Reply to Walkden, Fraser and Simms (2021): The age and formation mechanisms of Late Triassic fissure deposits, Gloucestershire, England: Comments on Mussini, G., Whiteside, D. I., Hildebrandt, C and Benton M.J.

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Supplementary response.

We have answered all the points by Walkden et al. (2021) in the main article in a thematic manner, but we wanted to make sure we also covered their points in sequence of their article as well. There is no doubt that a resolution of the dating of the Late Triassic fissure deposits to the north of Bristol is needed and has been the source of much controversy. The key to our work has been to look for evidence of dating wherever it can be found, and we have sought to discover if definitive Carnian, Norian or Rhaetian fossils are present.

1. '*Introduction*' of Walkden et al. (2021).

In regard to the sentence *'Tytherington Examples … include grey Rhaetian type sediments and a diversity of Rhaetian fossils whereas the Cromhall sediments are mainly green and red Norian types and their architecture is much less chaotic'* we make three points:

1. Has there been a direct lithological or chemical comparison of the green and red sediments at Cromhall with those of the Norian strata of the Mercia Mudstone Group (MMG)? —if not, the supposition lacks any evidence. Evans and Kermack (1994, p. 279) in their comment warning ''against the red is Norian fallacy" recognised the problem of making a spurious judgement of rock age by comparison with the colour of prominent regional and iconic strata. Also, as far as we are aware, the tetrapod genera described from the Cromhall fissure deposits have never been found in any UK Norian continental strata, so the statement is without foundation.
2. Fissure 14 at Tytherington is of the same type (green above red) as Cromhall (Whiteside and Marshall 2008; fig. 10d, e) and the green matrix has an assemblage of a distinctive procolophonid and the rhynchocephalians *Pelecymala*, and *Planocephalosaurus*, characteristic of a number of deposits in Cromhall. It also has *Gyrolepis* (Whiteside and Marshall 2008, fig. 5ll) and gastropod steinkerns and the lower red matrix yielded a few black lepidosaur bones suggesting they had originated in an anaerobic environment.
3. Considering the part of the sentence immediately preceding in Walkden et al. (2021) '*but the Tytherington examples described by Mussini et al. (2020) include grey Rhaetian type sediments...*' In fact, the exposure at 17m of Tytherington fissure 2 described by Mussini et al (2020) is composed overwhelmingly of red-brown or brown sediments. We would add that the rarity or absence of grey types at Cromhall is no guarantee of Norian (or Carnian) age, indeed it can be very misleading. Actually, the absence of evidence generally does not really constitute substantive evidence although it may lead to the seeking of observations that might contradict a hypothesis.

2. '*Late Triassic events*'

We agree that there are important reasons to distinguish the post-transgression faunas from those preceding.

3. '*Setting the challenges*'

We comment on the challenges listed:

1. Walkden et al. (2021) state that we said *'Coeval Rhaetian fish remains are found throughout the faunas recovered at Cromhall.'* That is not what we said in Mussini et al. (2020). Rather, our statement was 'The Durdham Down (Foffa et al., 2014), Cromhall (Whiteside et al., 2016) and Woodleaze (Klein et al., 2015) faunas all have coeval marine fossils, giving consistent evidence of a marine transgression event, which is best explained by a Rhaetian infilling.' The comment by Walkden et al. (2021) is surprising taking into account that Walkden and Fraser (1993) themselves identified a group of basal Penarth Group (PG) marine fish genera associated with *Clevosaurus hudsoni* in the Cromhall Quarry slot fissures and cover sequence! We are emphasising that all those fissure localities have yielded coeval fish fossils (usually teeth); we have never stated that they are found throughout Cromhall (which would not be the case). We consider the finding of coeval Rhaetian teeth in a Cromhall Western fissure below.
2. Mussini et al (2020) emphasised that '*evidence from the presence of* Euestheria brodieana *that sediments that contain* Clevosaurus hudsoni *at Cromhall are equivalent to the upper Rhaetian Cotham Member of the Lilstock Formation*'. This is the specific dating of the red deposits with *Clevosaurus hudsoni* (and associated tetrapods) rather than implying '*a late Rhaetian age for <u>all</u> the Cromhall fissure fills'*, However, we have pointed out that red and green deposits are known from Cotham Member strata in the UK (Morton et al 2017).
3. *'The Cromhall fissures lie at a stratigraphic level above the basal Rhaetian transgression so they cannot be Norian (e.g., Whiteside and Marshall, 2008; Whiteside et al., 2016).'* This overstates our views. Rather, the entrance of the Western fissures at Cromhall lie topographically above the basal Rhaetian, such as the cover sequence identified as such by Walkden et al. (1993), and this suggests that they could have been filled in the Rhaetian. The entrance of Cromhall fissure Site 2 is still 5m above the newly conjectured sub-Westbury Formation (WF) base of Walkden et al. (2021) and thus our suggestion remains essentially correct even if we accept their new analysis (which we don't).
4. *'A contemporaneous Rhaetian freshwater-seawater mixing zone dissolution model, based on Pleistocene and Recent carbonate environments, can be applied to fissure formation in the Carboniferous limestones at Tytherington and Cromhall.'* This statement misses the important issue of the postulated freshwater lens for the Late Triassic limestone islands. Freshwater lenses are frequently present on even tiny modern-day carbonate islands. A mixing zone is a consequence of a freshwater lens surrounded by saline waters and in these zones dissolution of limestone can be very rapid. We have invoked this effect particularly in Fissure 2 Ex 17 (Mussini et al. 2020) and fissure 13 at Tytherington Quarry (Whiteside and Marshall 2021). The evidence is detailed in those two papers and we stand by the suggestion.
5. '*Normal karstic processes cannot operate in deserts so that the fissures at both Cromhall and Tytherington must post date the Norian (Whiteside and Marshall, 2008).'* This was not stated at all in Mussini et al. (2020), nor is that what we said earlier (Whiteside and Marshall 2008). The statement by Whiteside and Marshall (2008), referenced by Walkden et al. (2021, section *5.2.5*), referred to *solutional* carbonate karst of the type at Tytherington with phreatic caverns near the limestone surface and dolines which are not *formed* in deserts. This accords with Webb and White (2013), who remark that karst features in hot deserts are '<u>not</u> because the karst features have <u>formed</u> in the desert environment; in every well-documented case they were developed in earlier wetter periods or by hypogene processes.'

4. 'Late Triassic at Cromhall'

Walkden et al. (2021) provide interpretations of a series of karstic cycles and fills which they link, often by colour comparisons with the Mercia Mudstone Group and particularly the Blue Anchor Formation; e.g., *'perhaps equivalent to the green Mercia Mudstones'.* Walkden et al. (2021, 4.2).

However, Walkden and colleagues provide no palaeontological evidence of Norian or Carnian fossils to back up any of their assertions. Rather, in previous papers they refer to the absence of fossils such as coeval fish and palynomorphs. Therefore, there is no confirmation of any of their suggested Carnian or Norian sedimentary interpretations for cycles 1 and 2.

In cycle 3 and the unconformity they report the presence of 'Late Triassic fish' in Cycle 3 (8m below the limestone surface) and in the unconformity. However, they do not state what the Late Triassic fish are, despite pointing out that it means a standing body of water in the locality. Can the fish be identified and compared with other UK Late Triassic forms? In the unconformity, Walkden et al. (2021, 4.4) refer to a 'sparse fauna' including coeval fish but previously they had designated this (Walkden and Fraser 1993, pp. 585, 586) as a '*rich fish fauna*', '*dominated by fish remains'* so there is some discrepancy here; Fraser (1994) described the fossils as *'abundant fish fragments.'* Moreover, they do not name the genera in Walkden et al. (2021) but did so in Walkden and Fraser (1993) and referenced them (Walkden and Fraser 1993, p. 590) to *marginal facies of the 'Rhaetic' sea and a lateral equivalent of the Bone Bed'* not just to consistency '*with a marginal marine environment.'* Fraser (1994, 219) was emphatic, stating in respect to the slot fissures and cover sequence, that '*the youngest sediments at Cromhall can be assigned with some certainty to the basal Penarth Group (Westbury Formation)*'.

There is another discrepancy between the descriptions of the sedimentary sequences of Walkden and Fraser (1993) and the current submission of Walkden et al. (2021). Walkden and Fraser (1993, p. 276) refer to an *in-situ* lens which is cf. a stromatolite similar to those of the Cotham Marble but lies 9 m deep in fissure S3. It is unclear how this fits into their system of cycles; it presumably features as 'dendritic algae' and is referred to as 'probably Norian'. Where are there other Norian stromatolites, particularly dendritic ones, in the UK? Walkden et al. (2021) also refer to a top fill of fenestral ('cyanobacterial mat') limestone in fissure site 1 (a microbial mat limestone is also present in the 'unconformity' or cover sequence) but do not explore any comparison of microbial mats within UK Late Triassic strata. For example, Fox et al. (2020) report widespread microbial-mats in the late Cotham Mbr. during a sea-level fall (lowstand) in this region of the SW UK.

5. *'Addressing the challenges':*

5.1 *'Contouring the sub-Westbury transgression'*

The Walkden et al. (2021) palaeogeographic analysis is equivocal because their baseline data are highly variable; for example, the closest 'boundary sampled' of the WF to Cromhall lies at 64 m (11 m below the conjectured sub-WF base) whilst the next nearest is 82 m (Walkden et al., 2021, table 1, locations 3 and 4), a difference in height of 18 m. Further, there is a lack of equivalence in the baselines chosen for the Walkden et al. (2021) calculations; e.g., location 11 is written as 'proven Rhaetian bone Bed', but location 10 is identified as the 'basal Rhaetian' and others such as location 12 as 'basal Penarth Group'. In any case, a sub-Westbury base is not basal Rhaetian, and this means that the approach cannot eliminate the postulated Tytherington and Cromhall Rhaetian palaeo-islands (with their tetrapods) from the start of the transgression.

In a new study (manuscript submitted), preliminarily summarised by Lovegrove (2019), we apply computational GIS methods including boreholes, mapped geological contacts and stratigraphic sections from the literature to generate a detailed 3D map of the region, and this contradicts the suggestion by Walkden et al. (2021, section 5.2.4) that "any surviving island after the transgression would have been insignificant and short lived". In fact, the new GIS work shows that Tytherington and Cromhall were islands in the early Rhaetian, and the latter persisted into the late Rhaetian.
We return to the cover sequence at Cromhall Quarry which was regarded 'with some certainty as basal PG' (Fraser 1994). This is now apparently considered pre-Rhaetian (not even pre-WF) by

Walkden et al. (2021). However, Walkden et al. fail to explain how their original palaeontological analysis fits with the reassigned time frame. They present no evidence of a comparison of this ichthyofauna and UK MMG or PG fish assemblages; without such an analysis their argument becomes circular and self-fulfilling. The ichthyofauna described by Walkden and Fraser (1993) is a good fit for the WF fish assemblages described by Mears et al. (2016) from the nearby Hampstead Farm Quarry, so if they were correctly ascribed by Walkden and Fraser (1993) and Fraser (1994) it would make their suggestion (Walkden et al. 2021) of a 75m sub-WF base nonsensical.

N.B. see 5.2.3 for further comments

5.2. *'The assertions discussed'*

Assertion 5.2.1. '*There are Coeval Rhaetian fish remains at Cromhall'.*

Walkden et al. (2021) state: '*The notion that amongst the many thousands of bone fragments recovered from vertebrate bearing deposits at Cromhall are fish remains representing a coeval marine Rhaetian fauna (Mussini et al., 2020) has persisted for more than a decade (e.g., Whiteside and Marshall, 2008; Whiteside et al., 2016; Morton et al., 2017).'* It is certainly true that we have additionally referenced the finding of small gyrolepidiform fish teeth from one site in Cromhall by Mike Curtis (pers. comm.) who recovered specimens from a green crinoidal rock containing *Planocephalosaurus* from Site 4 at Cromhall. The preservation of the 14 fish teeth is the same as the *Planocephalosaurus* (including a part maxilla) so there seems little doubt that they are from the same assemblage. Mike Curtis was a very careful collector, as witnessed by his detailed notes and painstaking and meticulous preparations of slides held by the Bristol City Museum (BRSMG). The specimens are BRSMG Cc 6087. Walkden et al. (2021) dismiss these, even though they have apparently never seen them.

They further state: *'…but it would still prove nothing as regards the age of the faunas that were securely locked into the recemented crinoid debris and thus impossible to contaminate. Instead, any such finds would co-date the later coeval fish-bearing dissolution slots beneath the unconformity on the east side of the quarry.'* So, if the debris is impossible to contaminate then why are they not coeval? We do not understand why such a find would *'co-date the later co-eval fish-bearing dissolution slots*' as that assumes that all such fossils are the same age. Furthermore, it suggests that the coeval fish dating of the slot fissures and cover sequence is not open to any debate from which we would demur. Gyrolepidiform teeth are found throughout the Rhaetian so we assign no specific date, but the presence of such fish teeth implies a nearby marine environment and therefore most likely Rhaetian. We would re-iterate the statement above that gyrolepidiform teeth have been found with a *Planocephalosaurus* assemblage in a green matrix in fissure 14 at Tytherington so that is a feature in common between the two localities.

The original mention of the BRSMG Cc 6087 specimens was in Whiteside and Marshall (2008), but this was either overlooked or not considered by Behan et al. (2012). We have never *'dismissed'* Behan et al. (2012) but considered it and presented counter evidence to its conclusions in Whiteside et al. (2016).

Assertion 5.2.2 '*Finds of Euestheria suggest a Late Rhaetian for the Cromhall fissure deposits.'*

To put into context the research on *Euestheria*, it is important to note that its presence at Cromhall was mentioned by Robinson (1957) and DIW had seen specimens in the BRSUG collection whilst studying for his thesis (1983). In journals kept by Tom Fry (employed by Professor W.F. Whittard of Bristol University who had first-hand knowledge of the original site) now held at the BRSMG, it is clear he collected specimens of *Euestheria* in 1947 and 1949 from the site of the original discovery of

Clevosaurus hudsoni by Hudson and described by Swinton (1939). Whittard gave all remaining *C. hudsoni* finds from pre-1939 to Pamela L. Robinson. From 1950 onwards, Robinson collected many specimens, including articulated *C. hudsoni* from a new excavation which is drawn as an extension of site 2 by Robinson (1957) and could be connected to site 1 of Walkden and Fraser (1993). In her field book held at the NHMUK she noted a number of collections of 'Estheria' (= *Euestheria*) from the same collecting site as the tetrapods. Those specimens are held at the NHMUK as detailed in Morton et al. (2017).

The Cromhall *Euestheria* have been convincingly identified as *E. brodieana* (Morton et al. 2017). Kozur & Weems (2007, 2010) identified a conchostracan zone based on the occurrence of this species in the late Rhaetian; Weems and Lucas (2015) re-emphasised the species as the marker of a conchostracan zone in the late Rhaetian, and it is regarded as restricted to the Cotham Member in the UK by Boomer et al. (1999).

The many specimens of *Euestheria brodieana* and *Clevosaurus hudsoni* collected by Fry and Robinson are found in a distinctly red matrix (see Morton et al. 2017, fig. 12 a–c and O'Brien et al. 2018, fig. 3a). Therefore, they are not the same as the matrix containing *C. hudsoni* of site 1 which Fraser (1988, p. 129) described as 'buff'. Yet the finding of a late Rhaetian conchostracan in a red matrix does not particularly concern Walkden et al. (2021); presumably because it is red it must be Norian? It is worth noting here that the Cromhall Quarry specimens of *Euestheria brodieana* are morphometrically most similar (based on all UK comparisons) to the nearby Almondsbury Cotham Member strata (Morton et al. 2017).

Nevertheless, Walkden et al. (2021) state,*' In short, the Robinson (1957) material, the cyanobacterial mat at Site 1 and the unconformable Late Triassic sediments all yield Clevosaurus hudsoni and offer a hint of the sea, and* ***hence they might share the same late Rhaetian date*** *suggested by Morton et al. (2017) using* Euestheria*.'* They appear to accept that this *Clevosaurus hudsoni* material could therefore be late Rhaetian which is a new (and welcome) statement and would take (at least some of) the Cromhall fills (including the slot fissures) up to the late Rhaetian as proposed by Morton et al. (2017).

However, Walkden et al (2021) then state '*but if the Cotham Member is present at Cromhall, then the easily recognised dark organic-rich Westbury Formation should lie beneath it (as on the sub-Westbury surface at Chipping Sodbury; Mears et al., 2016) which is not the case. An upper Rhaetian date for any deposits at Cromhall is unlikely on these simple stratigraphic grounds.*' This suggests a pre-conceived notion about the fissures (e.g., they had formed earlier and therefore would have been available to capture sediment from the Westbury Formation from the limestone surface). These fissure deposits are terrestrial and we would ask whether Walkden et al. (2021) discounted any notion that these particular fissures (with the *E. brodieana* in a red matrix) could have (to a significant extent) formed and infilled in any regressive phase of the middle Rhaetian or all within the Cotham Member? If there is a *'hint of the sea'* (and putting aside Walkden et al.'s 2021 newly conjectured 75 m sub-WF base) why can the cover not be younger than the most basal Penarth Group? Are there any *definitive* early Rhaetian fossils on the Carboniferous Limestone surface or capping the fissures in the west of the Quarry? Are there any fossils in the fissure deposits in the West of the quarry that are unambiguously pre-Rhaetian or at least pre-Penarth Group?

Assertion 5.2.3. '*The tops of the Cromhall fissures lie above the level of the Cromhall unconformity and so post-date it.'*

Walkden et al. (2021) state: *Although it would prove nothing as regards the age of the fissure deposits, this is another misapprehension and the true relationship is the other way around. Our topographical investigations (table 1 and fig. 1) reveal that, at 65-68 m, the tops of the fissures in question at Cromhall are below the level of the unconformity surface that lies between 70-74 m.'* We used the 1993 very detailed Cromhall Quarry map (Fig. 1 of our main response paper) professionally surveyed by the Quarry owners Amey Roadstone Corporation to make our suggestions in Whiteside and Marshall (2008) and Whiteside et al. (2016). This shows spot heights of 80.4 m next to site 2 and 74.9 m next to site 1 and a range of 73.2–73.7 m for the top of the cover sequence of Walkden and Fraser (1993). Also, our Ordnance survey digimap© (which Walkden et al. 2021 stated they consulted for accuracy) demonstrates (Fig. 1) that the 75 m contour runs along the top of the Western Quarry face at the entrances to the key fissures 1–7 (of Walkden and Fraser 1993) *c.* 5 m above the height of the slot fissures and base of the cover in the position detailed in the sketch map of Walkden and Fraser (1993). Note also that the 80 m contour on the OS map runs very close to fissure site S1 (see main response paper Fig. 1A). So, we have the comparisons the right way round. Walkden et al.'s (2021) statement that *'it would prove nothing as regards the age of the fissure deposits,'* is puzzling as such mapping approaches used by Robinson (1957) for Emborough were cited by Fraser et al. (1985) to suggest that mammal teeth they found in that Quarry were the earliest therians known.

Walkden et al. (2021) further state: *'The Westbury Formation flooding surface undoubtedly overtopped Cromhall (Fig. 1) and at c. 75 m (see 5.1) it was well above the base of the Cromhall 'cover' wedge noted above.* There is a great range of at least 18 m between the heights of the three nearest basal Penarth Group (PG) outcrops topographically using the data of Walkden et al. (2021, table 1). Furthermore, in each PG locality (Fig. 2) there are lower topographical areas in close proximity, up to 3 m lower. The nearest Rhaetian (= PG) outcrop (Fig. 2) on the digimap lies as low as 61–62 m. We have remeasured some of the distances (Table 1) given in Walkden et al. (2021, table 1) and found that measuring from fissures S6 (and S2) and relative distances from the PG outcrops results in a greater differential with the nearest about 60-70% closer than the next nearest. We do not put any great emphasis on this except to comment that it is clear that sophisticated mapping is needed to decide the landscape in the Rhaetian in this area. This is a project that we are close to completing. However, Walkden et al.'s (2021) use of a 'projected' 75 m is an estimation and in contrast to the lowest actual figure for the nearest PG base, is about 64 m as given by Walkden et al. (2021). Walkden et al. (2021) used the nearest Penarth Group outcrop to calculate their Tytherington island (see their assertion 4 section) so why use others (Walkden et al. 2021, table 1) here to therefore effectively raise the possible minimum base of the Penarth Group over Cromhall Quarry? Why the inconsistency in approach? At 64 m the level of the Lower Penarth Group over Cromhall would mean all the fissures were well above a sub-Westbury base. It is a lot lower than the 75 m (presumably based on an average of the nearest Rhaetian sites) that Walkden et al. (2021) prefer to use and would make all the Cromhall fissures including the slot fissures almost certainly open into the Penarth Group and therefore Rhaetian. For consistency, Whiteside et al. (2016) always gave greatest regard to the nearest Rhaetian deposit to the fissure entrances to produce their figures which in this case was the '*lateral equivalent to the Bone Bed*' cover sequence of Walkden and Fraser (1993, p. 590) and endorsed by Fraser (1994).

Walkden et al. (2021) now consider that their cover sequence might not even be Rhaetian and is possibly pre-Rhaetian stating that the '*Cromhall 'cover' sequence might easily be of pretransgressive Blue Anchor Formation age but it certainly predates the sub-Westbury transgression, further reinforcing the likely age of the fissure deposits beneath the unconformity as pre-Rhaetian.'* In the slot fissures and cover Walkden and Fraser (1993) recorded a number of fossils of fish including *Lissodus*, *Gyrolepis*, *Birgeria*, *Palaeospinax* (=*Synechodus*), *Polyacrodus* and a pholidophoriform (presumably with affinities to *Pholidophorus*). These fish are found in the early and late Rhaetian, particularly in the Westbury Formation (although all are found in Cotham strata). So, currently, these fish fossils do not provide a specific dating within the Rhaetian to the cover sequence but do indicate the presence of nearby marine conditions. It is interesting that faced with the conflict of a conjectured 'projected' sub-Westbury base significantly higher than a bed they previously considered Rhaetian 'with some certainty' (Fraser 1994), Walkden et al. (2021) prefer to abandon their confidence that the cover sequence is basal Penarth Group; now Walkden and colleagues say it had been 'tentatively assigned' which is at odds with the Fraser 1994 declaration.

Assertion 5.2.4: 'A contemporaneous Rhaetian freshwater/ seawater mixing zone dissolution model can be applied at Tytherington'

Walkden et al. (2021) have drawn a Tytherington island as it would have been in the time of the early Westbury Formation. It is very close to those that we have drawn (e.g., Whiteside 1983) so we appreciate their work.

Walkden et al. (2021) then state: *'Mussini et al. (2020) follow the Whiteside and Marshall (2008) model for fissure formation that relegates the role of meteoric-fed conduit development in favour of rapid dissolution at an internal fresh water/marine water phreatic mixing zone interface within an emergent limestone island'.* However, the mixing zone model is particularly in regard to fissure 2 and more specifically the site Ex 17 detailed in Mussini et al. (2020). This model was originally suggested by Whiteside and Robinson (1983) to encompass the Rhaetian mixed marine/terrestrial palynological and tetrapod/fish evidence together with their find of a glauconitic clay with a morphology and chemistry found in euryhaline environments (and therefore indicated mixed fresh/seawater). It was compiled well before any comparison with the Bahamian caves was made. Mussini et al. (2020) expanded our knowledge of the exposure by describing in detail the finding of terrestrial tetrapods with coeval marine fish and marine invertebrates such as gastropod and mollusc steinkerns. They also reported ostracod steinkerns. These results indicated the near presence of marine waters to a terrestrial environment. In other words, the margins of the land and marine waters. The marine components do not infer a specific dating but are all found in the Westbury Formation.

Marshall and Whiteside (2008) considered many features of void formation including dolines and caverns and discussed the contribution of vadose and phreatic conditions. Their model in Whiteside and Marshall (2008, fig. 16) and modified by Mussini et al. (2020, fig. 2 a) clearly shows that meteoric waters flow through freshwater tubes and follow (or sub-follow), as well as cutting across, the dip of the Carboniferous Limestone. Additionally, a doline, which would form in vadose conditions, is arrowed. Whiteside et al. (2016, p. 263) stressed that void formation such as caverns was probably related to the properties of the Black Rock Subgroup limestones at Tytherington and Cromhall (but the Clifton Down Formation Limestone morphology is also important in Cromhall). Therefore, Mussini et al. (2020) and previous authors (Whiteside and Marshall 2008) have suggested a classic karstic formation of the type Walkden et al. refer to.

Simms & Ruffell (1990) argued that because the water catchment area of the Tytherington aquifer is quite small (about 2 km^2), the rainfall needed to produce the 'conduits' such as the fissure 2 cavern must have been high and suggested it was formed in the Carnian. This seems highly implausible if the fissure 2 system particularly at Ex 17 was simply a cave formed by meteoric water alone. How much rain is needed for such a small catchment and when did it form the cave? If it was in the dry Mercia Mudstone Group times it is unlikely and if in the Carnian Pluvial Episode as suggested by Simms and Ruffell (1990) then where is the evidence? Simms and Ruffell (1990) stated that 'infilling must have started very soon after their formation' yet despite much searching for over 40 years no unequivocal Carnian or Norian fossils have been found.

The formation of this fissure 2 cavern at Ex 17 can be better explained by the rapid dissolution that occurs in a mixed freshwater/saline water regime (and the fossils that fill the void indicate they were in such an environment). In this particular case the fissure void effectively closes to a very thin vertical gap which persists to Ex 26 but after that there is no evidence of this fissure to the East or South-East. Furthermore, no fissures of any significant expansion were found on this quarried level as it continued to be worked eastwards. Also, no more Triassic fissure fossils of any kind were found eastwards or south-eastwards of this site on this level (or below). The question therefore arises, if this fissure was formed by meteoric waters only then what happened to those waters after the extremely narrow passages created after Ex 26? We therefore still consider a mixed freshwater/marine water dissolution of the cavern at Ex 17 near the edge of a freshwater lens as the most plausible explanation. Mussini et al. (2020) provided an analysis that demonstrated that the formation and filling of the cavern could be remarkably quick. We did invoke the suggestion that paragenesis was involved in the cavern formation but possibly this was missed by Walkden et al. (2021); paragenesis requires phreatic conditions so a high water-table is required for any cavern formed near the top of the limestone such as those at Cromhall.

Walkden et al. (2021) state: *'Even were conditions favourable, a mixing-zone environment could not have developed at Tytherington until the Rhaetian transgression was well underway, yet a meteoric water lens 15 km wide would be required to drive the mixing zone to a depth of 30 m.'* Theoretically, however, only a freshwater layer of 0.75 m above sea level is required to result in a 30 m depth of freshwater lens according to the Ghyben-Herzberg ratio (assuming a marine water specific gravity of 1.025 and freshwater of 1.000). Also, White and Falkland (2009, fig. 3) show that a limestone island of just 1 km across can have a freshwater lens of up to 20 m with a mixing zone another 12 m deeper. On the tiny (1.2 km across) Buariki island the freshwater lens was measured to a depth of 29 m by Bailey et al. (2008). The Tytherington island calculated by Walkden et al. (2021) is approximately 4.5 X 1.5–2 km and would have been substantially larger at the onset of the Rhaetian transgression. Therefore, the model of Mussini et al. (2020) is quite feasible particularly as the lowest part of the cavern is at 25 m.

Walkden et al. (2021) further remark: *'The mixing zone model is even less viable at Cromhall where the sub-Westbury Formation surface sweeps right over the top, leaving no potential for a Rhaetian island.'* We have already commented that the Quarry map shows a height of 80.4 m at fissure site 2, which is 5 m above Walkden et al.'s (2021) new calculation. The model (Lovegrove 2019, fig. 1C) is that the Cromhall fissure area is exposed as an island in the Westbury and Cotham Member and not inundated as suggested by Walkden et al. (2021). This independent GIS model has confirmed the findings of Whiteside et al. (2016). Even the 'hint of the sea' in the slot fissures and cover would provide the saline water that would sustain a freshwater lens and such lens are very common even on small islands of 270+ m across. If it was marine Rhaetian, then the lens could be expected to be at least 10 m deep which is quite sufficient to provide the phreatic conditions to form the cavern described by Robinson (1957). Of course, the recharge rate from rainwater needs to be taken into account but there are many solutional entrances into the fissures in sites 1–7 of Walkden and Fraser (1993) which indicates there would have been adequate rainfall capture for a lens.

Walkden et al. (2021) expressed doubt about the use of examples from the Bahamian karst to inform our ideas of the development and filling of the Late Triassic fissures. We fully understand that the massive Carboniferous Limestone is quite different than the more porous and much younger limestones that form the Bahamas. Rather, we use the research on the Bahamas to enhance our insight into the UK fissures. It is the Bahamas *setting* of often small limestone islands with a nearby marine environment that is most important. There are invariably freshwater lenses on very small limestone islands and as a consequence phreatic caves can form near the limestone surface by conduit flow (these can also be at some depth) and in the case of flank margin caves by the mixing zone. For example, there are fish living in the Bahamian freshwater pools and phreatic caves can form near the limestone surface. It is also the case that freshwater/seawater mixing zones at the edges of the lenses can result in rapid dissolution of the limestone. The Bahamas also have a history of sea level changes that have affected the karst and fossil lepidosaurs are found in small filled solution holes (Etheridge 1966) rather like some at Tytherington (e.g., fissure 14). We use these examples to illustrate what is possible in a low-lying karst next to the sea. However, although the Carboniferous Limestone fabric was very likely significantly less porous 200 Ma than the Bahamian limestone today, we regard it as extremely likely that a freshwater lens was present in the voids on the Carboniferous Limestone islands of the Late Triassic archipelago around Bristol. This lens model helps to understand the presence of caverns near the limestone surface at Tytherington (fissure 13) and those at Cromhall such as the one described by Robinson (1957). It can also account for the presence of fish skeletons in fissure 13 at Tytherington as well as *Euestheria* in top-level fissure 12 at Tytherington and those described from Cromhall (Morton et al. 2017) between sites 1 and 2. Living conchostracans (cf. *Euestheria*) need standing water for a few weeks to develop as otherwise they will be washed away by running water. The alga *Botryoccocus* found in significant quantities in palynological assemblages in the top-level fissures 13 and 16 at Tytherington (Whiteside and Marshall 2008) also needs standing fresh or brackish water to grow. A freshwater lens can provide this standing water.

A freshwater lens provides water near the limestone surface and thereby a lusher vegetation and a greater abundance of arthropods which all can result in greater numbers and possibly diversity of tetrapods than we find in the fissure deposits.

Assertion 5.2.5. '*Normal karstic processes such a fissure formation cannot operate in deserts'*
Walkden et al. (2021) state: *'The comment by Whiteside and Marshall (2008, p. 131) that 'this sort of karst does not form in deserts'….' apparently overlooks well-documented evidence for significant climatic variability in the Triassic (Simms and Ruffell, 1989, Mueller et al., 2016, Hounslow and Ruffell, 2006)'.* It is puzzling why Walkden et al. (2021) make this reference when there is no mention of desert karst in the Mussini et al. (2020) paper. However, the actual statement by Whiteside and Marshall (2008) was 'The *solutional fissures* could not have been mainly formed during any of the more arid periods of the Permo-Triassic, since this *type of karst* does not form in deserts (Jakucs, 1977)'—the italics are our emphasis. This accords with Webb and White (2013, p403), who remark that karst features in hot deserts are 'not because the karst features have formed in the desert environment; in every well-documented case they were developed in earlier wetter periods or by hypogene processes.'

The previous text in that section of the paper of Whiteside and Marshall (2008) considered the formation of solutional caverns by phreatic activity within 1 m of the limestone surface (suggesting a high-water table) and small (about 2 m across) closed dolines amongst other karstic features. The phreatic cavern was infilled with fossils that included fragmented skeletons of the fish *Pholidophorus* and terrestrial reptiles such as *Clevosaurus* indicating that the fish was living in permanent standing waters on the limestone. It is unlikely that such features were formed in the arid times of the Mercia Mudstone Group as a high-water table would be needed to maintain permanent standing water. Interestingly, also considering Tytherington and Cromhall caves, Simms and Ruffell (1990) accept the low probability of desert formation of the solutional voids, stating *'However, the frequency of occurrence of Triassic cave systems is comparable to or greater than that of recent cave systems, judging by the frequencies with which both Triassic and recent examples are exposed during quarrying (M. J. Simms, personal observation), and is very much higher than in desert regions such as Oman'* - our underlining.

Walkden et al. (2021) then state: *'Whiteside and Marshall (2008, Fig. 9) specifically dismiss the suggestion that the Tytherington systems are conduit karst systems.'* This is simply untrue, Fig. 9 of Whiteside and Marshall (2008) concerns fissure 2 and describes the section at Ex 17 (and Ex 14) as 'a complex development of a short phreatic *tube'* (= conduit; our emphasis); it does not suggest generalisations against the presence of conduit flow at Tytherington. We have already stated that Whiteside and Marshall (2008, fig. 16) and Mussini et al. (2020, fig. 2A) show that phreatic conduits followed the dip and cut across the dip of the Carboniferous Limestone. Further, in both those figures we mark uncertainty about how fissure developed by question marks in the SE and East. Mussini et al. (2020, fig. 2C) shows that the cavern had disappeared so was a localised development.

There was no cavern (or significant Triassic conduit) development eastwards of fissure 2 at this level (or in visits up to 1988 in the levels above or below) just a few narrow joints with brown marl fillings so the '?' on the model queries what happened to the apparent conduit. In fact, there is no sign of it after Ex 26. As Mussini et al. (2020) stated, 'the cavern was a localised development'. We would expect conduit development in the phreatic zone of the postulated Tytherington freshwater lens and that is what Whiteside and Marshall (2008, fig. 16) and Mussini et al. (2020, fig. 2A) show diagrammatically.

Walkden et al. (2021) state: *'The sediment-filled fissures we see now at Tytherington were once open looped vadose to phreatic cave systems, with conduits descending along bedding planes and rising steeply up joints and fractures.'* Whiteside and Marshall (2008) included much discussion of a vadose and phreatic cave contribution to the fissures at Tytherington. Fissures 11, 12, 14 and 16 were all considered to have formed mainly by solution above the water table (i.e., vadose) with some expansion suggesting phreatic conditions at a shallow depth e.g., in fissure 16 (Whiteside and Marshall 2008, fig. 3). Whiteside and Marshall (2008) reported water droplet impressions in fissure 12 which indicated the subaerial conditions noted by Walkden et al. (2021), referencing Simms (1990) viz '*even desiccation cracks indicating long periods of inactivity in the vadose zone'.* The presence of *Euestheria brodieana* in fissure 12 also supports this view that there were long periods of inactivity in the vadose zone. Walkden et al. (2021) make a detailed speculation about what 'may' (their word) have happened to fissure 2 such as *'Truncation of one loop crest, by excavation of the quarry level above, may account for the apparent horizontal disappearance of Tytherington 'fissure 2'.* It does not account for it, as DIW had started his thesis research in summer 1976 and a number of visits had been made previously with R.J.G. Savage from the initial finds of *Thecodontosaurus* bones; no aspect of any substantial (or any noticeable) conduit like the Ex 17 exposure was observed on the second level in this area or eastwards/south eastwards. We have already noted that no conduit was observed in the trend eastwards or south eastwards of fissure 2 on levels 2/3 or on level 4 in visits made in the early-mid 1980s to 2012. We have already suggested the alternative to a vadose interpretation of the lower part of the keyhole shaped fissure 2 at Ex 17 in Whiteside and Marshall (2008) and Mussini et al. (2020) based on the clear joint which can be seen above and below the cavern. We continue to have this view based on the detailed evidence given in Mussini et al. (2020).

Walkden et al. (2021) finally state in this section: *'The lowest cave passages encountered at Tytherington lie more than 30 m below the top of the quarry (Marshall and Whiteside, 2008, Fig. 3) suggesting that they were hydrologically active well before the Rhaetian. This was one of the key lines of evidence for increased humidity during the Carnian Pluvial Episode 1, an interval of widespread climatic and biotic change in the early Late Triassic, (Simms and Ruffell, 1989; 2018), and as such these caves formed in a humid environment rather than the arid one envisaged by Whiteside and Marshall (2008).'* In fact, it was Whiteside (1983) in his thesis who first suggested that the earliest time that these caves could have formed was in a Carnian 'Pluvial Episode' (a phrase he coined on page 40, line 11 of the thesis); Simms read this thesis, citing it in Simms (1990). Marshall and Whiteside (2008, pp. 27–28), far from 'dismissing' any idea of an earlier formation of the Tytherington caves, also considered the possibility of a Carnian time of formation based on evidence of possible vadose notches and the presence of a single *Euestheria minuta* in fissure 4. They came to the view that this evidence was equivocal. There was vastly better evidence considering void morphology, palynology (they had 11 separate samples from 6 sites from at least 6 different lithologies) including mixed terrestrial pollen/marine dinocysts, gastropod steinkerns, coeval fish teeth and scales that the vast bulk (possibly all) of the infills were all Rhaetian. This dating is further supported by the evidence of Westbury Formation fossils recorded in detail from fissure 2 Ex 17 in Mussini et al. (2020).

Walkden et al. (2021) state further: *'Subsequently these cave systems were progressively closed down as sediment levels rose to bury the Carboniferous landscape. Some parts will have clogged with muds and sands whilst others remained open before finally flooding with marine water during the*

Rhaetian transgression’. If Walkden et al. (2021) regard Ex 17 as being formed in the Carnian, then why is there consistency of the fossils (none that can be ascribed to any other dating except the Rhaetian) in the *c.*6 m high infill from the lowest L1 to U10? On their model it would exist for 20 million years with the void unfilled by any Carnian or Norian sediment or fossils despite their noting that these times were biologically productive with tetrapods; this seems most unlikely. Despite our constant searching in many localities and hundreds of fissures for fossils that could be definitively referable to the Norian or Carnian, we have found none, but instead we have found a great abundance of Rhaetian (particularly Westbury Formation) fossils.

5.3. ‘The assertions – resolution and new model’:

Walkden et al. (2021) state: ‘*There is no reason to regard the Cromhall fissures with their mostly well organised terrestrial content as anything other than pre-Rhaetian.’* In fact, as we discussed, they provide no evidence for this suggestion. The only biostratigraphically useful fossils in the Cromhall fissures are some ‘Rhaetian’ coeval fish teeth found by them in their association ‘D’ (Walkden and Fraser 1993, p. 586). However, they now consider them more likely to be earlier. The three most numerous genera of lepidosaurs (*Clevosaurus*, *Diphydontosaurus* and *Planocephalosaurus*) common to Cromhall and Tytherington have all been dated as Rhaetian at Tytherington with palynomorphs and Rhaetian fish fossils (Whiteside and Marshall 2008). We now also know that they co-occur in numbers and association with a variety of marine Penarth Group invertebrates (Mussini et al. 2020).

Walkden et al (2021) then state: *‘Even today voids remain above the sediment fill in places (Simms 1990) and undoubtedly many others existed prior to the Rhaetian transgression or were created through differential subsidence of sediment fills, to then be inundated by the Rhaetian sea.’* We are not sure why this is undoubted; where is there any dateable evidence for this statement? It is simple speculation. Simms (1990) pointed out that Triassic sediments have been washed out by hydrological reactivation during quarrying.

Walkden et al. (2021) go on to state: *‘Applying the mixing zone dissolution model at Tytherington is ingenious but flawed. t is a way of introducing early Rhaetian materials into the Tytherington caves, but it cannot account for many very specific features of these cavities and their fills, so that an alternative model is required.* As explained in ‘assertions’ above, the model fig. 2A in Mussini et al. (2020) accounts well for the vertical (doline-like) passages, the small phreatic tubes, phreatic caves with vadose notches (e.g., fissure 13; Whiteside and Marshall 2008) and large deep-seated caverns such as the Ex 17 of fissure 2. The alternative model of Walkden et al. (2021) has no dateable evidence of any sediments and is simply conjecture.

Continuing, Walkden et al (2021) argue: *‘The existence of a sizeable and persistent island in the Early Rhaetian is easily challenged on topographic and sequence stratigraphic grounds, but the same cannot be said for the ensuing Late Rhaetian, a widely recognised marine lowstand (Hesselbo et al., 2004) might have been the moment for the highest point on the platform to re-emerge. Shallowing around a high point would have led to winnowing and reworking of Early Rhaetian (WF) sediments into the unroofed tops of the Tytherington fissure along with contemporaneous Late Rhaetian material.* It is barely worth commenting on a speculation such as this where no evidence whatsoever is provided. There are for example, no infills where marine WF strata cap the typical red, red-brown, brown, green or yellow Tytherington fissure sediments. As suggested by Whiteside and Marshall (2008), there is a possible Cotham Member infill (Fissure 12) but this does not have anomalous Westbury clasts. There is no other unequivocal evidence of any Upper Penarth Group input into the main fissures (1,2,4, 6, 8 ,9, 10, 11 or 13) at Tytherington.

There is however, widespread evidence of Westbury marine fauna in fissures 1, 2, 6 and 9. Whiteside and Marshall (2008) described Fissure 12 which has the zonal conchostracan *E. brodieana* but also has a distinctive lepidosaur (lepidosaur B) found nowhere else; it may have formed and infilled during the Late Rhaetian lowstand suggested by Hesselbo et al. (2004). The description of *E. brodieana* at Cromhall by Morton et al. (2017) indicates a red deposit of Cotham Member equivalence so this was quite possibly infilled at least partly in the Late Rhaetian lowstand.

Walkden et al. (2021) state: *'Subaerial emergence at this stage cannot be discounted, but prolonged exposure to throughput of oxygenated water would have altered the dark coloured Westbury-type sediments …'* There is certainly evidence of oxidised Westbury sediments e.g., along with the *Thecodontosaurus* breccias (see Whiteside and Marshall 2008, fig. 7h) but these are caused *in situ* by permeating oxygenated water. Near pristine palynomorphs are found (Whiteside and Marshall 2008, fig. 6) in well preserved organic-rich laminae and have no alteration from oxygen damage which infers they were deposited quickly in an anaerobic environment and not reworked. The assemblages include a mixture of marine and terrestrial palynomorphs representing the marginal marine environment described by Marshall and Whiteside (1980).

Walkden et al. (2021) then go on to discuss seismites: '*A striking feature of the Tytherington fills is their chaotic stratigraphy, considerably more so than seen at Cromhall. Pockets of clay, sand, conglomerate and breccia, some slumped or fining upwards, sit alongside more normally bedded units (Mussini et al., 2020, Fig. 2C).'* Walkden et al. (2021), and in previous papers, repeatedly compare the Tytherington and Cromhall deposits and regard the latter as much less chaotic. However, fissure 2 at exposure 17 shows features not dissimilar to Cromhall e.g., Fraser (1985, figs. 7, 10, 12) as both show prominently tilted beds with gravitational slumping and erosive surfaces. Although there is some slumping in the beds in this Tytherington fissure 2 fill it is no more than the slumping in many cavern infills caused by, for example, new sediment input and gravity. The removal of soft sediment in the 5 years of the exposure also led to rocks moving and slumping; as reported by Mussini et al (2020) there was a rock fall in 1980 that terminated the collecting activity. Also, the beds are frequently lens-shaped, and their exposure can give an appearance of slumping. Nevertheless, most of the exposure 17 of fissure 2 comprises horizontal layered beds, cross-bedding and coarse bedding, particularly in the conglomerates (Mussini et al. 2020, fig. 2C) Importantly, Mussini et al. (2020) report consistency of the fauna, with sphenodontians such as *Diphydontosaurus* found from the lowest sample to the highest. There is also coherence in the general findings with a greater proportion of terrestrial fauna in the lower part of the fissure and much more marine input in the main part of the cavern (upper part of the fissure). It should be noted that the marine fauna in the samples consists of very small gastropods, probable bivalve mollusc steinkerns and *Gyrolepis* teeth. Marine Rhaetian sharks are very rare (two specimens) so the marine component likely derives from a very shallow surface water, most likely near-shore littoral.

Walkden et al. (2021) add: *'At Tytherington Fissure 1, Whiteside and Marshall (2008, Figs. 7a-d) noted slumped sediment, fractured calcite and a fallen boulder that had deformed 'Westbury-type' sediment. They attributed the effects to 'earth movements' comparable to synsedimentary deformation in some well-known Cotham member successions both north and south of the area thought by Mayall (1983) to result from earthquakes.'*

Walkden et al. (2021) then refer to a block of 'Westbury' Grey mud and conglomeratic fissure fill collected in 1981 by GW about 25–30 m down in the quarry they suggest is site 1 of Marshall and Whiteside (2021). They then develop an argument that the sediments were moved axially (presumably along a sub-horizontal axis) stating *'The coarser components are angular fragments of disintegrated sediment ranging from grey and green mud and silt to white limestone and pieces crystalline calcite (Fig. 4). They cannot have travelled far.'* Walkden et al (2021) continue: *'We interpret the graded units as the product of shock-induced internal sediment redistribution, and the graded sequence may be a proxy for a small part of the Late Triassic seismicity.'* However, the palynologically dated sequence on the right-hand side of the fissure (Whiteside and Marshall 2008), which also contains at least four repeated graded beds, were shown by Whiteside and Marshall (2008) to range from the Lower Westbury (equivalent to beds 2–3 at Hampstead Farm Quarry, HFQ) to Upper Westbury (beds 7–9, most likely 7, at HFQ). So, there is convincing evidence that the graded beds were formed within the Westbury.

The seismic activity, caused a widening of this section of fissure 1 and it is not surprising that space opened up for the compressed Westbury sediment to fill. This can have come from above where the fallen Carboniferous Limestone block clearly impacts (see Whiteside and Marshall 2008, fig. 7a, b) or from an oblique resultant. However, further exposures of this fissure (before it merges with fissure 2), have horizontally bedded 'Westbury' type sediments (see Whiteside and Marshall 2008, fig. 16) so the slumped bed phenomenon was localised to this part of the fissure with the fallen Carboniferous Limestone Block. Noticeably it only affected the 'Westbury' deposit; there was no sign of any other fissure deposits being disturbed in a similar manner. The seismic activity may have occurred in the Cotham Member as suggested by Whiteside and Marshall (2008) but it may have been at the end of the WF or later than the Cotham Member.

6. 'Conclusions'

Walkden et al. (2021) write: *'A properly argued and fully evidenced case that the Triassic fissure fills at Cromhall all post-date the Norian would be welcome. In its absence we reiterate and reinforce here the evidence that all the Triassic fissure fills at Cromhall Quarry, and likewise significant volumes of the fill material at Tytherington, are of pre-Rhaetian age.'* We have detailed above the evidence that dateable fissure fills at Cromhall are post-Norian including their own original dating (Walkden and Fraser 1993, Fraser 1994) of their association D as basal Westbury Formation. Walkden et al. (2021) provide no analysis of the association D ichthyofauna to demonstrate why it must now be pre-Rhaetian rather than PG, yet it is the same fauna as before. Walkden et al. (2021) and in previous papers have not produced any fossil that is of Norian or Carnian age despite their constant protestations that the Cromhall fissure fills are of this age. Walkden et al. (2021) provide no fossil dated example of any pre-Rhaetian age sediments at Tytherington; rather they simply conjecture in its absence. Marshall and Whiteside (1980), Whiteside (1983), Whiteside and Marshall (2008), Van den Berg et al (2012), Whiteside et al. (2016) and Mussini et al. (2020) have together provided palynological data and evidence from marine and non-marine fish fossils as well as a number of invertebrates (gastropods, ostracods, bivalve molluscs and conchostracans) that all dateable sediments at Tytherington are Penarth Group Rhaetian. Morton et al. (2017) have assigned a date of Late Rhaetian to the red beds that include *Euestheria brodieana* and *Clevosaurus hudsoni* (and associated tetrapods) from the now destroyed fissure that extended from the current Site 2. We would therefore suggest that our case for a post-Rhaetian transgression age for Tytherington and for all palaeontologically dateable deposits at Cromhall is robust whilst Walkden et al. (2021) rely on speculation, particularly their repeated references to the absence of evidence as evidence of absence.

Walkden et al. (2021) then continue: *'Whiteside and Marshall (2008) provide inaccurate estimates for the height of the plane defined by the tops of the Cromhall fissures.'* We have used the detailed Cromhall Quarry map survey compiled by the original quarry company and the 1:5000 OS map of the site to demonstrate that the Western fissures are topographically higher (e.g., >6 m at site 2) than the cover sequence (or unconformity) of Walkden and Fraser (1993); we are therefore correct in our statements. Site 2 is also 5 m above the Walkden et al. (2021) newly conjectured 75 m base of the WF so that remains valid if we accept Walkden and colleagues' new analysis (which we don't.).

The follow-on assertion by Walkden et al. (2021), that *'The interesting finds of* Euestheria (brodieana) *… cannot be used to imply that the fissure and unconformity deposits described by Walkden and Fraser (1993) are also post-Norian, and on sequence stratigraphic grounds this can be dismissed'* can in itself, therefore, be dismissed and the fissure fill with *Clevosaurus hudsoni* can be referable to the Penarth Group with the zonal conchostracan suggesting an equivalence to the Cotham Member, Lilstock Formation.

Walkden et al. (2021) also comment: *'whilst Whiteside et al. (2016) are unjustified in claiming that Behan et al. (2012) overlooked coeval Rhaetian fish species within the pre-unconformity fissure deposits at Cromhall.'* Behan et al. (2012) overlooked the reference (made 4 years earlier) to coeval fish in Whiteside and Marshall (2008) as they did not cite that paper. Whiteside et al. (2016) simply made the point in counter evidence that coeval fish teeth are found with *Planocephalosaurus* from a Cromhall fissure (by Mike Curtis and in the BRSMG collections). Rhaetian (although they now suggest otherwise) coeval fish teeth were found by Walkden and Fraser (1993) with *Clevosaurus* and *Diphydontosaurus* in the slot fissures/ cover sequence at Cromhall Quarry. Notwithstanding those specimens, the absence of any Late Triassic fish teeth in the processing of material by Behan et al. (2012) does not constitute good evidence that the deposits must be Norian or earlier.

Walkden et al. (2021) write further: *'Our modelling of the sub-Westbury transgressive surface shows all but perhaps the highest points on the Tytherington – Cromhall – Wickwar - Barnhill palaeohigh would have been flooded during the Westbury Formation marine highstand. This eliminates the possibility of significant subaerial exposure at Tytherington in the Early Rhaetian with the development of a floating lens of meteoric water sufficiently large for effective Bahamian type marine/meteoric mixing zone dissolution, and the model fails on other counts such as the radically changed diagenetic state of the Carboniferous limestones, their complex stratigraphy and very different geological structure.'* The Tytherington island, even using the Walkden et al. (2021) calculation of area is large enough to maintain a freshwater lens as suggested by Whiteside and Robinson (1983), Whiteside and Marshall (2008) and Mussini et al. (2020). Freshwater lenses are very common on many carbonate islands worldwide, particularly above 1 km width, not just on the Bahamas. Our reference to the Bahamian islands is to the setting of carbonate islands surrounded by warm marine waters rather than specific equivalence of the limestones. The geology of the massive Black Rock Carboniferous Limestone is different to the Bahamas and so the water flow would have been different, and we have shown conduit flow along and across the bedding planes as well as vertical and vadose input on our diagrams (e.g., Mussini et al. 2020, fig. 2A). It is the case though that horizontal passages can persist e.g., the (at least) 17 m passage of fissure 2 figured by Whiteside and Marshall (2008) and Mussini et al. (2020).

The importance of the morphology of the Carboniferous Limestones influencing different types of void formation was also made clear by Whiteside et al. (2016, p. 263). However, the effect of a mixed marine/freshwater environment which would provide enhanced dissolution at the edges of freshwater lenses is considered in our work particularly for fissure 2 Ex 17 where the nature of the cavern and its sedimentary fill suggests that it is in a freshwater/seawater margin. Considering how frequently they occur on modern-day carbonate islands, it is unlikely that a freshwater lens was absent at Cromhall, particularly when they occur on islands of 270 m+ across and there was the 'hint of the sea' suggested by Walkden et al. (2021). We regard these types of freshwater lenses as an entirely plausible model to explain for caverns at Cromhall (such as in Robinson 1957) as they would maintain a high-water table for phreatic voids to form. Walkden et al. (2021) use the paragenesis model of cave formation for caverns in Cromhall but this still requires phreatic conditions (Farrant and Smart 2011) and Walkden et al. (2021) have not provided the data that can show how much rainfall and recharge would be needed to produce such caverns. We have invoked paragenesis as a possible action in the cavern formation of Tytherington fissure 2 Ex 17 where the postulated freshwater lens provides the phreatic conditions.

Walkden et al. (2021) produce a sub-Westbury strata model of around 75 m and therefore report that Cromhall would have been inundated in Penarth Group times. It is unclear to what extent this estimate is actually based on a weighting regarding the proximities of the basal Westbury (and how do they know it is basal?) in the vicinity of Cromhall Quarry. This new calculation conflicts with their previous statements about cover sequence they had regarded as basal Westbury (Walkden and Fraser 1993, Fraser 1994). Rather than re-analyse the association C and D ichthyofauna they prefer to just ignore the anomaly and stick to their Carnian-Norian model and their view that Red and Green Beds are Norian. Rather, their first thought is to dismiss the possibility that they are Rhaetian. Walkden et al. (2021) reference the Cromhall Member lowstand of Hesselbo et al. (2004) to Tytherington but do not consider any possibility that this would apply to the Cromhall Quarry locality in the Latest Triassic such as the continuation of the topographically high fissure S2 into the caverns reported by Robinson (1957). They certainly do not give any serious thought that the *Euestheria brodieana* specimens might indicate a fissure at least infilled (and possibly formed) during that time.

Preliminary findings of our new GIS project on the Carboniferous-Mesozoic unconformity and base of the Rhaetian around Bristol (Lovegrove 2019) suggest that there was an island in the Cromhall Quarry locality during the Westbury Formation and this persisted into the Cotham Member. The size of the island would have been small but freshwater lenses can exist up to 7 m depth on islands of only 270 m wide.

Walkden et al (2021) state their theory of the Tytherington sediments and slumping: *'It was then* (Cotham marine lowstand) *that the fissures became extensively contaminated by Rhaetian material as the sea invaded their tops, introducing new or reworked coeval sediment with a marine fauna.'* Walkden again speculate on happenings without any dateable evidence. They do not present, for example, any dateable Early Cotham sedimentary deposits worked into these conjectured contaminated materials. If the 'Rhaetian sea invaded the tops of the fissures', where is the evidence? —there are no examples at Tytherington of a 'Westbury or Cotham' strata cap on any fissure. In fact, the main grey or black strata is deep in the limestone mainly in tier 3 of the Quarry but two small exposures were on tier 2. We can demonstrate repeated associations between Westbury fossils and terrestrial reptiles with the Westbury fauna (particularly fish teeth and scales) preserved in the same manner as the reptile fossils (as per fissure 2 Ex 17 of Mussini et al. 2020). Those examples are in red-brown, brown or red sediments, not grey or black. Further, for example, we have demonstrated that there are black laminae yielding Early Rhaetian palynomorphs set between red and green layers containing lepidosaur bones (Whiteside and Marshall 2008, fig. 8e).

Mussini et al. (2020) demonstrated clearly that it was a very shallow littoral fauna, not deeper marine fish, that was found in multiple samples with terrestrial reptiles. Walkden et al. (2021) suggest that the land was inundated and then these marine sediments were reworked into the fissure, yet typical sharks from that marine fauna are represented by two specimens out of 1,523 identifiable specimens (>4.600 in all; Mussini et al. 2020). The multiple palynological samples support the model that Tytherington was an island in a time equivalent to the Westbury Formation as all have a mixed terrestrial/marine component. Some have a higher terrestrial palynomorph count and the highest proportion, in a bedded limestone from fissure 16 at Tytherington (Whiteside and Marshall 2008, table 2), dominated by *Ovalipollis* underlay a deposit with *Clevosaurus* and *Diphydontosaurus*. To re-iterate, despite continual research we have not found any proven Norian and Carnian sediments at Tytherington; Walkden et al. (2021) and previously have failed to find any at Cromhall.

Summary

We have summarised this response and presented research challenges to Walkden et al (2021) in our main reply.

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Table 1. The database used for the construction and analysis of the contoured sub-Westbury transgressive surface with amendments and additions (in italics) to include fissure sites 6 and 2.

Location	Distance from Cromhall cover sequence	Distance from Site 6 Cromhall	Distance from Site 2 Cromhall	Grid Reference	Height (OD)	Boundary sampled
1.Cromhall Quarry *(cover sequence)*	0 m	*251 m*	*296 m*	7066 9172	70 m	Base of 'cover' sequence on unconformity
2. Cromhall Quarry *(Site 6)*	*251 m*	0 m	*142 m*	7035 9172	67 m *(75 m on OS digimap)*	Top of limestone bench above Site 6 on west side
3. NW of Cromhall Quarry	757 m	*660 m*	*793m*	7026 9236	64 m	Basal Penarth Group in small outlier on Mercia Mudstones
4. Field W of Poundhouse Farm	796 m *(857 m)*	*1017 m*	*1104 m*	7150 9155	82 m	Base of Penarth Group on limestone
5. Road S of Tortworth Copse	935 m	*1102 m*	*1200 m*	7118 9249	74 m	Base? of Penarth Group on Mercia Mudstones
5b. Near road S of Tortworth Copse	*1186 m*	*1279*	*1354*	*7144 9244*	*70 m*	*Base of Penarth Group on Mercia Mudstones*

Fig. 2. Geological map and rock labels based on BGS digimap© of the strata near Cromhall Quarry including the spot heights cited by Walkden et al (2021). The fissure localities S2 and S6, two more spot heights at 62 m and 70 m, as well as the cover measuring positions are also shown.