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### The Homeric carbon isotope excursion (Silurian) within graptolitic successions on the Midland Platform (Avalonia), UK

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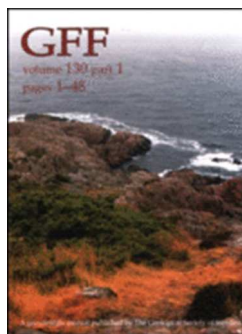
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**The Homeric carbon isotope excursion (Silurian) within graptolitic successions on the Midland Platform (Avalonia), UK: implications for regional and global comparisons and correlations**

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24 **Abstract:** New  $\delta^{13}\text{C}_{\text{carb}}$  data from the most stratigraphically extensive graptolitic  
25 sections of Homeric age in the study area are reported from Wenlock Edge and the  
26 Ludlow Anticline (UK). These sections, situated upon the Midland Platform  
27 (Avalonia), were key in establishing the Homeric graptolite biozonation used within  
28 the type Wenlock Series, and are consequently of international importance. Based  
29 upon 162  $\delta^{13}\text{C}_{\text{carb}}$  samples from four outcrops (Eaton Track, Longville-Stanway Road  
30 Cutting, Burrington Section and Mortimer Forest Stop 1), new graptolite collections  
31 and a re-evaluation of the original graptolite collections, the onset of both lower  
32 (older) and upper (younger) peaks of the Homeric Carbon Isotope Excursion have  
33 been calibrated to a revised graptolite biozonation (*lundgreni* - *nassa* - *praedeubeli*-  
34 *deubeli* - *ludensis* biozones). In addition, high resolution correlation between the  
35 Ludlow Anticline and Wenlock Edge has been achieved by bio-, chemo- and  
36 sequence stratigraphic techniques. These correlations suggest a uniformity of  
37 depositional rates across the study area and indicate minor diachroneity at the base  
38 of the Much Wenlock Limestone Formation. Finally, correlations of the Midland  
39 Platform Homeric Carbon Isotope Excursion have allowed for better comparisons  
40 with other sections from which high-resolution graptolite and carbon isotope data are  
41 available. Such comparisons highlight the pan-regional synchronicity of the  
42 Homeric Carbon Isotope Excursion.  
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47 **Key Words:** Avalonia, Homeric carbon isotope excursion, Midland Platform,  
48 revised graptolite biozonation, Silurian.  
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50  
51 **Introduction**

52 The Silurian is characterized by a highly dynamic, glacially mediated climate,  
53 associated with strong eustatic sea-level fluctuations, marine biodiversity crises and  
54 carbon isotope excursions (Loydell 2007; Calner 2008; Munnecke et al. 2010;  
55 Melchin et al. 2012). There are five prominent Silurian carbon isotope excursions  
56 that are well studied and widely recognised (the sedgwickii Zone excursion of Štorch  
57 & Frýda 2012; and the Ireviken, Mulde, Lau and Klonk carbon isotope excursions of  
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3 Cramer et al. 2011; Saltzman & Thomas 2012). The “Mulde” or Homeric carbon  
4 isotope excursion (CIE) occurs within the Homeric Stage of the Wenlock Series  
5 (Silurian) and is a double-peaked positive CIE. The Homeric CIE has been  
6 recognised from a range of marine depositional settings and from multiple  
7 palaeogeographic regions including Avalonia, Baltica, Laurentia and peri-Gondwana  
8 (Corfield et al. 1992; Porębska et al. 2004; Noble et al. 2005; Cramer et al. 2006;  
9 Calner 2012; Frýda & Frýdová 2014). The lower (older) peak of the Homeric CIE is  
10 associated with marked extinction events (“Big Crisis” or *lundgreni* event impacting  
11 graptolites; and the preceding Mulde Event impacting conodonts) and is well  
12 biostratigraphically constrained by graptolite and conodont occurrences (Cramer et  
13 al. 2012). Above, the upper (younger) peak is less well age constrained, but appears  
14 to occupy much of the remainder of the Homeric and ends close to the Homeric-  
15 Gorstian (Wenlock-Ludlow) boundary (Blain et al. 2016).  
16

17  
18 In spite of the Homeric CIE being among the better age constrained of the  
19 Silurian carbon isotope excursions, it has not been fully documented within the key  
20 graptolitic successions of the Midland Platform of England. Furthermore, the  
21 Homeric of the Midland Platform is of global significance because it was  
22 instrumental in the establishment of the Wenlock Series (Murchison 1872; Holland et  
23 al. 1963; Holland et al. 1969; Bassett et al. 1975; Bassett 1989; Lawson & White,  
24 1989; Aldridge et al. 2000; Davies et al. 2011) and contains the Global boundary  
25 Stratotype Sections and Points (GSSPs) (Melchin et al. 2012). The aim of this article  
26 is to document the presence of the Homeric CIE within the most stratigraphically  
27 extensive graptolitic sections of the Midland Platform, which are developed along  
28 Wenlock Edge (Shropshire) and within the Ludlow Anticline (Shropshire and  
29 Herefordshire). This documentation allows for a comparison of the Homeric CIE  
30 with a revised graptolite biozonation recognised within the type Wenlock succession,  
31 as well as with other graptolite-constrained carbon isotopic records upon other  
32 palaeocontinents.  
33

### 34 35 **Regional lithostratigraphy and biostratigraphy**

36 The Homeric Stage as developed along Wenlock Edge and the Ludlow Anticline  
37 consists of the Coalbrookdale and Much Wenlock Limestone formations. Broadly  
38 these formations show an upward shallowing from shales and nodular limestones of  
39 the Coalbrookdale Formation, to the skeletal limestones of the Much Wenlock  
40 Limestone Formation; representing shallowing from Benthic Assemblage 5 to outer  
41 Benthic Assemblage 1 (Brett et al. 1993), within the north-eastern part of Wenlock  
42 Edge (Ray & Butcher 2010). Variations in relative water-depth are also observable  
43 laterally along the outcrop belt, with the north-eastern part of Wenlock Edge being  
44 relatively shallower than the south-western part of Wenlock Edge and the Ludlow  
45 Anticline. This variation in relative water-depth is most obvious in the Much Wenlock  
46 Limestone Formation along Wenlock Edge. Here the formation may be divided into  
47 reef and off-reef tracts, based upon the presence or absence of coral-stromatoporoid  
48 reefs (Bassett 1989; Ray et al. 2010). Of particular significance is the restriction of  
49 graptolites within the Much Wenlock Limestone Formation to the relatively deeper-  
50 waters of the off-reef tract (Figure 1). Similarly the Coalbrookdale Formation appears  
51 more graptolitic within the south-western part of the outcrop-belt, indicating a  
52 deepening of the platform towards its margin with the Welsh Basin in the west.  
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### 56 **FIGURE 1 HEREBOUTS**

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Figure 1. An outcrop map of the Much Wenlock Limestone Formation (thick black band) and Coalbrookdale (CF) Formation showing the location of key sections and facies belts along Wenlock Edge and the Ludlow Anticline. BEQ, Benthall Edge Quarry (SJ 664 034); LQS, Lea South Quarry (SO 594 982); MF, Mortimer Forest stops 1 to 3 (SO 471 730 to SO 472 730); GR, Goggin Road (SO 472 719).

The Eaton Track (SO 5016 8999), Longville-Stanway Road Cutting (SO 5397 9270) and Burrington Section (SO 4439 7241 to SO 4417 7257) are of importance as a result of them being stratigraphically extensive, containing important lithostratigraphic boundaries and key graptolite occurrences (Figures 1 and 2); features instrumental in the establishment of the upper Wenlock Series (Homerian). In particular, the graptolite occurrences documented in Holland et al. (1969) and Bassett et al. (1975) originally allowed for the classic tripartite graptolite subdivision of the Homerian into the *lundgreni*, *nassa* and *ludensis* biozones (Bassett 1989; Zalasiewicz et al. 2009) and now, based upon a reassessment of the same graptolites, enable a revised subdivision into the *lundgreni*, *nassa*, *praedeubeli-deubeli* and *ludensis* biozones. Such features make these sections ideal for the identification and biostratigraphic calibration of the Homerian CIE within the type Wenlock area, and allow for comparison with other successions across Avalonia and beyond.

## FIGURE 2 HEREABOUTS

Figure 2. Location maps for Eaton Track (A), the Longville-Stanway Road Cutting (B) and Burrington Section (C) identifying key geologic features, carbon isotopic sampling intervals (thick grey line) and the biostratigraphy locations (Loc.) from Holland et al. (1963) and Bassett et al. (1975). TP46 and TP47 correspond to numbered telegraph poles at the Burrington Section.

### A reassessment of the middle to upper Homerian graptolite biozonation

The middle to upper Homerian graptolites of the Ludlow district were described and illustrated by Holland et al. (1969), whilst those of the type Wenlock area (which includes the Eaton track and Longville-Stanway road sections discussed herein) were listed in Bassett et al. (1975). At the time of these publications there was a tripartite graptolite biozonal division of the Homerian, with the *Cyrtograptus lundgreni* Biozone succeeded by the *Gothograptus nassa* Biozone and this in turn by the *Colonograptus ludensis* Biozone. Subsequently, Jaeger (in Barca & Jaeger 1990) erected a new species *Colonograptus praedeubeli*, which can be distinguished from *C. ludensis* by its lesser dorso-ventral width and generally longer sicula. The first appearance of *C. praedeubeli* precedes that of *C. ludensis* and, as a result, the upper Homerian (post-*nassa* Biozone) is now routinely divided into a lower *praedeubeli-deubeli* Biozone overlain by the *ludensis* Biozone (Loydell 2012).

For the present work additional graptolite material has been collected from the Burrington area and the figures in Holland et al. (1969) re-assessed. In addition, the Wenlock Edge specimens of Bassett et al. (1975), housed in the Sedgwick Museum of Earth Sciences, Cambridge, have been re-examined.

*Gothograptus nassa* was recorded from a surprisingly low stratigraphical level (within the Apedale Member of the Coalbrookdale Formation) from the Eaton track section by Bassett et al. (1975). The specimens concerned are small fragments, lacking the dense reticulum and apertural hoods characteristic of *G. nassa*. They are

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3 indeterminate, but presumably belong instead to one of the numerous retiolitid  
4 species recorded from the *lundgreni* Biozone. *Gothograptus nassa* is present in the  
5 section (Figure 3A), however, from Location 25, close to the base of the Farley  
6 Member (Coalbrookdale Formation) at the highest level to yield graptolites from this  
7 section.

8 Bassett et al. (1975) recorded *Colonograptus ludensis* (and cf. *ludensis*) from  
9 four localities along the Longville-Stanway road cutting, one high in the Farley  
10 Member, the other three within the Much Wenlock Limestone Formation. *C. ludensis*  
11 is not, however, present in the collections, with the identifiable specimens being *C.*  
12 *praedeubeli* (Figure 3B, D). This is accompanied by *C. deubeli* (Figure 3C) in the  
13 lower two collections. These four collections can be assigned to the *praedeubeli-*  
14 *deubeli* Biozone.

15  
16 Holland et al. (1969, text-fig. 4) recorded *C. ludensis* from localities assigned  
17 to the "Wenlock Shale" (= Coalbrookdale Formation) in the Burrington area, west of  
18 Ludlow. All *Colonograptus* specimens collected from localities 114B and 61 (the  
19 latter in the Burrington section discussed herein) can be assigned to *C. praedeubeli*  
20 (which is common) or *C. deubeli* (which is less common). The specimen illustrated  
21 by Holland et al. (1969, pl. 130, fig. 2, text-fig. 2a) from Location 61 is also, based on  
22 its narrow, slowly widening rhabdosome, clearly *C. praedeubeli*. Location 62 yielded  
23 a new species, *Holoretiolites lawsoni*, to Holland et al. (1969). Now assigned to  
24 *Spinograptus*, the species is shown as restricted to the lower part of the *praedeubeli-*  
25 *deubeli* Biozone by Kozłowska et al. (2013). A broader *Colonograptus* proximal end  
26 (Holland et al. 1969, text-fig. 2g, h), which can be assigned to *C. ludensis*, is from  
27 Location 41, at the base of the Much Wenlock Limestone Formation, which is shown  
28 by Holland et al. (1969, text-fig. 4) to be stratigraphically just below the level of  
29 Burrington Location 63. The presence of *C. deubeli* at Location 114D, slightly higher  
30 in the formation, indicates a level no higher than the middle of the *ludensis* Biozone  
31 (Koren' & Urbanek 1994; Lenz 1995).  
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34

### 35 **FIGURE 3 HEREBOUTS**

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37 Figure 3. Biostratigraphically important graptolites from the Eaton track and  
38 Longville-Stanway road sections. Locality numbers are those of Bassett et al. (1975)  
39 as used also on figures 2 and 4. All specimens are housed in the Sedgwick Museum  
40 of Earth Sciences, Cambridge. Scale bar represents 1 mm. A. *Gothograptus nassa*  
41 (Holm), SM A. 80195, Location 25. B, D. *Colonograptus praedeubeli* (Jaeger, in  
42 Barca & Jaeger): B. SM A. 80063, Location 50; D. SM A. 80067a, Location 49. C.  
43 *Colonograptus praedeubeli* (Jaeger), SM A. 80073, Location 47.  
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### 48 **Eaton Track lithostratigraphy and biostratigraphy**

49 The Eaton Track section in the hamlet of Eaton is near the base of the Wenlock  
50 Edge escarpment. The section contains the upper Coalbrookdale Formation, the  
51 boundary between its constituent members (Apedale and Farley members) and the  
52 boundary between the *lundgreni* and *nassa* biozones. In total Eaton Track contains  
53 c. 54 m of the Coalbrookdale Formation, but vegetation and soil cover obscure much  
54 of the succession and make accurate estimates of thickness difficult. As a result of  
55 such difficulties, carbon isotopic sampling has focused upon the upper part of the  
56 track (c. 20.5 m) which contains the key biozone and lithostratigraphic boundaries  
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(Figure 4); the lower half of the succession has been sampled less extensively. The carbon isotopic results described herein are derived from graptolite sampling locations 19 to 25 of Bassett et al. (1975), and a large cliff section between locations 20 and 21. The succession is of international significance in that it was put forward as the stratotype for the base of the Gleedon Chronozone of the Homeric Stage, at a position coincident with boundary between the *lundgreni* and *nassa* biozones (Bassett et al. 1975; Bassett 1989; Aldridge et al. 2000). Here the base of the *nassa* Biozone is marked by the disappearance of *Monograptus flemingii* within sampling location 24 (Bassett et al. 1975). Above, the boundary between the Apedale and Farley members occurs within sampling location 25 (Bassett et al. 1975) and is associated with the appearance of frequent nodular limestone (carbonate mudstone) beds separated by shales; gradational over a few metres. The first appearance of *Gothograptus nassa* is within location 25. The top of the current exposure is within the lower Farley Member and contains the lower of the two thin bentonites noted by Ray et al. (2010, p. 132).

#### FIGURE 4 HEREBOUTS

Figure 4. Eaton Track (SO 5016 8999) and Longville-Stanway Road Cutting (SO 5397 9270) sections showing the likely position of graptolite collections (from Bassett et al. 1975), graptolite and conodont biozonation, lithostratigraphy, general sedimentology including marker bentonites (MB), and carbon isotopic sampling locations and values. PS9 and PS10 relates to the position of the boundary between the parasequences of Ray et al. (2010). a. graptolite biozones; b. conodont biozones; c. formations; d. members.

#### Longville-Stanway Road Cutting lithostratigraphy and biostratigraphy

The Longville-Stanway Road Cutting, near the hamlet of Longville in the Dale, occurs along the lower part of the Wenlock Edge escarpment and contains a succession that begins approximately 20 m above that exposed at the top of the Eaton Track Section (c. 4.6 km to the southwest). The succession consists of the uppermost part of the Coalbrookdale Formation (Farley Member) and the Longville and Edgton members of the Much Wenlock Limestone Formation (Aldridge et al. 2000; Ray et al. 2010). Within this succession graptolite occurrences are restricted to 0.9 m below, and 0.6 m, 3.9 m and 5.7 m above the base of the Much Wenlock Limestone Formation (Figure 4) and correspond to sampling locations 46, 47, 49 and 50 of Bassett et al. (1975). The stratigraphic distribution of graptolite occurrences broadly corresponds to the extent of good continuous roadside exposure (c. 7.1 m) and forms the focus of the carbon isotopic sampling described herein. Based upon the presence of *Colonograptus praedeubeli* and *Colonograptus deubeli*, the uppermost Farley Member and Longville Member may be attributed to the late Homeric *praedeubeli-deubeli* Biozone. In addition, the Longville Member has also yielded *Ozarkodina bohémica bohémica* (Aldridge et al. 2000), a conodont broadly indicative of the middle to late Homeric (Slavík 2014).

#### Burrington lithostratigraphy and biostratigraphy

The hamlet of Burrington is located on the northern limb of the Ludlow Anticline, some 8 km west-south-west of the town of Ludlow. The Burrington Section contains c. 26 m of strata, within a number of discontinuous exposures within sunken lanes and disused quarries. These exposures begin within the hamlet itself and extend north-westwards up the hillside for c. 300 m. The succession consists of the upper

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3 Coalbrookdale and Much Wenlock Limestone formations and is considered  
4 representative of the Ludlow area. Unlike at Wenlock Edge a subdivision of the  
5 Coalbrookdale and Much Wenlock Limestone formations into constituent members  
6 has not been made here, owing to more gradational and relatively subtle lithological  
7 changes. Indeed during our fieldwork the precise position of the boundary between  
8 Coalbrookdale and Much Wenlock Limestone formations was difficult to establish  
9 with confidence; a situation not helped by poor exposure. This transitional interval  
10 may be partly equivalent to the Farley Member (the Tickwood Beds of Bassett, 1974)  
11 as developed along Wenlock Edge. Graptolites have been collected from localities  
12 60 to 64 of Holland et al. (1963) (also see Holland et al. 1969; Aldridge et al. 2000).  
13 However, in comparison to the Longville-Stanway Road Cutting and Eaton Track  
14 these biostratigraphic collections are more difficult to locate accurately and have  
15 consequently been shown as occurring over broader stratigraphic intervals than was  
16 probably the original case (Figure 5). Of particular biostratigraphic significance is the  
17 occurrence of *Gothograptus nassa* from location 60 indicating the *nassa* Biozone,  
18 *Colonograptus praedeubeli*, *C. deubeli* and *Spinograptus lawsoni* from the overlying  
19 Coalbrookdale Formation (locations 61 and 62) indicating the *praedeubeli-deubeli*  
20 Biozone, and *C. ludensis* from the Much Wenlock Limestone Formation indicating  
21 the *ludensis* Biozone (locations 63 and 64). In addition, location 64 is the highest  
22 record of graptolites within the Much Wenlock Limestone Formation of this area and  
23 the section as a whole is key in demonstrating the graptolite biozonation of the  
24 uppermost Wenlock (Holland et al. 1969).  
25  
26  
27

#### 28 **FIGURE 5 HEREBOUTS**

29 Figure 5. The Burrington Section (SO 4439 7241 to SO 4417 7257) showing the  
30 likely position of graptolite collections (Holland et al. 1963; 1969), graptolite  
31 biozonation, lithostratigraphy, general sedimentology including marker bentonites  
32 (MB), and carbon isotopic sampling locations and values. a. graptolite biozones;  
33 b. formations. See figure 4 for lithology key.  
34  
35

#### 36 **Carbon Isotope Stratigraphy**

37 Each section was logged and sampled at a range of intervals depending upon  
38 accessibility (Table 1). Up to 2 mg of carbonate rock powder, per sample, was  
39 analysed at the University of Birmingham's SILLA laboratory facility. This method of  
40 analysing bulk rock for stable isotopes, which inevitably does contain some skeletal  
41 material, has been shown to provide reliable results in other Silurian studies (e.g.  
42 Cramer *et al.* 2006; Hughes & Ray 2016). The powdered carbonate was placed in a  
43 vial in a heated sample rack (90°C), where the vial head space was replaced by pure  
44 helium via an automated needle system as part of an Isoprime Multiflow preparation  
45 system. Samples were then manually injected with approximately 200 µl of  
46 phosphoric acid and left to react for at least 1 hour before the headspace gas was  
47 sampled by an automated needle and introduced into a continuous-flow Isoprime  
48 mass-spectrometer. Duplicate samples were extracted from each vial and a mean  
49 value obtained for both  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ . Samples were calibrated using IAEA  
50 standards NBS-18 and NBS-19 and reported as ‰ on the VPDB scale. An external  
51 precision of better than 0.1‰ is typically achieved for both  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ . In total,  
52 162 samples provided results.  
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#### 56 **TABLE 1 HEREBOUTS**



1  
2  
3 Table 1.  $\delta^{13}\text{C}_{\text{carb}}$  and  $\delta^{18}\text{O}$  data from Eaton Track, Longville-Stanway Road Cutting,  
4 Burrington Section and Mortimer Forest Stop 1.  
5

### 6 **Eaton Track carbon isotope stratigraphy**

7 The Eaton Track section contains the oldest investigated succession and, based  
8 upon the identification of the *lundgreni* and *nassa* biozones, it should contain the  
9 lower positive peak of the Homeric CIE (Figures 2 and 4). As a means of assessing  
10 the isotopic variability within the *lundgreni* Biozone, samples were taken from below  
11 the main measured section (between 12.5 and 33.0 m below location 21 of Bassett  
12 et al. 1975). These samples (Figure 2; Table 1) range between -1.75 ‰ and -0.40 ‰  
13  $\delta^{13}\text{C}_{\text{carb}}$  (mean -1.13 ‰) and are typical of that biozone and the Apedale Member  
14 more generally, when compared with records from the nearby Lower Hill Farm  
15 Borehole (SO 5817 9788) (Hughes & Ray 2016). Within the main measured section  
16 and the uppermost 12.15 m of the *lundgreni* Biozone,  $\delta^{13}\text{C}_{\text{carb}}$  values fluctuate  
17 between -0.39 ‰ and +1.43 ‰ (mean +0.23 ‰). Immediately above the *lundgreni*  
18 Biozone is an interval of no exposure approximating to 3.5 m of missing section. The  
19 overlying outcrop corresponds to the lowest graptolite collection of the *nassa*  
20 Biozone (Location 24 of Bassett et al. 1975) and yields an initial  $\delta^{13}\text{C}_{\text{carb}}$  value of  
21 +2.64 ‰. This positive shift in values is considered to indicate that the onset of the  
22 Homeric CIE is at a stratigraphic position somewhere between the last graptolite  
23 collection of the *lundgreni* Biozone and the first of the *nassa* Biozone. From this  
24 initial peak, values decline over three closely spaced isotopic measurements to a low  
25 of +1.08 ‰. Above, the succession contains the transition from the Apedale Member,  
26 into the lowest part of the Farley Member (Coalbrookdale Formation) (Location 25 of  
27 Bassett et al. 1975). Here  $\delta^{13}\text{C}_{\text{carb}}$  values show a broad rise, over multiple samples,  
28 with a peak value of +2.79 ‰ (mean +2.37 ‰). Such values are considered to reflect  
29 the rising limb of the lower peak of the Homeric CIE, which has been previously  
30 reported from the Farley Member (Schmidt et al. 2002).  
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### 35 **Longville-Stanway Road Cutting carbon isotope stratigraphy**

36 The succession at the Longville-Stanway Road Cutting is exclusively within the  
37 *praedeubeli-deubeli* Biozone and contains a succession that begins approximately  
38 20 m above that exposed at the top of the Eaton Track Section. The basal few  
39 metres of the succession contain the transition between the Farley Member  
40 (Coalbrookdale Formation) and Longville Member (Much Wenlock Limestone  
41 Formation), and are accompanied by a progressive rise in  $\delta^{13}\text{C}_{\text{carb}}$  values from +1.35  
42 ‰ to +2.25 ‰. Above, values broadly plateau (mean +2.20 ‰), albeit with notable  
43 fluctuations between 2.98 m and 4.69 m (+1.66 ‰ to +2.44 ‰). This rise and plateau  
44 in values are considered to reflect the lower part of the upper peak of the Homeric  
45 CIE.  
46  
47

### 48 **Burrington carbon isotope stratigraphy**

49 The Burrington Section is representative of the *nassa*, *praedeubeli-deubeli* and  
50 *ludensis* biozones and therefore is partly synchronous with the Eaton Track and  
51 Longville-Stanway Road Cutting sections. Location 60 (Holland et al. 1963) is the  
52 oldest part of the succession (*nassa* Biozone) and contains  $\delta^{13}\text{C}_{\text{carb}}$  values between  
53 +0.60 ‰ to +1.21 ‰ (mean +0.99 ‰). Above, the sunken lane-side section contains  
54 the uppermost Coalbrookdale Formation and its gradational transition with the  
55 overlying Much Wenlock Limestone Formation. Within the Coalbrookdale Formation  
56 (between marker telegraph poles 46 and 47)  $\delta^{13}\text{C}_{\text{carb}}$  values range from - 0.83 ‰ to  
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3 +0.85 ‰ (mean +0.24 ‰), and based upon the slight lowering of values, in  
4 comparison with those below and above, may reflect the trough in values between  
5 the dual peaks of the Homeric CIE (*praedeubeli-deubeli* Biozone). The transition  
6 interval with the Much Wenlock Limestone Formation shows initially similar values to  
7 those observed below, before values rise sharply to +4.04 ‰. While this marked  
8 positive shift is only identified in a single sample within the lane-side section,  
9 distinctly higher values are reported from the Much Wenlock Limestone Formation,  
10 which is exposed within a small disused quarry stratigraphically above. Here,  $\delta^{13}\text{C}_{\text{carb}}$   
11 values range from +1.24 ‰ to +3.80 ‰ (mean +2.17 ‰), and are likely characteristic  
12 of the upper peak of the Homeric CIE (*ludensis* Biozone). Particularly notable  
13 features of this interval are the positive spikes in values at 26.60 m, 36.36 m and  
14 39.36 m. While these appear to be part of a broader positive shift in values between  
15 the Coalbrookdale and Much Wenlock Limestone formations, they are clearly  
16 anomalous and may reflect a diagenetic effect or pulses of platform-derived  
17 carbonate deposited during storm events, as described by Blain et al. (2016) for the  
18 uppermost Much Wenlock Limestone Formation of the Ludlow Anticline. The  
19 youngest part of the succession occurs back on the lane at a marked bend (Location  
20 64 of Holland et al. 1963) and gives values between +1.79 ‰ and +1.99 ‰ (mean  
21 +1.89 ‰). The minor fall in values between the underlying quarry and this section  
22 may reflect the onset of the declining values within the upper peak of the Homeric  
23 CIE, which is observed elsewhere near the top Much Wenlock Limestone Formation;  
24 such values are only marginally higher than those obtained from c. 6.5 m below the  
25 top of the Much Wenlock Limestone Formation at the nearby Goggin Road section  
26 (Blain et al. 2016) and may represent the fall in values between Mortimer Forest  
27 stops 1 and 2, c. 7 m to 9 m below the top of the Much Wenlock Limestone  
28 Formation (Figure 6).  
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### 33 **Regional and pan-regional correlation**

34 Upon the Midland Platform the best documented and most stratigraphically extensive  
35 records of the Homeric CIE are derived from the Silurian inliers of the West  
36 Midlands (Wren's Nest Hill, Dudley (SO 937 920)) (Cramer et al. 2012; Marshall et  
37 al. 2012), and it is from these inliers that the initial documentation of a double-  
38 peaked late Homeric CIE was made (Corfield et al. 1992). In addition, the upper  
39 peak of the Homeric CIE has been documented within the reef tract along Wenlock  
40 Edge, and the declining limb of the upper peak further documented from Ledbury  
41 and the Ludlow Anticline (Corfield et al. 1992; Thomas & Ray, 2011; Marshall et al.  
42 2012; Blain et al. 2016). While these sections are, for the most part, well correlated  
43 via bentonites and sequence stratigraphy (Ray et al. 2010; 2011; 2013), direct  
44 graptolite biostratigraphic control is poor; owing to a very limited number of graptolite  
45 finds. Accordingly, the establishment of the Homeric CIE within the graptolitic  
46 sections described herein, and the correlation of these sections with the established  
47 carbon isotopic and sequence stratigraphic records should help to improve  
48 chronostratigraphic constraints across the Midland Platform (Figure 6), and further  
49 enable improved correlation with successions outside of the Midland Platform for  
50 which detailed graptolite and carbon isotopic determinations have been obtained.  
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### 55 **FIGURE 6 HEREABOUTS**

56 Figure 6. A correlation of key sections along Wenlock Edge and the Ludlow Anticline  
57 based upon biozones and carbon isotopic curves. The generalised carbon isotopic  
58 curve is derived from the inner platform area situated within the West Midlands  
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3 (Corfield et al. 1992; Cramer et al. 2012; Marshall et al. 2012). Carbon isotopic  
4 curves for Benthall Edge, Lea South and Goggin Road are taken from Blain et al.  
5 (2016) and Mortimer Forest stops 2 and 3 are from Thomas & Ray (2011). Thick  
6 grey lines indicate the correlation of lithostratigraphic boundaries. Dashed thin grey  
7 lines indicate the correlation of biozonal boundaries. S1, start of lower peak of the  
8 Homeric CIE; P1, peak of lower CIE; E1/S2, end of lower CIE and the start of the  
9 upper; P2, peak of upper CIE; E2, end of upper CIE. a. Stage; b. Stage Slices  
10 (Cramer et al. 2011); c. graptolite biozones; d. lithostratigraphic formations within the  
11 West Midlands (inner platform); e. lithostratigraphic members within the West  
12 Midlands (inner platform). Gor., Gorstian; L. E. Fm., Lower Elton Formation; LQL  
13 Mb., Lower Quarried Limestone Member; UQL Mb. Upper Quarried Limestone  
14 Member. Scale bar is applicable only to the sections.  
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18 The onset of the lower peak of the Homeric CIE is associated with the base  
19 of the Much Wenlock Limestone Formation within the West Midlands from which  
20 there are reports of *Monograptus flemingii* (Butler, 1939; Bassett, 1976; Ray et al.  
21 2010). At Eaton Track a similar situation occurs with the onset of the Homeric CIE  
22 approximating to the last appearance of *M. flemingii* and a marked lithological  
23 change marking the transition between the Apedale and Farley members (of the  
24 Coalbrookdale Formation). Unfortunately, the poor exposure and limited lithological  
25 variability within the Eaton Track succession precludes the clear identification of the  
26 parasequences attributed to this stratigraphic interval within the West Midlands (Ray  
27 et al. 2010). However, it is notable that in both of the successions the onset of the  
28 Homeric CIE is approximately synchronous with the replacement of distal shales  
29 with a shallower limestone-rich succession. This synchronous appearance of  
30 limestones may be explained by a basinward shift of proximal facies during a marine  
31 regression, and this sea-level fall, in association with the onset of the lower peak of  
32 the Homeric CIE, has been reported from multiple palaeo-continent (Johnson,  
33 2006; Calner, 2008) and is considered likely to be glacio-eustatic in origin (Loydell  
34 1998; Trotter et al. 2016).  
35

36 Outside of the Midland Platform and Avalonia the close association of the last  
37 appearance of *M. flemingii* and the onset of the lower peak of the Homeric CIE is  
38 well established. Upon Baltica the Bartoszyce IG 1 (north-eastern Poland),  
39 Gröttingbo-1 (Gotland, Sweden) and Viduklė-61 (Lithuania) boreholes record the last  
40 appearance of *M. flemingii* immediately prior to pronounced positive shifts in  $\delta^{13}\text{C}$   
41 values (Porębska et al. 2004; Calner et al. 2006; Radzevičius et al. 2014). Similarly  
42 upon Laurentia the Simpson Park I section (Nevada, USA) documents the same  
43 series of events (Cramer et al. 2006). A further similarity between these four  
44 successions is the first appearance of *Gothograptus nassa* within the lower peak of  
45 the Homeric CIE. Based upon the reassessment of the Eaton Track graptolite  
46 biozonation this same relationship can be observed upon the Midland Platform.  
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48 The subdivision of the former *ludensis* Biozone (Bassett et al. 1975) on the  
49 Midland Platform into the *praedeubeli-deubeli* and *ludensis* biozones allows for the  
50 trough and upper peak of the Homeric CIE to be correlated and compared in detail.  
51 Broadly the trough and upper rising limb of the Homeric CIE occur within the  
52 *praedeubeli-deubeli* Biozone, with peak isotopic values likely occurring high in the  
53 same biozone (+4.04 ‰ within the Burrington Section) or within the lowermost part of  
54 the overlying *ludensis* Biozone. Above, values typically plateau before declining  
55 towards the top of the Homeric Stage. In terms of regional correlation and age  
56 constraints, the establishment of the *praedeubeli-deubeli* Biozone and the rising limb  
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3 of the upper peak of the Homerian CIE within the Longville-Stanway Road Cutting  
4 are particularly helpful, in that they are associated with the widely traceable flooding  
5 surface between parasequences 9 and 10 of Ray et al. (2010) (Figure 4). In  
6 particular, the correlation of these parasequences along Wenlock Edge and to the  
7 West Midlands allows for comparison with more extensive carbon isotope records  
8 (Marshall et al. 2012) and reveals that the upper peak of the Homerian CIE is  
9 restricted to an interval encompassing Parasequence 9 and the lower part of  
10 Parasequence 10, above which carbon isotopic values broadly plateau and then  
11 decline towards the top of Parasequence 10. Such an arrangement suggests that the  
12 maximum isotopic values of the upper peak of the Homerian CIE may be very close  
13 to the studied interval at the Longville-Stanway Road Cutting and therefore within the  
14 *praedeubeli-deubeli* Biozone. Comparison with the Burrington Section also reveals a  
15 change from the rising limb of the upper peak of the Homerian CIE to a plateau in  
16 carbon isotopic values, which corresponds to the transition between *praedeubeli-*  
17 *deubeli* and *ludensis* biozones. Based upon this section the peak values of the upper  
18 peak of the Homerian CIE likely occur close to the boundary between the  
19 *praedeubeli-deubeli* and *ludensis* biozones. This same relationship may also be  
20 observed outside of the Midland Platform and Avalonia with both the Bartoszyce IG 1  
21 (north-eastern Poland) and Viduklė-61 (Lithuania) boreholes (Porębska et al. 2004;  
22 Radzevičius et al. 2014) revealing a minimum in isotopic values within the lower part  
23 of the *praedeubeli-deubeli* Biozone, above which values rise towards the upper part  
24 of the biozone, with peak values achieved close to the boundary between the  
25 *praedeubeli-deubeli* and *ludensis* biozones.

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28 A further correlative feature of Parasequence 10 is that it represents a  
29 significant marine regression resulting in the progradation of shallow limestone-rich  
30 facies across much of the Midland Platform (Ray et al. 2010). This sea-level fall, in  
31 association with the upper peak of the Homerian CIE, has been reported from  
32 multiple palaeo-continent (Johnson, 2006) and is considered likely to be glacio-  
33 eustatic in origin (Loydell 1998; Trotter et al. 2016). Within the Ludlow area the  
34 progradation of shallow limestone-rich facies has resulted in the replacement of the  
35 deep-marine shales of the Coalbrookdale Formation with the Much Wenlock  
36 Limestone Formation. However, graptolite age constraints indicate that the base of  
37 the Much Wenlock Limestone Formation is diachronous between Wenlock Edge  
38 (*praedeubeli-deubeli* Biozone) and the Ludlow Anticline (*ludensis* Biozone). This  
39 south-westward younging reflects the time taken for shallow-marine limestone facies,  
40 typical of the off-reef tract of the Much Wenlock Limestone Formation, to prograde  
41 out into the somewhat deeper platform setting present at Ludlow. According to  
42 Thomas & Ray (2011) the flooding surface between parasequences 9 and 10 can be  
43 observed in the Ludlow area near the base of Mortimer Forest Stop 1. Based upon  
44 the diachroneity described herein, this is erroneous, and the parasequence 9-10  
45 boundary should occur stratigraphically below, within the *praedeubeli-deubeli*  
46 Biozone and in association with the plateau in carbon isotopic values. This would  
47 correspond to the transition interval between the Coalbrookdale and Much Wenlock  
48 Limestone Formation at the Burrington Section, and fits well with the progradational  
49 nature of Parasequence 10 resulting in the deposition of the Much Wenlock  
50 Limestone Formation.

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54 Mortimer Forest stops 1 to 3 are of particular significance for the stratigraphy  
55 of the Homerian Stage and Ludlow area, in that they represent near continuous  
56 exposure of the upper 15 m of the Much Wenlock Limestone Formation and contain  
57 the GSSP for the overlying Gorstian Stage and Ludlow Series (Mortimer Forest Stop  
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3 3, Pitch Coppice Quarry (Melchin et al. 2012)). While carbon isotope values are  
4 available for stops 2 and 3 (Thomas & Ray 2011) these do not display values that  
5 could definitely be attributed to the upper peak of the Homeric CIE (+0.44 ‰ to  
6 +1.25 ‰). As a means of improving our understanding of the upper part of the Much  
7 Wenlock Limestone Formation, carbon isotope values have been established for all  
8 but the inaccessible upper 2 m of the Mortimer Forest Stop 1 quarry face. Here  
9 carbon isotope values range between +0.88 ‰ and +2.33 ‰ (mean +1.89 ‰; Table  
10 1) and are considered representative of the plateau in values associated with the  
11 upper peak of the Homeric CIE (Figure 6). By combining the carbon isotopic record  
12 for the Burrington Section and Mortimer Forest stops 1 to 3 the upper peak of the  
13 Homeric CIE can now be better resolved within the Ludlow area. As with the off-  
14 reef tract along Wenlock Edge the upper peak of the Homeric CIE appears to  
15 occupy the majority of the Much Wenlock Limestone Formation. However, while the  
16 thickness of the Much Wenlock Limestone Formation at the south-western end of  
17 Wenlock Edge (River Onny Section, south of Craven Arms) is reported as 21 m  
18 (Bassett et al. 1975), Cocks et al. (1992) considered the Much Wenlock Limestone  
19 Formation to be much thicker within the Ludlow area (55 m to 144 m). The apparent  
20 thickening of the Much Wenlock Limestone Formation might, in part, reflect the  
21 transition from shelf to basin, which takes place to the immediate west of the Ludlow  
22 Anticline. However, a combination of poor exposure, faulting and the transitional  
23 nature of the base of the formation are also important and may have led to an  
24 overestimate of thickness. Indeed within the nearby Wigmore Rolls area of the  
25 Ludlow Anticline the difficulties in unequivocally distinguishing the Much Wenlock  
26 Limestone Formation from the shales and limestones of the upper Coalbrookdale  
27 Formation led Whitaker (1994) to combine all the shale-limestone sequences into a  
28 new formation, the Wigmore Rolls Formation. The Wigmore Rolls Formation ranges  
29 in thickness from 30 m to 163 m and corresponds to successions previously  
30 attributed to the Much Wenlock Limestone Formation.  
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34 Considerations of the thickness of the Much Wenlock Limestone Formation  
35 between Mortimer Forest Stop 3 and the Burrington Section are of significance in  
36 that the Burrington Section contains the highest record of Homeric graptolites  
37 (Location 64) below the Gorstian GSSP (Mortimer Forest Stop 3). According to  
38 Lawson & White (1989) Location 64 within Burrington Section is within the lower third  
39 of the Much Wenlock Limestone Formation and occurs 40 m below the top of the  
40 formation, indicating a significant stratigraphic thickness between the last graptolites  
41 of the Homeric and the first graptolites of the Gorstian. However, the River Onny  
42 Section with a reported thickness of 21 m for the Much Wenlock Limestone  
43 Formation is only 8.5 km north of the Burrington Section and is representative of a  
44 gradual thinning of the formation (33 m to 21 m) along Wenlock Edge and towards  
45 the Ludlow area. Furthermore, 220 m to the northeast of the top of the Burrington  
46 section (Location 64), and across a minor fault, is Burrington Common Quarry (SO  
47 4438 7266; Location 65 of Holland et al. 1963). This small disused quarry contains  
48 5.9 m of Much Wenlock Limestone Formation with features indicative of the very  
49 highest part of the succession. In particular, a highly distinctive 0.18 m thick shale  
50 horizon, within fine comminuted crinoidal grainstones, is present and almost certainly  
51 corresponds to the widely traceable flooding surface at the base of Parasequence 11  
52 (Lawson & White 1989; Thomas & Ray 2011; Blain et al. 2016). In addition, below  
53 the flooding surface are *Favosites* corals, which are generally rare within all but the  
54 uppermost Much Wenlock Limestone Formation within the Ludlow Anticline. Based  
55 upon these considerations it seems likely that the thickness of the Much Wenlock  
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3 Limestone Formation between Mortimer Forest Stop 3 and the Burrington Section is  
4 likely to be similar to that reported along Wenlock Edge (21 m to 33 m) and Location  
5 64 and the highest records of Homeric graptolites may therefore be stratigraphically  
6 higher within the formation than previously thought.  
7

### 8 **Conclusions**

9  
10 New  $\delta^{13}\text{C}_{\text{carb}}$  data from the most stratigraphically extensive graptolitic sections of late  
11 Homeric age are reported from Wenlock Edge and the Ludlow Anticline, thereby  
12 encompassing the type Homeric succession. The establishment of the Homeric  
13 CIE within graptolitic successions increases our understanding of the scale and  
14 timing of carbon isotopic variations and improves both regional and global  
15 correlation. The main conclusions are summarized below:  
16

- 17 1. The 162  $\delta^{13}\text{C}_{\text{carb}}$  samples from four outcrops (Eaton Track, Longville-Stanway  
18 Road Cutting, Burrington Section and Mortimer Forest Stop 1) provide evidence for  
19 the onset of both lower and upper peaks of the Homeric CIE in association with  
20 graptolite records. Based upon this data the lower excursion begins in association  
21 with the last appearance of *Monograptus flemingii* and appears restricted to the  
22 overlying *nassa* Biozone. Above, the trough between excursions and the upper rising  
23 limb of the Homeric CIE occur within the *praedeubeli-deubeli* Biozone, with peak  
24 values corresponding to the boundary between the *praedeubeli-deubeli* and *ludensis*  
25 biozones. The declining limb of the upper excursion is within upper part of the Much  
26 Wenlock Limestone Formation and is likely restricted to the *ludensis* Biozone.  
27
- 28 2. Based on a biostratigraphical re-assessment, the base of the Much Wenlock  
29 Limestone Formation is diachronous, lying within the *praedeubeli-deubeli* Biozone in  
30 the off-reef tract along Wenlock Edge, but at a higher level, close to the base of the  
31 *ludensis* Biozone, within the Ludlow Anticline.  
32
- 33 3. Based upon carbon isotopic, lithological and sequence stratigraphic  
34 considerations, the Burrington Section, Mortimer Forest Stop 1 and Longville-  
35 Stanway Road Cutting allow for high resolution correlation between the Ludlow  
36 Anticline and Wenlock Edge. These correlations suggest a uniformity of depositional  
37 rates across the study area and suggest that the thickness of the Much Wenlock  
38 Limestone Formation between its top at Mortimer Forest Stop 3 and base in the  
39 Burrington Section is similar to that reported along Wenlock Edge (21 m to 33 m).  
40
- 41 4. The application of  $\delta^{13}\text{C}_{\text{carb}}$  chemostratigraphy to graptolitic successions has  
42 allowed for better comparisons with other sections outside of Avalonia from which  
43 high-resolution graptolite and carbon isotope data are available. Such comparisons  
44 highlight the apparent synchronicity of the Homeric CIE with respect to the  
45 *lundgreni*, *nassa*, *praedeubeli-deubeli* and *ludensis* biozones.  
46

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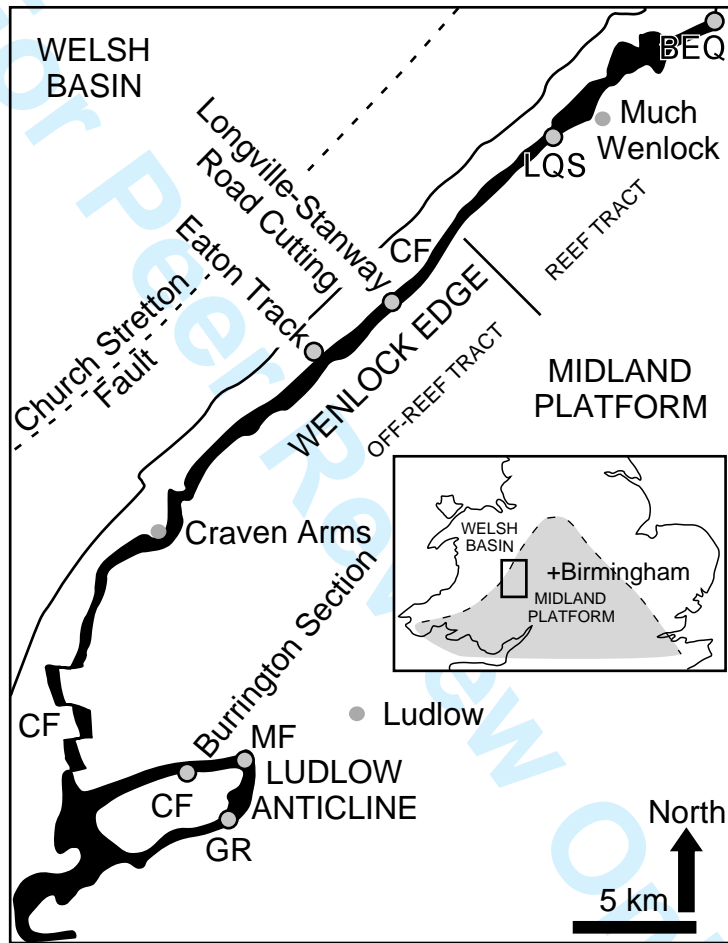
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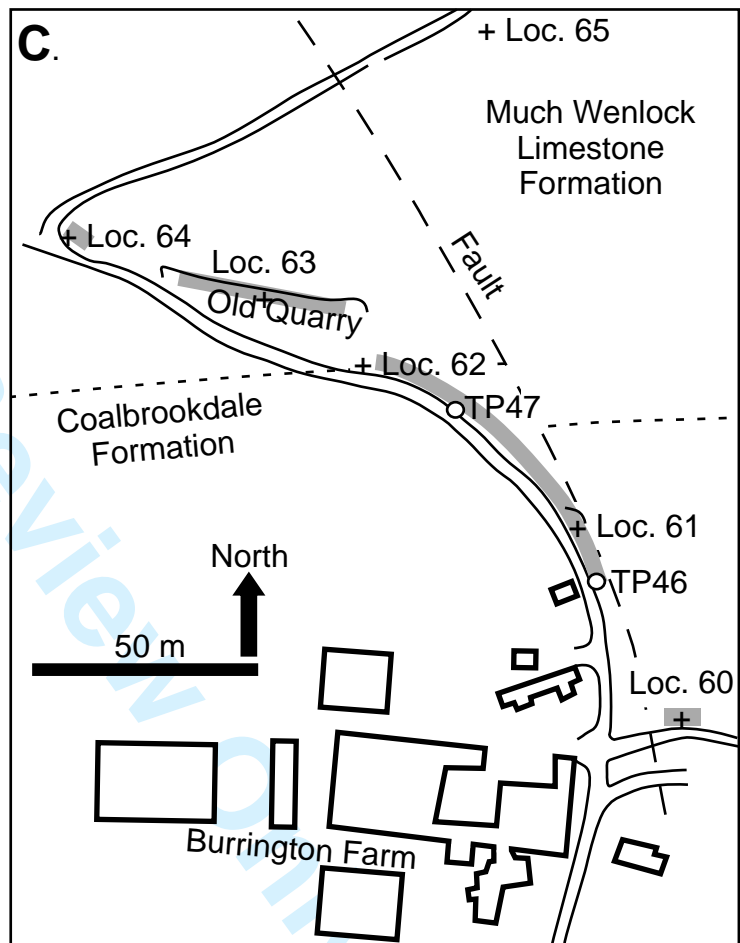
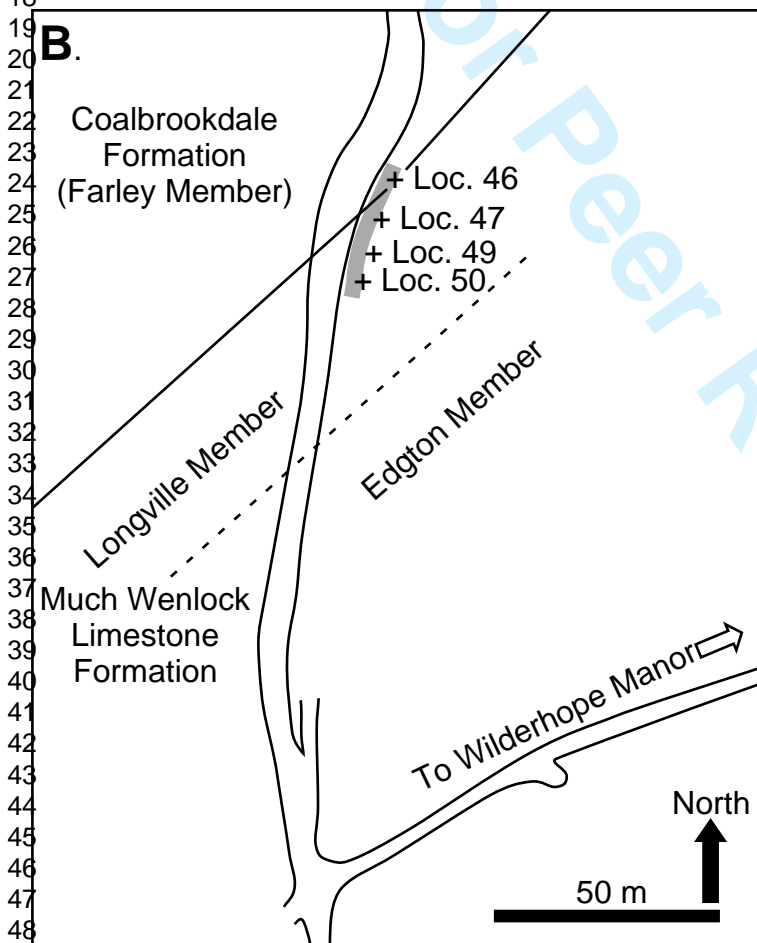
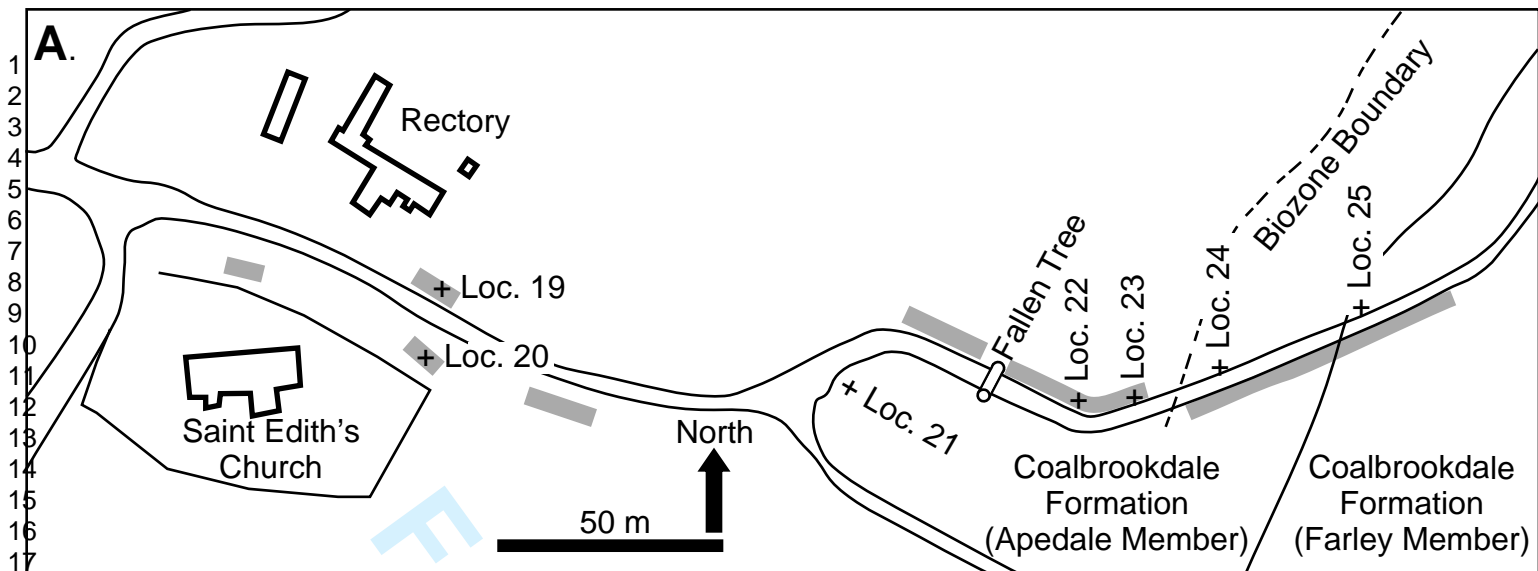


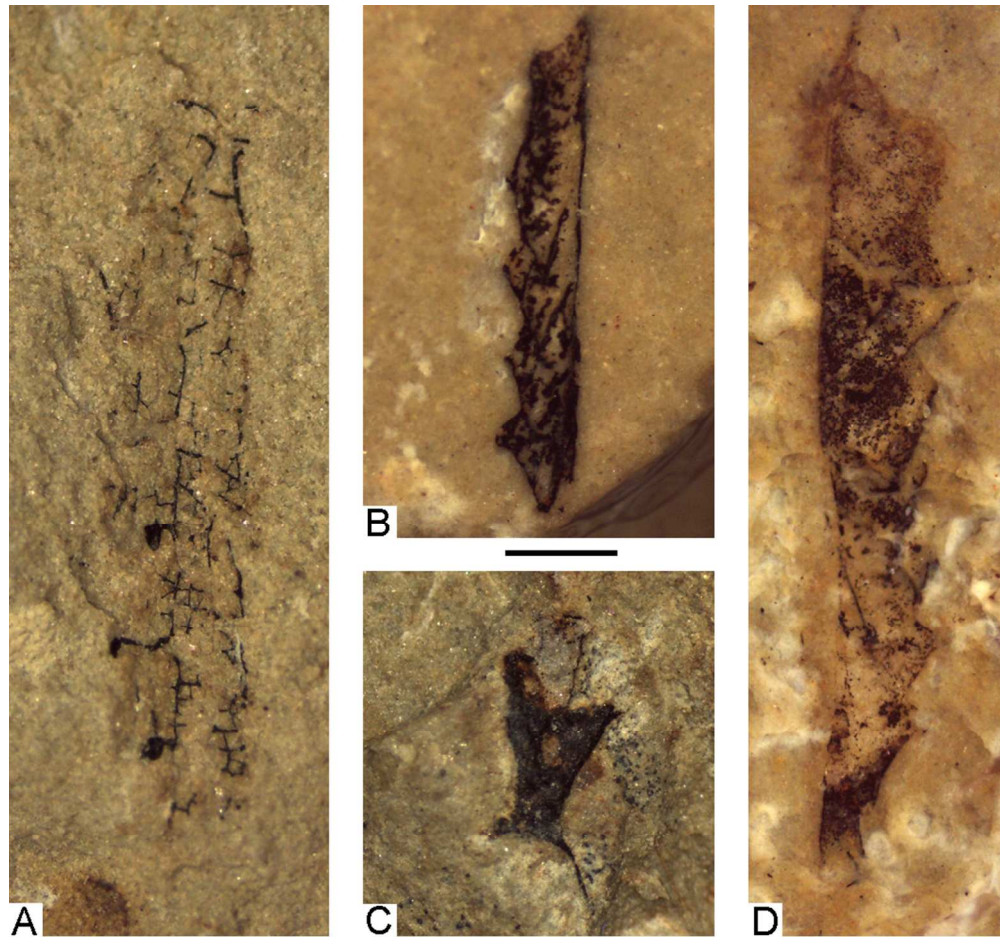
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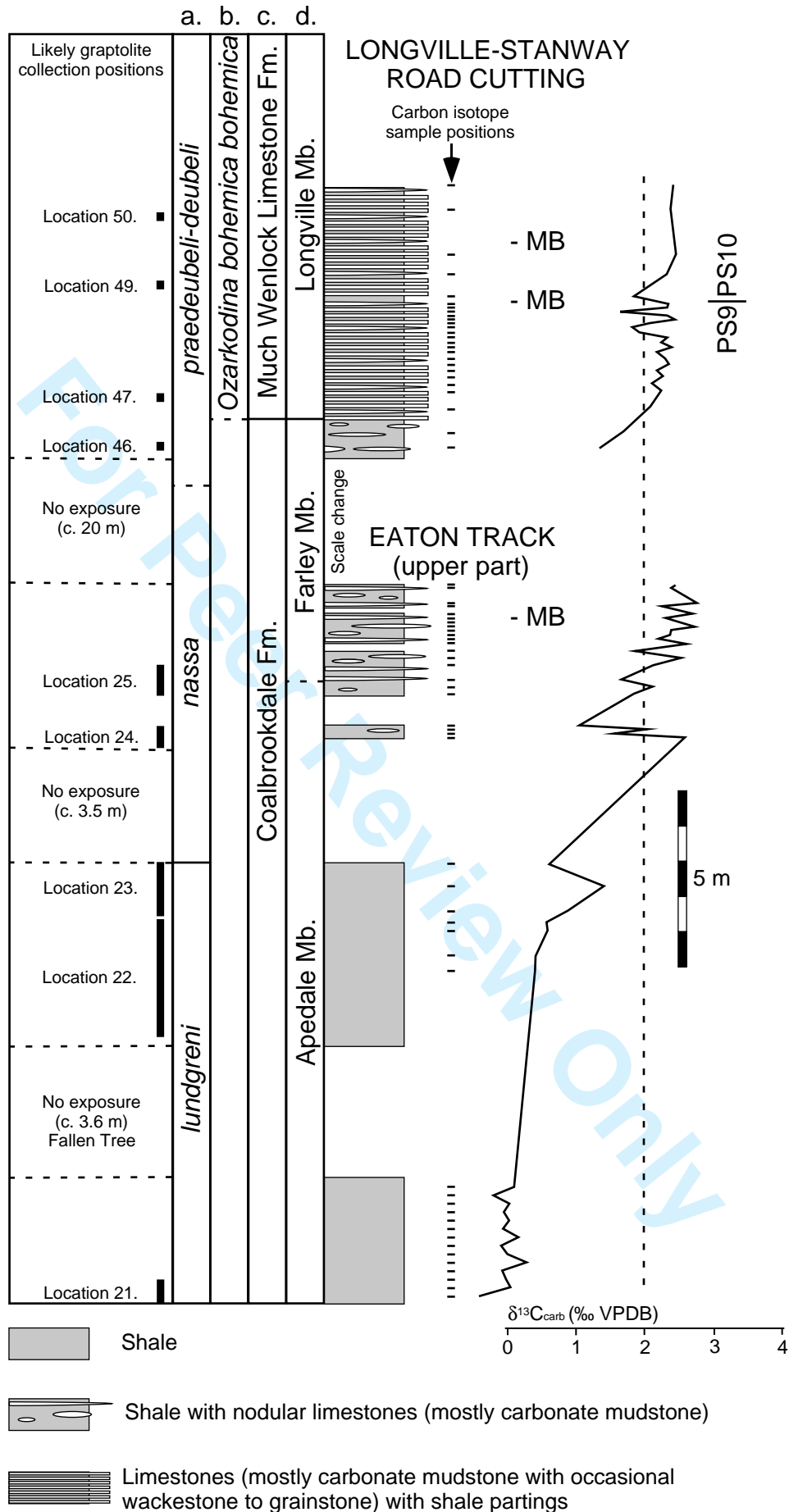
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Figure 3. Biostratigraphically important graptolites from the Eaton track and Longville-Stanway road sections. Locality numbers are those of Bassett et al. (1975) as used also on figures 2 and 4. All specimens are housed in the Sedgwick Museum of Earth Sciences, Cambridge. Scale bar represents 1 mm. A. *Gothograptus nassa* (Holm), SM A. 80195, Location 25. B, D. *Colonograptus praedeubeli* (Jaeger, in Barca & Jaeger): B. SM A. 80063, Location 50; D. SM A. 80067a, Location 49. C. *Colonograptus praedeubeli* (Jaeger), SM A. 80073, Location 47.

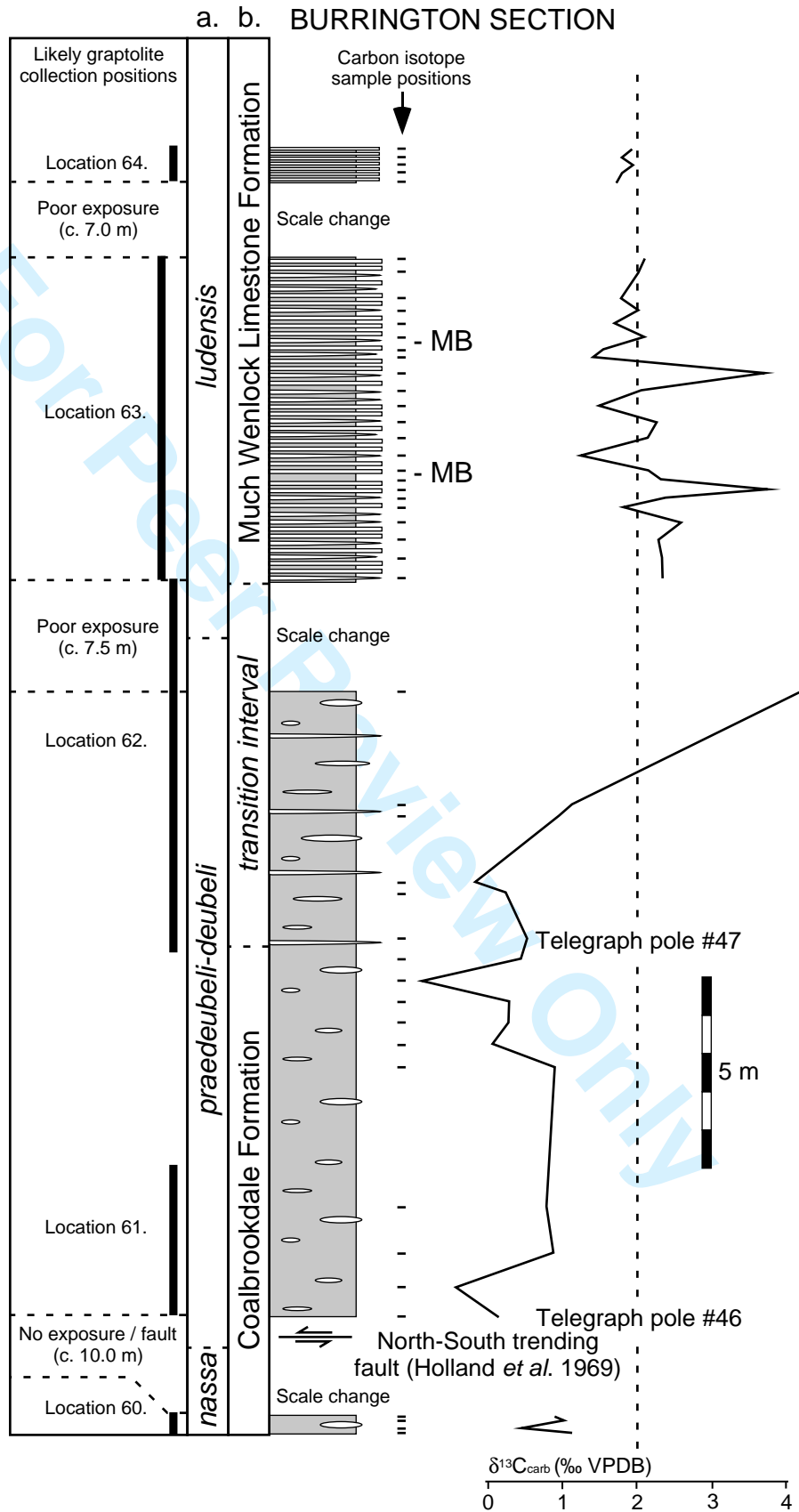
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Sample Code	Position from lowest sample (m)	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	Sample Code	Position from lowest sample (m)	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	Sample Code	Position from lowest sample (m)	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	Sample Code	Position from lowest sample (m)	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$
<b>Eaton Track (EAT)</b>				<b>Longville-Stanway Road Cutting (LON)</b>				<b>Burrington Section (BUR)</b>				<b>Mortimer Forest Stop 1 (MOR)</b>			
EAT001	c. -33.00	-0.97	-9.5	LON001	0.00	1.35	-3.8	BUR001	0.00	1.21	-6.5	MOR001	0.00	1.61	-7.9
Location 19				LON002	0.47	1.69	-3.7	BUR002	0.10	0.60	-7.0	MOR002	0.25	2.11	-5.9
EAT002	c. -29.0	-1.14	-8.5	LON003	1.13	2.09	-5.8	BUR003	0.30	1.13	-7.8	MOR003	0.50	2.07	-6.1
EAT003	c. -28.8	-1.03	-8.8	LON004	1.56	2.25	-5.9	BUR004	0.40	1.01	-7.5	MOR004	0.75	1.64	-6.2
EAT004	c. -28.6	-1.75	-8.5	LON005	1.76	2.11	-5.9	c. 10 m gap in section, plus fault				MOR005	1.00	2.26	-6.4
EAT005	c. -28.4	-1.19	-8.9	LON006	1.93	2.28	-5.7	BUR005	10.40	0.15	-6.9	MOR006	1.25	1.45	-7.1
EAT006	c. -28.2	-1.23	-8.8	LON007	2.11	2.20	-6.0	BUR006	11.18	-0.40	-6.7	MOR007	1.50	2.15	-6.1
EAT007	c. -28.0	-1.15	-8.9	LON008	2.28	2.36	-5.1	BUR007	12.08	0.84	-6.7	MOR008	1.75	2.22	-5.8
EAT008	c. -27.8	-1.25	-8.7	LON009	2.41	2.31	-6.7	BUR008	13.27	0.75	-7.9	MOR009	2.00	2.19	-6.3
EAT009	c. -27.6	-1.11	-8.8	LON010	2.58	2.19	-6.2	BUR009	16.87	0.85	-6.9	MOR010	2.25	1.89	-6.1
EAT010	c. -27.4	-1.14	-9.7	LON011	2.72	2.41	-5.7	BUR010	17.47	0.07	-7.5	MOR011	2.50	2.22	-6.2
Location 20				LON012	2.83	2.25	-6.1	BUR011	18.00	0.27	-7.3	MOR012	2.75	2.14	-6.0
EAT011	c. -27.0	-0.97	-8.3	LON013	2.98	2.34	-6.1	BUR012	18.58	0.28	-7.6	MOR013	3.00	0.88	-7.9
EAT012	c. -26.8	-1.42	-8.5	LON014	3.12	1.93	-7.4	BUR013	19.10	-0.83	-7.2	MOR014	3.25	1.47	-8.0
EAT013	c. -26.6	-1.55	-8.4	LON015	3.24	1.83	-6.4	BUR014	19.67	0.43	-6.9	MOR015	3.50	2.18	-6.0
EAT014	c. -26.4	-1.50	-8.0	LON016	3.37	2.08	-5.8	BUR015	20.17	0.51	-6.6	MOR016	3.75	2.21	-6.0
Between locations 20 and 21				LON017	3.45	2.44	-6.0	BUR016	21.40	0.23	-7.1	MOR017	4.00	2.24	-5.9
EAT015	c. -15.0	-0.89	-8.3	LON018	3.58	2.35	-6.1	BUR017	21.66	-0.15	-7.4	MOR018	4.25	2.33	-6.0
EAT016	c. -14.5	-1.44	-8.6	LON019	3.66	1.66	-8.0	BUR018	23.37	0.92	-7.5	MOR019	4.50	2.17	-5.8
EAT017	c. -14.0	-0.71	-8.4	LON020	3.77	2.34	-6.1	BUR019	23.67	1.09	-6.6	MOR020	4.75	2.02	-6.2
EAT018	c. -13.5	-0.83	-8.7	LON021	3.89	2.35	-5.7	BUR020	26.60	4.04	-6.7	MOR021	5.00	1.06	-8.2
EAT019	c. -13.0	-0.92	-8.2	LON022	4.08	1.86	-6.5	c. 7.5 m gap in section				MOR022	5.25	2.14	-6.5
EAT020	c. -12.5	-0.40	-8.7	LON023	4.69	2.33	-5.8	BUR021	34.06	2.36	-5.4	MOR023	5.50	1.05	-8.4
Locations 21 to 25				LON024	5.22	2.47	-5.8	BUR022	34.61	2.34	-5.3	MOR024	5.75	1.42	-8.4
EAT021	0.00	-0.39	-7.5	LON025	6.45	2.39	-5.5	BUR023	35.02	2.30	-5.3	MOR025	6.00	2.16	-6.5
EAT022	0.25	0.06	-7.2	LON026	7.09	2.43	-5.6	BUR024	35.49	2.60	-5.4				
EAT023	0.50	-0.01	-7.5					BUR025	35.93	1.84	-7.4				
EAT024	0.75	-0.07	-8.0					BUR026	36.14	2.42	-6.1				
EAT025	1.00	0.28	-7.9					BUR027	36.36	3.80	-0.9				
EAT026	1.25	0.01	-8.0					BUR028	36.61	2.34	-6.1				
EAT027	1.50	-0.09	-8.2					BUR029	36.86	2.17	-6.1				
EAT028	1.75	0.17	-9.0					BUR030	37.22	1.24	-6.5				
EAT029	2.00	-0.06	-8.3					BUR031	37.72	2.16	-6.0				
EAT030	2.25	0.03	-7.8					BUR032	38.09	2.27	-6.0				
EAT031	2.50	-0.06	-7.6					BUR033	38.52	1.51	-6.9				
EAT032	2.75	0.04	-7.6					BUR034	38.91	2.08	-6.1				
EAT033	3.00	-0.18	-8.3					BUR035	39.36	3.74	-0.8				
EAT034	3.25	0.12	-7.6					BUR036	39.80	1.42	-5.5				
EAT035	8.95	0.41	-6.8					BUR037	39.97	1.56	-5.7				
EAT036	9.40	0.42	-6.5					BUR038	40.30	2.11	-5.7				
EAT037	10.14	0.60	-6.0					BUR039	40.63	1.72	-5.5				
EAT038	10.41	0.58	-7.2					BUR040	41.01	2.04	-5.6				
EAT039	10.77	0.89	-7.0					BUR041	41.30	1.81	-5.0				
EAT040	11.47	1.43	-7.9					BUR042	41.94	2.02	-5.3				
EAT041	12.15	0.62	-8.3					BUR043	42.33	2.12	-5.7				
EAT042	15.93	2.64	-6.1					c. 7.0 m gap in section							
EAT043	16.06	1.59	-7.7					BUR044	49.33	1.79	-7.3				
EAT044	16.17	2.08	-7.8					BUR045	49.53	1.85	-6.4				
EAT045	16.29	1.08	-4.3					BUR046	49.73	1.99	-5.5				
EAT046	17.24	1.87	-7.8					BUR047	49.93	1.85	-5.5				
EAT047	17.45	2.15	-7.5					BUR048	50.13	1.97	-5.3				
EAT048	17.69	1.69	-4.6												
EAT049	18.11	2.17	-7.3												
EAT050	18.33	2.57	-5.2												
EAT051	18.52	1.90	-5.2												
EAT052	18.73	2.66	-6.3												
EAT053	18.91	2.25	-8.0												
EAT054	19.03	2.42	-6.8												
EAT055	19.16	2.44	-6.3												
EAT056	19.27	2.79	-4.5												
EAT057	19.41	2.55	-6.3												
EAT058	19.53	2.37	-6.8												
EAT059	19.66	2.75	-4.7												
EAT060	19.89	2.31	-6.4												
EAT061	19.98	2.82	-5.1												
EAT062	20.43	2.44	-6.2												
EAT063	20.51	2.51	-4.9												



