBESTONE CARBONATE MICROBIALITE FROM THE UPPER TRIASSIC SOUTHWESTERN U.K. (IBARRA ET AL., 2014)

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INTRODUCTION

Mayall and Wright question interpretations in our microfacies analysis of the Cotham Marble microbialites (Ibarra et al., 2014) in which we primarily highlight previously overlooked aspects of Cotham Marble microbialite formation. They are specifically unconvinced about the Cotham Marble's potential relevance to the end-Triassic mass extinction and our interpretation that *Microtubus* is not integral to the formation of the dendrolitic microbialite phases. Here we address Mayall and Wright's comments under the same headings in which they present them.

COTHAM MARBLE AS AN INDICATOR OF LATE TRIASSIC MASS EXTINCTION

Regional distribution of the Cotham Marble

Mayall and Wright state that the Cotham Marble's aerial extent of ~2,000 km^2 is 'misleading' due to its morphological variability and patchy distribution. The 'Cotham Marble' has long been known to contain many 'forms' (Short, 1903), acknowledged on page 2 of Ibarra et al. (2014). Along with a description of the various forms (and to try to avoid subsequent confusion about an already deceiving term), Short (1903) proposed the use of the term 'Landscape' to reference samples that contain any form of the 'tree-like' or dendrolitic phase. All of the sites referenced in the regional distribution map shown in Ibarra et al. (2014) contain examples where the 'arborescent' or 'Landscape' (cf. Short, 1903) form of the Cotham Marble has been reported. The double Landscape variety shown in Ibarra et al. (2014) is indeed more common around Bristol (Hamilton, 1961), but is certainly not restricted to that region (Fig. 1A) as Mayall and Wright incorrectly assert in their comment.

With respect to the continuity of the Cotham Marble, we do not imply the Cotham Marble, in any 'form', is a single continuous layer. The Cotham Marble microbialites are patchy and occur as individual mounds (Owen, 1754), which is stated in the Abstract section of Ibarra et al. (2014). Although the 'continuity' of phases that we demonstrate in Figure 2 of Ibarra et al. (2014) focuses on samples collected in and around Bristol (up to ~20 km apart), similar phases have been reported in outcrops as far south as the Devon coast (Hamilton, 1961; Gallois, 2007; Fig. 1A). In fact, samples collected well outside of Bristol that occur approximately 100 km apart show considerable fine scale lateral persistence despite occurring as discontinuous mounds (Fig. 1B-C). The succession of facies (e.g., a shallowing upward cycle of subtidal wackstones/packstones overlain by intertidal mudstones) can repeat in sedimentary successions, such that a similar succession of facies in isolation from far-removed localities would not be taken for isochronous deposition. However, the identical microstratigraphy, down to the mm-scale succession of microfacies, found ~100 km apart (Fig. 1B-C) suggests some phases of the Cotham Marble were deposited at the same time under identical regional-scale forcing. The significance of the lateral persistence of the dendrolitic and stromatolitic phases is at least twofold: 1) widespread, non-local environmental factors were the dominant controls on microbialite formation, despite evidence for local microbial influence and 2) although their morphology is not entirely uniform across the region, the striking persistence of fine-scale textures across tens of kilometers suggests some phases of the Cotham Marble were deposited under isochronous conditions. Thus, when combined with examples from Bristol and Lower Woods, Figure 1 validates the aerial extent presented in Ibarra et al. (2014).

Stratigraphic and Depositional Setting

Mayall and Wright state that the term 'dead zone' (cf. Mander et al., 2008) is used to support the case that the Cotham Marble is an 'indicator' of extinction. While we agree that the depositional setting is debated and the depauperate zones surrounding the Cotham Marble may be attributable to a fluctuating environment and potential salinity changes, we do not base our association of the Cotham Marble with the extinction event solely on its stratigraphic co-occurrence with an interpreted 'dead zone'. We emphasize the Cotham Marble's 1) lateral extent, 2) co-occurrence with an interpreted prasinophyte bloom also found in other European Upper Triassic sections, and 3) occurrence at the same level as a stable isotopic excursion of $\delta^{13}C_{org}$, a global marker of the end-Triassic extinction

(Hesselbo et al., 2002, 2004). It is the combined manifestation of all of the listed aspects that is used to interpret the Cotham Marble microbialites as previously overlooked, yet relevant, geobiological sedimentary archives intimately associated with the events of the end-Triassic. Therefore, the geochemical and biological changes observed across the Tethys realm during the Late Triassic are captured in the Cotham Marble despite any putative environmental restriction that may or may not have existed.

The issues surrounding the abrupt faunal and facies changes recorded in the Upper Cotham Member (including depositional setting) have been discussed elsewhere (Radley et al., 2008). In light of that and other discussions, it is clear the depositional setting of the Cotham and Langport Members continues to be disputed (Hallam et al., 2004; Radley et al., 2008). We demonstrate the Cotham Marble itself, upon initiation of the first dendrolitic phase, contains conflicting evidence of depositional conditions by the presence of echinoderm fragments (stenohaline conditions) and calcite pseudomorphs after gypsum (desiccation) (Figure 3E-D in Ibarra et al., 2014) and thus state on page 2 that the depositional setting is interpreted as a shallow coastal environment that alternated between periods of restriction and connection to open marine waters.

Presence of *Tasmanites*

Mayall and Wright ask for clarification as to the lateral extent of the organic-walled putative 'disaster taxon' *Tasmanites*. All of the samples we investigated contained organic-walled microfossils we interpret as *Tasmanites*; the northernmost site we investigated is Lower Woods and the southernmost site is Charton Bay (Fig. 2), a range of ~100 km.

THE ROLE OF *MICROTUBUS* IN FORMING THE COTHAM MARBLE

Mayall and Wright demonstrate notable examples of *Microtubus* in their Figures 2-3. However, the samples that were the subject of investigation in Ibarra et al. (2014) have a mesostructure distinct from those shown in Figure 2 of Mayall and Wright. Perhaps the reason for the 'reduced form' of the Cotham Marble figured by Mayall and Wright is because *Microtubus* may have inhibited the development of the 'typical' dendrolitic structures of the Cotham Marble rather than promoting them, as originally proposed by Wright and Mayall (1981). On page 8 of Ibarra et al. (2014), it is stated that 'we found *Microtubus* to be a significant component of the microbialites only in our sample from Pinhay Bay' but it is not implied that *Microtubus* is completely absent in the northern sections. Figures 10B-C in Ibarra et al. (2014) contain tubular structures typical of *Microtubus* (and see also Figure 3, with examples of *Microtubus* from Bristol samples).

What we wished to clarify in Ibarra et al. (2014) is that *Microtubus* is not *necessary* for the formation of the dendrolitic phases. For example, Figure 3 illustrates only a marginal presence of *Microtubus* in a typically figured example of the 'arborescent' structures. Notice that most of the spar-filled ovoid structures are the result of evenly spaced microbial mat branching, which can manifest as round structures when viewed in only two dimensions. While *Microtubus* is present in the samples collected near Bristol (Fig. 3) and across the region, the tubular microfossil is not intimately associated with the dendrolitic structures, ruling out 'a *Microtubus*-algal association' giving rise to the dendrolitic phases. The structures in Figure 14C-D of Ibarra et al. (2014) are irregularly shaped, vary in size, and do not have the same micritic wall of *Microtubus* shown in Figure 14A.

The reason why this observation and distinction is significant is because the Cotham Marble is an exceptionally preserved example of the ways in which microbial mats can grow into intricate patterns, leaving behind evenly spaced cavities (now filled with calcite cement) that can resemble burrows and other tubular fossils. The similarity in size and shape of the various spar-filled ovoid structures of the Cotham Marble dendrolites is deceptive (Fig. 14 in Ibarra et al., 2014), and in most instances will require the use of multiple slabs along several orientations together with petrographic study to decipher taxonomic differences.

ADDITIONAL COMMENTS

Mayall and Wright feel that a minor injustice has been done when discussing their interpretation of the 'hedge' features. We simply highlight that the clumping of microbes is not the only mechanism that forms structures resembling the 'hedges' of the Cotham Marble. Recently, Mata et al. (2012) showed that the production of gas bubbles within mats can cause microbial filaments to become oriented, providing a potential alternative mechanism for the formation of the 'hedges'.

Mayall and Wright suggest that the application of the term tubestone to the Cotham Marble is incorrect. Citing the definition of tubestones as "laterally continuous stromatolite sheets that enclose and isolate intra-stromatolite depressions filled with sediments" (Corsetti and Grotzinger, 2005, p. 361), they argue the Cotham Marble is not a 'continuous sheet' and therefore not a tubestone. In fact, the key feature of a tubestone (Corsetti and Grotzinger, 2005) is, in plan view, the isolated intra-stromatolite depressions filled with sediment (that is, the "tubes"—hence, the term "tubestone"). Thus, as demonstrated in Figure 4A-B in Ibarra et al. (2014), the Cotham Marble microbialites display a classic tubestone morphology in plan view where the microbialite encloses depressions filled with sediment. Aside from megascopic differences, several diagnostic meso- to microscopic characteristics of tubestone microbialites are consistent with the Cotham Marble's morphology: intradendrolite depressions filled with sediment, a reticulate microbialite network in horizontal cross section, bridging laminae, and shrub textures (Ibarra et al., 2014).

SUMMARY

It seems that Mayall and Wright have overlooked outcrops located south of Bristol and along the Devon coast that contain the 'classic' form of the Cotham Marble (Fig. 1). Although the Cotham Marble is patchy and the unit is morphologically variable, laminated and dendrolitic phases can be traced for at least 100 km (Fig. 1), thus making the microbialite unit, in our opinion, remarkably laterally extensive, encompassing a conservative aerial extent of ~2,000 km^2.

Ibarra et al. (2014) highlight the Cotham Marble's previously unreported lateral extent and the widespread co-occurrence of *Tasmanites*. These observations along with the stratigraphic level at which the Cotham Marble occurs, link the Cotham Marble to the end-Triassic extinction in the southwestern United Kingdom and to other end-Triassic sections across Europe.

The Cotham Marble continues to be known primarily for its 'Landscape-like', dendrolitic features. The paucity of *Microtubus* in the typical dendrolitic 'Landscape' shown in Figure 3 and as explained in Ibarra et al. (2014), reveals that although *Microtubus* is indeed associated with the Cotham Marble, it is not integral to the construction of its iconic dendrolitic phases. The samples shown by Mayall and Wright appear to be an unusual exception and would likely fall under one of the alternate 'forms' (cf. Short, 1903) as they exhibit a reduced dendrolitic morphology, highlighting that unusual occurrences can unintentionally bias broader conclusions. These examples are nonetheless informative in illustrating the vast extent of the enigmatic *Microtubus* in the Upper Cotham Member across the region.

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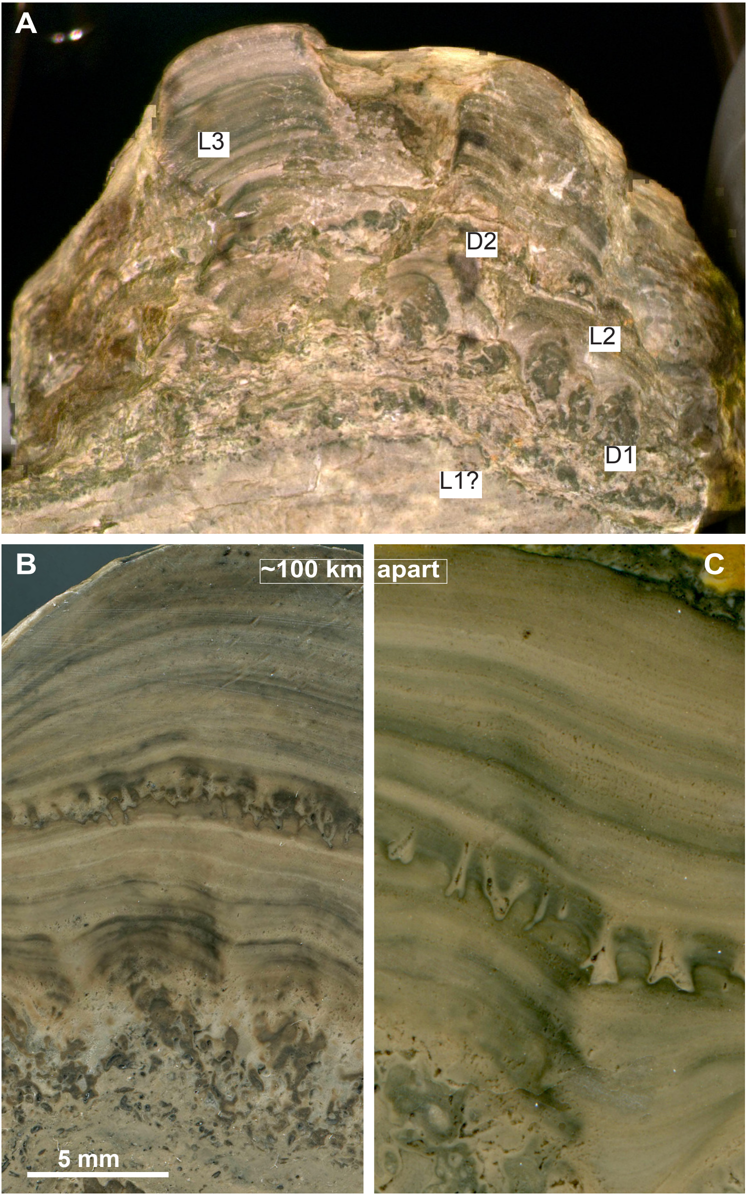
FIGURE CAPTIONS

Fig. 1. —Cotham Marble samples from well outside the Bristol area. **A**) Double 'Landscape' sample from Culverhole Point, Devon, (~85 km south of Bristol) showing the common phases of the Cotham Marble (L=Laminated, D=Dendritic); British Geological Survey sample MR_5769 (the sample is approximately 10 cm across). **B**) Cotham Marble high-resolution scan from Charton Bay (~85 km south of Bristol). **C**) Cotham Marble high-resolution scan from Lower Woods (~20 km north of Bristol).

Fig. 2. —Putative *Tasmanites* microfossils from Charton Bay, Devon. **A**) *Microtubus* and organic-walled microfossils. **B—D**) Arrows denote a thick cell wall and linear sutures typical of *Tasmanites*; scale bar = 20 μm.

Fig. 3. —Dendrolitic phases of the Cotham Marble. **A**) High-resolution scan of the typical 'arborescent' phase of the Cotham Marble; Bristol Museum and Art Gallery, number Cb 4127. **B**) Photomicrograph of dendrolitic structure highlighting the various spar-filled ovoid structures. Samples A and B are from Bristol.


A
L3
D2
L2
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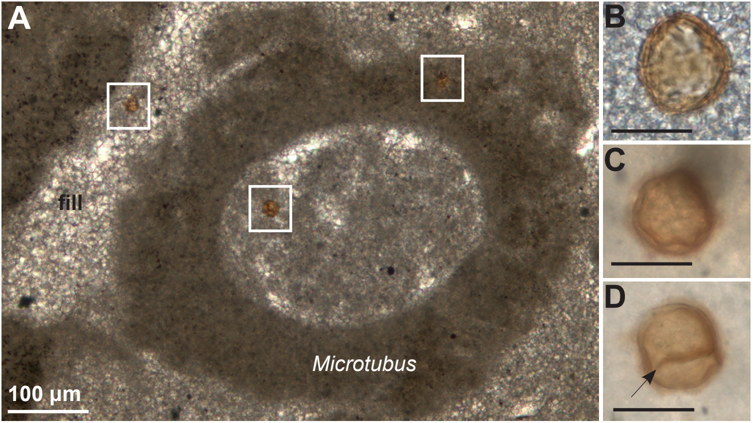
L1?
B
~100 km apart
C
5 mm


A
B
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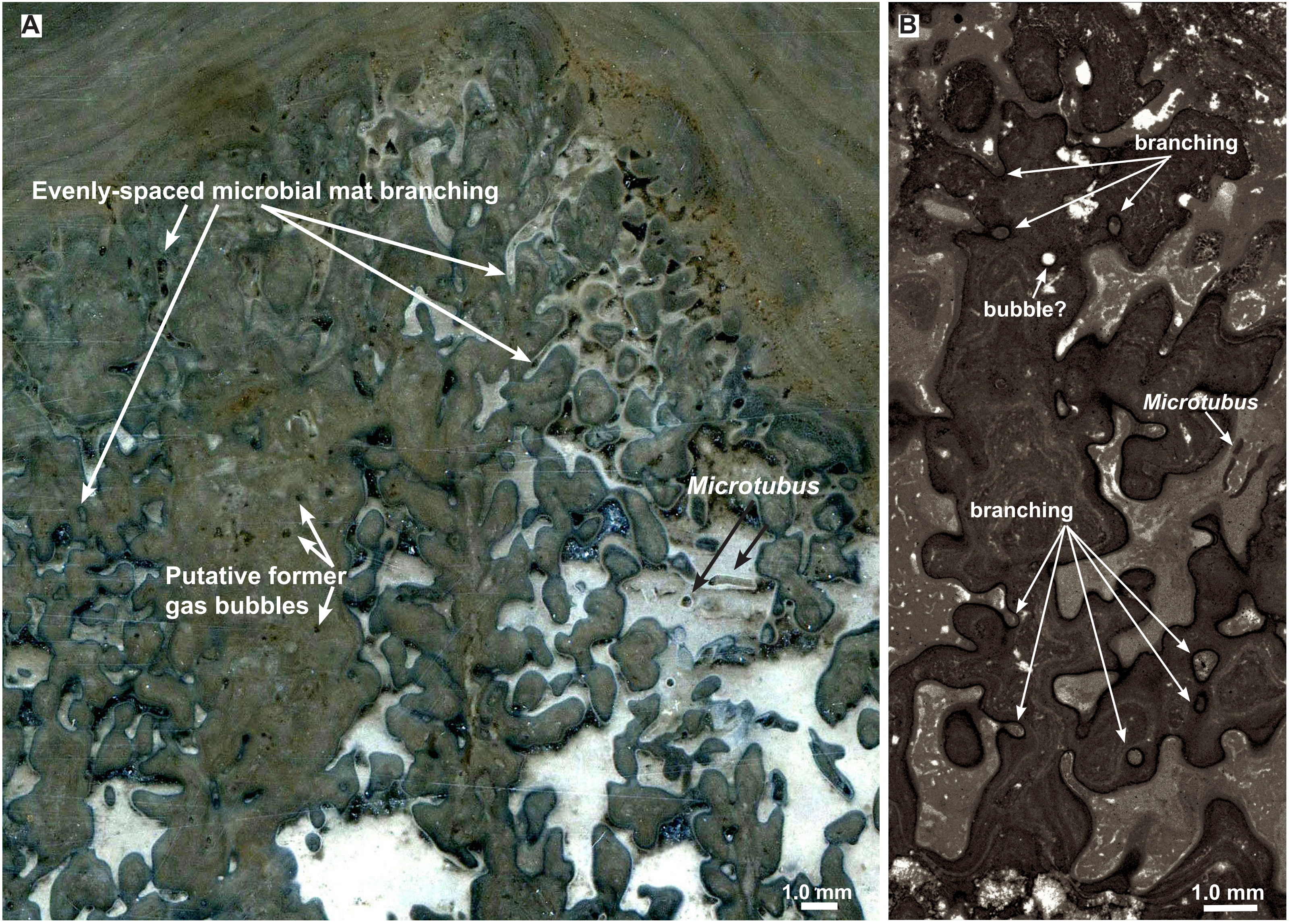
D
fill
Microtubus
100 μm


A
Evenly-spaced microbial mat branching
Microtubus
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1.0 mm
B
branching
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Microtubus
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