

2023-06

# Terrestrial carbon isotope stratigraphy of the EoceneOligocene transition, Petrockstowe and Bovey basins, Devon, UK

Chaanda, MS

<https://pearl.plymouth.ac.uk/handle/10026.1/21172>

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10.1016/j.pgeola.2023.05.003

Proceedings of the Geologists' Association

Elsevier BV

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1 **Terrestrial carbon isotope stratigraphy of the Eocene–Oligocene transition, Petrockstowe and**  
2 **Bovey basins, Devon, UK**

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11 **ABSTRACT**

12 The terrestrial sediments of the Petrockstowe and Bovey basins in Devon, UK were examined. Their  
13 age is considered to be Eocene and Oligocene. The sediments (kaolinitic clays, silts, sands, gravels,  
14 and lignites) from both basins were analysed for carbon isotopes of organic material, in conjunction  
15 with total organic carbon and palynological analyses used to unravel the type of and provenance of  
16 organic matter present. Within the Petrockstowe Basin, the lowermost interval examined shows a  
17 palynological distribution dominated by phytoclasts, whilst the upper part of the core is dominated  
18 by higher concentrations of palynomorphs (up to 90%) and an increase in amorphous organic  
19 matter consistent (up to 37%) with a change from sand-filled fluvial channels followed by an  
20 ephemeral lake or lake margin setting. Our palynological data from South John Acres Lane Quarry  
21 section, Bovey Basin, show that within the lignites palynomorphs are high again (up to 95%)  
22 consistent with them representing more ephemeral lakes or lake margins periodically exposed with  
23 mires. Our palynological data set further allows us to determine that isotope trends are not overly  
24 determined by the source of carbon in the basins. Our study suggests that the observed patterns  
25 were primarily produced by variations of the isotope ratios of terrestrial atmospheric carbon  
26 reservoirs. Even with our less than well constrained biostratigraphic control, the data indicate that  
27 the carbon isotope excursions seen in the Eocene and Oligocene could be associated with several  
28 transient carbon isotopic shifts (associated with the Palaeocene-Eocene Thermal Maximum). Our

29 findings therefore appear to lend support to the surface ocean and atmosphere behaving as  
30 coupled reservoirs at this time.

31

32 Keywords: Eocene Oligocene Petrockstowe Bovey terrestrial carbon isotope, Palynological analyses

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## 38 1. Introduction

39 The terrestrial sediments of the Petrockstowe and Bovey basins in Devon, UK offer an  
40 opportunity to examine the carbon cycle during the Eocene–Oligocene transition (~33.9 million  
41 years ago), an interval, that saw a climate shift from a largely ice-free greenhouse conditions to an  
42 icehouse world (Miller et al., 2009; Coxall and Wilson, 2011; Hutchinson et al. 2021). At this time  
43 major changes in fauna and flora record a shift toward more cold-climate-adapted species (e.g., Sun  
44 et al., 2014). For this pivotal interval in Earth's climate, our understanding the role of the carbon  
45 cycle, is much more limited (Coxall and Wilson, 2011; Armstrong McKay et al. 2016). Across the  
46 Eocene–Oligocene boundary a positive carbon isotope( $\delta^{13}\text{C}$ ) excursion of ~1.0‰ is typically  
47 recorded in the marine record followed by a decline to pre-excursion values (~0.7‰) in the  
48 Oligocene (e.g., Nilsen et al. 2003; Armstrong McKay et al. 2016). This well-documented  
49 perturbation may be used to correlate marine and terrestrial sections from around the globe as  
50 previous studies have shown that  $\delta^{13}\text{C}$  obtained from terrestrial organic material such as wood and  
51 lignites typically records a global signal (e.g., Heimhofer et al., 2003; Collinson et al. 2003; Gröcke et  
52 al. 2005; Bechtel et al. 2009; Hodgson et al. 2011; Jerrett et al. 2015; Lenz et al. 2022).

53 The Petrockstowe and Bovey basins lie on the Sticklepath - Lustleigh Fault and owe their  
54 origin to subsidence within this zone (Blyth 1962, Dearman 1963). About 600 m of Eocene–  
55 Oligocene sediments are present in the Petrockstowe Basin (Freshney et al. 1979) and ~ 1200 m in  
56 the Bovey Basin (Edwards 1976). In this study, we present new organic  $\delta^{13}\text{C}$  data from terrestrial  
57 Eocene–Oligocene aged sediments from these basins. Our data is used to improve age constraints  
58 on the succession via comparison of our terrestrial  $\delta^{13}\text{C}$  record with that of the extensively  
59 described time-equivalent marine sections. The similarity and magnitude of the  $\delta^{13}\text{C}$  excursions  
60 between terrestrial and marine records can also be used to assess whether these archives behaved  
61 as coupled reservoirs during this time.

62

## 63 2. Location and Geological setting

64 The Petrockstowe Basin, nr Newton Abbott, Devon, UK (Fig. 1), lies on the Sticklepath –  
65 Lustleigh Fault (Dearman 1963; Holloway and Chadwick, 1986). The fault became active during the  
66 Paleogene and most activity ceased before deposition of the upper part of the Bovey Formation  
67 (Blyth 1962). Bristow and Robson (1994) proposed a structural model for the development of the  
68 basin – a pull-push model – and suggested that the development was in two phases: an early,

69 transitional phase, during which much of the sedimentation occurred, and a subsequent  
70 transpressional phase in which boundary thrust faults developed. Geophysical measurements,  
71 confirmed by a British Geological Survey (BGS) borehole from the centre of the basin proved a basin  
72 fill of 660 m of sands and silts (Freshney et al. 1979). The sediments, kaolinitic clays, silts, sands,  
73 gravels, and lignite, were likely to have been derived from weathering granite under warm  
74 temperate or sub-tropical conditions of the early Paleogene (Bristow 1968; Edwards 1976). The  
75 succession consists of fining-upwards cycles comprising of one or more of a gravel lag, gravelly  
76 sands, silty sands, and are probably representative of point bar and swale-fill deposits of a river  
77 system. These interstratify with clays and silts of lacustrine origin (Freshney 1970; Freshney et al.  
78 1979). Based on palynological evidence, Turner (cited by Freshney et al. 1979) suggested these  
79 were deposited in a subtropical climate with palms, ferns and heathers and many plants with  
80 swamp affinities.

81 The Bovey Basin is located between Newton Abbot, Kingsteignton and Bovey Tracey, Devon  
82 UK (Fig. 2) and is 45 km southeast of the Petrockstowe Basin. The Bovey Basin lies southeast of the  
83 Dartmoor granite and is approximately 7 km from east to west and 5 km from north to south. In the  
84 northern and eastern boundaries of the basin there are sedimentary contacts between the  
85 Dartmoor granite and the Upper Greensand and Aller Gravel. The bulk of the basin is filled by a  
86 thick (~ 1200 m) succession of Paleogene kaolinitic clays, silty clays, silts, lignites and sands,  
87 referred to as the Bovey Formation (Edwards 1976). Edwards (1976) proposed a morphological sub-  
88 division of the basin into two parts, lying to the north and to the south of Newton Abbot. The part  
89 between Bovey Tracey and Newton Abbot is considered as the main basin; the second part lies  
90 south of Newton Abbot and is referred to as Decoy Basin (Fig. 2). Edwards and Freshney (1982)  
91 proposed an informal sub-division of the Bovey Formation into 'lower', 'middle' and 'upper'. The  
92 'lower' is not exposed and the 'middle' and 'upper' Bovey Formation includes 14 members, some of  
93 uncertain stratigraphic position or lateral equivalents and are described in detail by Edwards and  
94 Freshney (1982) and Selwood et al. (1984). Of the top 350 exposed at the surface (Edwards 1976),  
95 48 m of the Abbreek Clay and Sand and Southacre Clay and Lignite members of the 'middle' Bovey  
96 Formation were examined in the exposed working section at the South John Acre Lane Quarry.  
97 Chandler (1957) and Edwards (1976), suggest that during the Oligocene the lignites accumulated in  
98 swamps with associated fluvial sands and plant debris swept in from a warm hinterland into a lake

99 basin lying on Palaeozoic strata (see also Selwood et al. 1984). The lake was surrounded by  
100 marshland tree covered slopes (Chandler 1957).

101

### 102 **3. Age of the Petrockstowe and Bovey basins**

103 The age of the Bovey lignites has for a long time been debated (Chandler 1964). Based upon  
104 the macroflora in the lignite beds of the Bovey Formation, these were originally regarded as  
105 Miocene, but later assigned to the Oligocene (Chandler 1957, 1964). Likewise, Wilkinson (1979)  
106 cited by Selwood et al. (1984) noted that pollen from a borehole, near Heathfield that penetrated  
107 185 m of Blatchford Sand (upper Bovey Formation), 69 m of South Acre Clay and Lignite and 51 m  
108 of Abbrook Clay and Sand and from below 290 m depth, Eocene indicators like *Anacolosidites* and  
109 *Pompeckjoidaepollenites* were observed (Fig. 3). It is also important to note that the Blatchford  
110 Sand is an obsolete unit name and has been replaced by the Woolley Grit Member. The South Acre  
111 Clay and Lignite Member is therefore likely to be early to middle Oligocene in age (Selwood et al.  
112 1984) and the Abbrook Clay and Sand Member would contain the Eocene–Oligocene boundary.  
113 Freshney et al. (1982) also suggested that the lowermost ~ 700–800 m of the Bovey Formation  
114 could probably be assigned to Eocene (see also Wilkinson et al. 1980; Wilkinson and Boulter, 1981).  
115 For the Petrockstowe Basin, Turner (cited by Freshney et al. 1979) reported that pollen data  
116 indicate a boundary between the Oligocene and Eocene at ~120 m depth in the BGS Borehole No.1  
117 (Fig. 3).

### 118 **4. Methods**

119 From Petrockstowe 2 borehole cores (Petrockstowe 1A and 1B) held in the core repository  
120 at the BGS, Keyworth, Nottingham, UK were logged, and sub sampled. The sampled section was 640  
121 m long, and samples were collected, on average, every 6 m. Within the region of the Eocene  
122 Oligocene boundary as proposed by Turner (cited by Freshney et al. 1979), as well as the early  
123 Eocene of Core 1B higher resolution sampling was undertaken. In the Bovey Basin, the Abbrook  
124 Clay and Sand and Southacre Clay and Lignite members of the Bovey Formation from the accessible  
125 exposed working section at South John Acre Lane Quarry (Grid Reference SX 858758) were  
126 sampled. The sampled section was 48 m and samples were collected, on average, every 0.6 m. It  
127 was necessary to excavate the sediment surface by up to 0.5 m before sampling with a trowel to  
128 ensure fresh samples. All sediment types were sampled.

129 For the determination of the carbon isotope composition of total organic carbon ( $\delta^{13}\text{C}_{\text{TOC}}$ ),  
130 samples were ground to a fine powder using an agate pestle and mortar. Powdered samples were  
131 decarbonated by placing each sample in a 50 ml polypropylene centrifuge tube and treating with  
132 10% HCl for 1 h until any carbonate had reacted. Samples were then rinsed with deionized water,  
133 centrifuged, and rinsed again until neutrality was reached (using universal indicator paper). For  
134  $\delta^{13}\text{C}_{\text{TOC}}$  analysis, samples were weighed, to achieve  $\sim 0.5$  mg TOC, into a tin capsule and placed into  
135 a Carlo Erba 1500 EA for analysis using an online VG Triple Trap Mass Spectrometer. The  $\delta^{13}\text{C}_{\text{TOC}}$   
136 results were calibrated against Vienna PeeDee Belemnite (V-PDB) through laboratory (BROC1) and  
137 International Standards (NBS19, NBS22, CH6). Standards were evenly distributed throughout the  
138 individual isotope runs to correct for daily drift. The mean standard deviation on replicate  $\delta^{13}\text{C}_{\text{TOC}}$   
139 analyses of laboratory standard (BROC1) and soil (SOILB) was between  $\pm 0.1\%$  and  $0.5\%$  (1  
140 Standard Deviation,  $\sigma$ ) for  $\delta^{13}\text{C}_{\text{TOC}}$ . Replicate analyses showed an average precision of  $\pm 0.1\%$ . TOC  
141 content for each sample was measured using a Carlo Erba 1500 elemental analyser with acetanilide  
142 used as the calibration standard.

143 Palynological analyses were used to unravel the type of organic matter associated with the  
144 sediments and as a means of determining the source of carbon reservoir in the basins. Samples  
145 were processed using standard palynological processing (Brown, 2008)(hydrochloric acid followed  
146 by hydrofluoric acid for demineralisation). Slides were studied using a Zeiss standard microscope,  
147 normally using standard transmitted light. This is the first time such a method was used in both  
148 Petrockstowe and Bovey basins. To achieve this, counts of  $>300$  organic matter types from each  
149 sample was made. There are several schemes to classify different components of the particulate  
150 organic matter (e.g., Tyson, 1995, Aggarwal et al., 2019). Four main categories of palynological  
151 matter were identified in this study (Fig. 4): (1) Non-opaque phytoclasts includes woody remains,  
152 tracheid material, poorly lignified, tissue fragments derived from higher plants, yellowish-brown  
153 organic remains (2) Opaque phytoclast includes palynodebris with irregular shapes and charcoal (3)  
154 Palynomorphs in this study include pollen, spores and undifferentiated forms (4) amorphous  
155 organic matter (AOM) and other palynodebris which appears grey, pale yellow or brown in colour,  
156 partly translucent masses of variable thickness and with no cellular detail. The AOM group probably  
157 originates from bacteria, phytoplankton and degraded organic aggregates. Their size varies from  $<5$   
158 to about  $45\ \mu\text{m}$  in diameter.

## 159 5. Results

### 160 5.1 Total Organic Carbon (%TOC)

161 The sediments from the Petrockstowe core have highly varying wt. % TOC values ranging  
162 from 0.02 to 42.7 wt. % TOC (Fig. 5). Unsurprisingly, the highest %TOC values coincide with the  
163 lignitic clays and lignites. These lignitic clays and lignites are seen in the middle and upper parts of  
164 the core (Core 1A). The lower part (core 1B) consists mostly of gravels, sands, and clays with very  
165 low wt. % TOC contents. The wt. % TOC values from the South John Acres Lane Quarry section,  
166 Bovey Basin, range from 0.1 to 61.8 % (Fig. 6). As for the Petrockstowe Basin, the highest wt. % TOC  
167 values coincide with either lignitic clays or the lignites. These sediments are seen within the  
168 Southacre Clay and Lignite Member whereas the underlying Abbrook Clay and Sand Member is  
169 dominated by sands and silty clays with fewer lignitic clay beds.

### 170 5.2 Palynology

171 Within the cores of the Petrockstowe Basin, the lowermost interval shows a palynological  
172 distribution dominated by phytoclasts with at certain intervals nearly 100% and low palynomorphs  
173 and AOM. The upper part of the core is dominated by much higher concentrations of palynomorphs  
174 and an increase in AOM (up to 37%) and low concentrations of phytoclasts.

175 With respect to South John Acres Lane Quarry section, Bovey Basin, phytoclasts are highest in the  
176 Abbrook Clay and Sand Member. When phytoclasts are high (opaque phytoclasts reach 91%), the  
177 palynomorphs shows lowest concentrations and vice versa. High AOM concentrations (up to 66%)  
178 are seen at the base of Abbrook Clay and Sand Member and decline upwards. In the overlying  
179 Southacre Clay and Lignite Member, dominated by lignites, opaque phytoclast concentrations are  
180 low, palynomorphs consistently high (spore-pollen and non-opaque phytoclasts reach 95%, Fig. 6).

### 181 5.3 Carbon Isotopes ( $\delta^{13}C_{TOC}$ )

182 The  $\delta^{13}C_{TOC}$  values of samples in the Petrockstowe cores range from  $-28.5\text{‰}$  to  $-23.5\text{‰}$   
183 with a mean value of  $-26.5\text{‰}$ . As can be seen in Figure 5, values at the base of core 1B begins with  
184 a  $\delta^{13}C_{TOC}$  value of  $\sim -26.1\text{‰}$  at 645 m. A carbon isotope excursion with a magnitude of  $\sim 2.5\text{‰}$  can  
185 be seen at  $\sim 586$  m depth with  $\delta^{13}C_{TOC}$  values reaching a minimum of  $-28.6\text{‰}$ . The entire excursion  
186 occurs over a thickness of  $\sim 19$  m, from 586 – 605 m. The data then shows a return to more positive  
187 values of  $-26.2\text{‰}$  at 585 m. Thereafter, the  $\delta^{13}C_{TOC}$  values remain relatively consistent between 584  
188 m and 540 m with  $\delta^{13}C_{TOC}$  in the range of  $-27.0\text{‰}$  and  $-26.3\text{‰}$ . There is a lack of core (because of



189 poor recovery) between 513.59 m to 431.60 m. In the upper part of the Petrockstowe 1A core, the  
190  $\delta^{13}\text{C}_{\text{TOC}}$  values generally vary around  $-26.0\text{‰}$ . In the uppermost (Oligocene) part of the core the  
191 most positive  $\delta^{13}\text{C}_{\text{TOC}}$  values are seen.

192 At South John Acres Lane Quarry section, Bovey Basin the  $\delta^{13}\text{C}_{\text{TOC}}$  values range between –  
193  $27.8\text{‰}$  to  $-22.5\text{‰}$  with a mean value of  $-26.0\text{‰}$  (Fig. 6). In this succession,  $\delta^{13}\text{C}_{\text{TOC}}$  values show  
194 limited variability. In the uppermost (Oligocene) part of the section within the lignitic clays and  
195 lignites the most positive  $\delta^{13}\text{C}_{\text{TOC}}$  values ( $-22.5\text{‰}$ ) are found.

196

## 197 **6. Discussion**

### 198 *6.1 Palynological Interpretation*

199 In the Petrockstowe 1A and 1B cores, close to the base of the succession the high opaque  
200 phytoclast content, together with low TOC values (down to 0.1 wt. %), and low AOM and non-  
201 opaque phytoclast contents may be related to local oxidation of organic matter (Figs. 5, 7) or  
202 diagenesis. Opaque phytoclasts are typically derived from the oxidation of structured organic  
203 matters (translucent brown wood, tracheids, cuticle, etc.) and along with a low proportion of the  
204 other organic matter types has been documented in oxic swamps and river sediments (e.g., Martín-  
205 Closas et al., 2005; Pieńkowski and Waksmundzka, 2009). In the upper part of the Petrockstowe  
206 section (Fig. 5) palynomorphs dominate which could indicate suboxic/anoxic waters (Tyson, 1995).  
207 Consequently, a restriction of water circulation rather than productivity, may serve as the  
208 controlling factor for the organic rich sediment accumulation. Also, the fluctuating, but relatively  
209 high percentages of palynomorphs and AOM (up to 37%), could suggest diverse source of areas of  
210 the organic matter (e.g., Martín-Closas et al. 2005) with deposition within an ephemeral lake or lake  
211 margin. These observations agree with the Petrockstowe 1A and 1B cores, representing a  
212 succession of sand-filled fluvial channels followed by an ephemeral lake or lake margin setting (Fig.  
213 5, see Freshney et al., 1979). This represents an overall deepening-up sequence.

214 In the Abbrook Clay and Sand and Southacre Clay and Lignite members, the base sees a  
215 diversity in palynological types (Fig. 6) with high percentage of AOM and phytoclasts potentially  
216 reflecting enhanced preservation in low energy, stagnant, oxygen depleted environment (Tyson  
217 1995, Fig. 7). Only a single high opaque phytoclast level is seen, possibly associated with deposition

218 within an oxidising environment. In the overlying Southacre Clay and Lignite Member, dominated  
219 by lignites, palynomorph concentrations are consistently high and as such suggests a depositional  
220 environment associated with a swamp or ephemeral lake or marginal lake. These observations are  
221 in agreement that the Abbrook Clay and Sand and Southacre Clay and Lignite members of the  
222 Bovey Formation, represents a long-lived lake followed by sediments representing more ephemeral  
223 lakes or lake margins periodically exposed with mires (see Chandler, 1964; Edwards, 1976).

224 Our palynological data set further allows us to determine whether isotope trends are carbon  
225 source related. For example, within the Abbrook Clay and Sand Member, when phytoclasts are  
226 high, the palynomorphs shows lowest concentrations and vice versa. High, but variable, AOM  
227 concentrations are also seen. No correspondence is seen here with fluctuations in carbon isotopes,  
228 suggesting organic matter associated with the sediments is not overly determining the source of  
229 the carbon reservoir in the basins. Nevertheless, changes in the dominance of gymnosperms,  
230 angiosperms or pteridophytes/bryophytes within the vegetation could be of importance.

## 231 *6.2 Carbon isotope trends*

232 Carbon isotopic ratios from terrestrial organic materials have been previously used to study  
233 global carbon-isotope excursions in the Cenozoic (Collinson et al. 2003, Bechtel et al. 2009;  
234 Holdgate et al. 2009; Hodgson et al. 2011; Fang et al., 2013; Jerrett et al. 2015; Garel et al. 2020;  
235 Lenz et al. 2022). These studies (which use discrete plant fragments, lignites or disseminated  
236 organic matter) identify reproducible patterns in atmospheric carbon isotopic compositions. There  
237 are just a few terrestrially sourced high-resolution carbon isotope stratigraphies to compare our  
238 Eocene and Oligocene data to (e.g., Holdgate et al. 2009; Garel et al. 2020). Nevertheless, our  
239  $\delta^{13}\text{C}_{\text{TOC}}$  data are, consistent with terrestrially sourced  $\delta^{13}\text{C}$  values of the Eocene (e.g., Collinson et al.  
240 2003, Bechtel et al. 2009; Hodgson et al. 2011). Considering the carbon isotope excursion of -2.5‰  
241 from the lower part of Petrockstowe core 1B (Fig. 5), the magnitude of this excursion falls within  
242 the lower limit of that is associated with the Palaeocene-Eocene Thermal Maximum (PETM), which  
243 ranges from -2.4 to -6.3‰ (see summary of McInerney and Wing 2011). This suggests it could be  
244 related to this event. However, biostratigraphically there is limited data from the Petrockstowe  
245 core (see Turner cited by Freshney et al. 1979). The biostratigraphic constraints allow the carbon  
246 isotope excursion to also be associated with one of the other transient carbon isotopic shifts that  
247 occurred after the Palaeocene-Eocene Thermal Maximum i.e., the Eocene Thermal Maximum (ETM-  
248 2). For example, the magnitude of the ETM-2 carbon isotope excursion documented in the

249 continental succession of the McCullough peaks, Bighorn Basin, Wyoming, USA, using paleosol  
250 carbonate is of  $-3.8\text{‰}$  (Abels et al. 2012).

251 The presence of the Eocene – Oligocene boundary in the Petrockstowe core 1A has been  
252 proposed, based on pollen data, by Turner (cited by Freshney et al. 1979). The Abbrook Clay and  
253 Sand Member is also likely to contain the Eocene–Oligocene boundary (Selwood et al. 1984) but  
254 because of the limited biostratigraphic data the exact positioning of the boundary is less certain.  
255 The Eocene – Oligocene boundary is one of the most prominent abrupt climatic events in the  
256 Cenozoic and is considered to represent the initiation of major permanent Palaeogene ice sheets  
257 on Antarctica (Miller et al., 2009; Coxall and Wilson, 2011; Hutchinson et al. 2021). The glaciation of  
258 Antarctica is thought to result from the tectonic opening of Southern Ocean gateways, which  
259 enabled the formation of the Antarctic Circumpolar Current and the subsequent thermal isolation  
260 of the Antarctic continent (e.g., Zachos et al. 2001) Modelling studies implicate low atmospheric  
261  $\text{CO}_2$  also as an important factor (DeConto and Pollard, 2003). The carbon isotope changes across  
262 this boundary are, however, less pronounced, and certainly less well documented in the terrestrial  
263 system. This is perhaps due to the lack of suitable terrestrial sections to study.

264 Nevertheless, the marine records (Zachos et al. 2001; Coxall and Wilson, 2011) show a  $\delta^{13}\text{C}$   
265 excursion of  $\sim 1.0\text{‰}$  in benthic foraminifera, peaking in the earliest Oligocene and followed by a  
266 decline to  $\sim 0.5\text{‰}$ , 1 million years after the boundary. The Petrockstowe and Bovey  $\delta^{13}\text{C}_{\text{TOC}}$  data do  
267 show some correspondence with this marine record whereby for the Eocene stable but the most  
268 negative carbon values are observed, whereas the most positive carbon isotope values are present  
269 in the Oligocene. More positive  $\delta^{13}\text{C}_{\text{TOC}}$  values have been linked to increased organic carbon burial  
270 (Coxall and Wilson, 2011). Our study therefore supports the notion that the surface ocean and  
271 atmosphere behaved as coupled reservoirs at this time, similar to other times in the Cenozoic  
272 (Jerrett et al. 2015; Cui et al., 2021; Lenz et al. 2022), as opposed to a decoupled system (cf.  
273 Holdgate et al. 2009; Fang et al., 2013), but more data is required to fully test this possibility.

## 274 **7. Conclusions**

275 In conclusion, and in agreement with Freshney et al., (1979), our palynological observations  
276 show that the Petrockstowe 1A and 1B cores, represent a succession of sand-filled fluvial channels  
277 followed by an ephemeral lake or lake margin setting. The Abbrook Clay and Sand and Southacre  
278 Clay and Lignite members of the Bovey Formation, represents a long-lived lake followed by

279 sediments representing more ephemeral lakes or lake margins periodically exposed with mires (see  
280 Chandler, 1964; Edwards, 1976). Our palynological data set further allows us to determine that  
281 isotope trends are not overly determined by the source of carbon in the basins.

282 Our study suggests that the observed  $\delta^{13}\text{C}_{\text{TOC}}$  trends in the Eocene–Oligocene of the Petrockstowe  
283 and Bovey basins were primarily produced by variations of the carbon isotope ratios of terrestrial  
284 atmospheric carbon reservoirs. Even with our less than well constrained biostratigraphic control,  
285 the data indicate that the carbon isotope excursions seen in the Eocene and Oligocene could be  
286 associated with a number of transient global carbon isotopic shifts (e.g., the PETM). Our findings  
287 therefore appear to lend support to the surface ocean and atmosphere behaving as coupled  
288 reservoirs at this time.

### 289 **Acknowledgements**

290 We would like to thank the British Geological Survey for access to cores and Sibelco UK for access  
291 and information regarding South John Acres Lane Quarry. MC was funded by the Tertiary Education  
292 Trust Fund (TETFund) Abuja, via the intervention of academic staff training and development  
293 programme to the Federal University of Petroleum Resources, Effurun, Nigeria. This manuscript  
294 benefited from the extensive and constructive reviews of two anonymous reviewers, who are duly  
295 thanked.

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417

418 **Figure 1.** A. Map showing the southern part of the UK and location of inset. B. General geological  
419 map of the southwest UK showing Petrockstowe and Bovey basins (modified from Bristow  
420 and Robson 1994).

421 **Figure 2.** A. Map showing the location of Petrockstowe and Bovey basins (modified from Bristow  
422 and Robson 1994). B. Geological map of the Petrockstowe Basin showing the location of  
423 Borehole 1 (cores 1A and 1B) and the relative positions of the axial trough and the marginal  
424 shelves with their dividing fault (modified from Freshney 1970; Freshney et al., 1979). C.  
425 Geological map of the Bovey Basin showing the location of the South John Acres Lane  
426 Quarry (modified from Selwood et al. 1984).

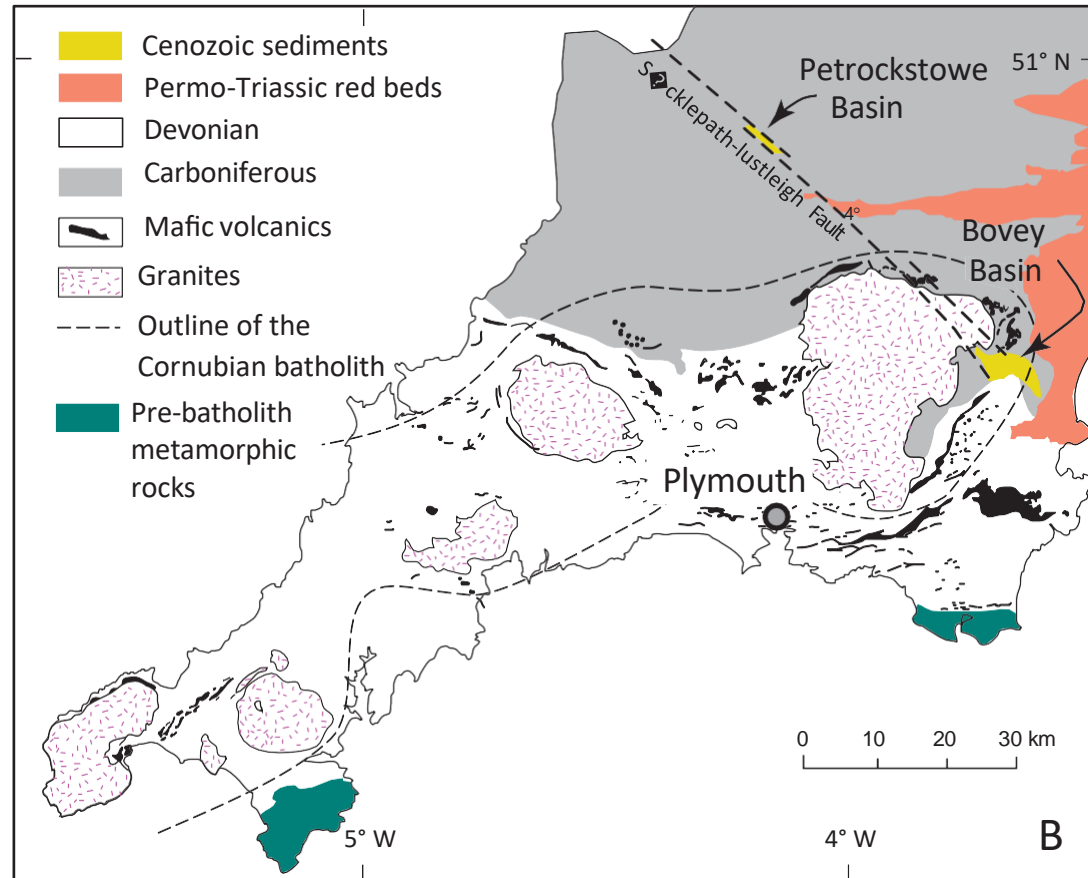
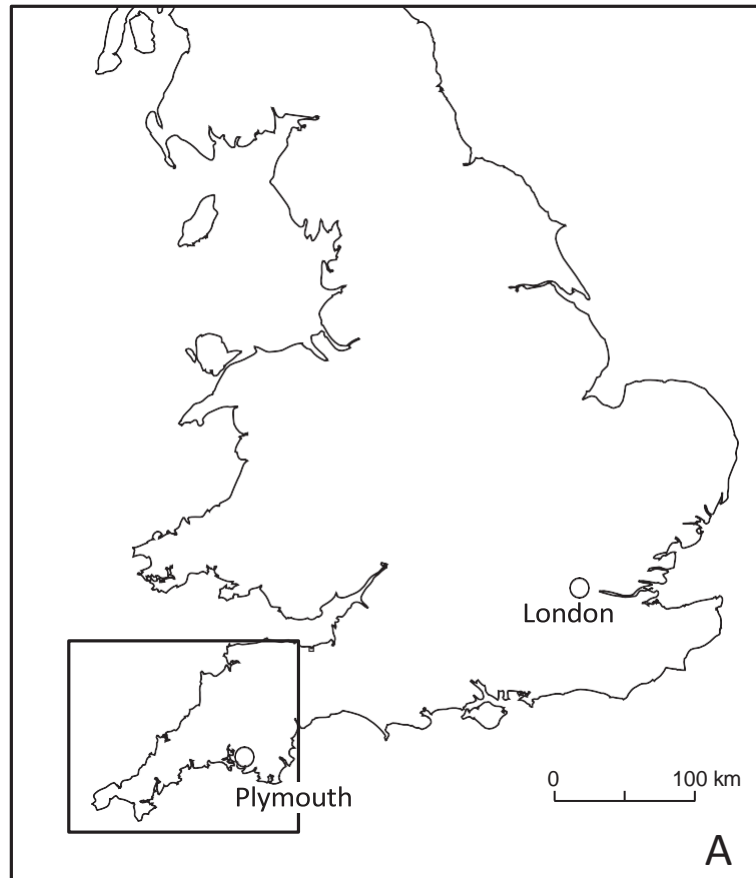
427 **Figure 3.** Summary stratigraphic logs (and correlation) of the Bovey succession with data derived  
428 from (Edwards 1976) and Wilkinson (1979) cited by Selwood et al. (1984) and Petrockstowe  
429 with age data from Turner (cited by Freshney et al. 1979).

430 **Figure 4.** Phytoclasts from the Petrockstowe and Bovey basins. (A) Opaque lath-shaped phytoclast,  
431 sample MC95 Petrockstowe Basin; (B) Large opaque lath shaped phytoclast; sample MC3  
432 Petrockstowe; (C) Multicellular fungal 'fruiting body', sample MC19 Petrockstowe; (D) Mass  
433 of melanised fungal hyphae; sample MC58, Petrockstowe. (E) Multicellular fungal 'fruiting  
434 body' sample MC19, Petrockstowe. (F) Well preserved, pale brown in colour, partly  
435 translucent AOM sample SJAL029, Bovey Basin. (G) well preserved pale yellow AOM seen in  
436 transmitted white light; sample SJAL002, Bovey Basin (H) is a cross section of plant fragment  
437 sample SJAL013, Bovey Basin; (I) Phytoclast (biostructured) composed of gymnosperm  
438 tracheids; sample MC76 Petrockstowe Basin.

439 **Figure 5.** TOC and  $\delta^{13}\text{C}_{\text{TOC}}$  data, compared to palynological data, Petrockstowe Basin, Devon. Age  
440 assignments based on Wilkinson (1979) cited by Selwood et al. (1984).

441 **Figure 6.** TOC and  $\delta^{13}\text{C}_{\text{TOC}}$  data, compared to palynological data, Bovey Basin, Devon. Age  
442 assignments of Turner (cited by Freshney et al. 1979).

443 **Figure 7.** Distribution of the different categories of palynological matter in the ternary diagram  
444 (proposed by Hacquebard and Donaldson, 1969 and modified by Marchionni, 1980; and  
445 Aggarwal et al., 2022).



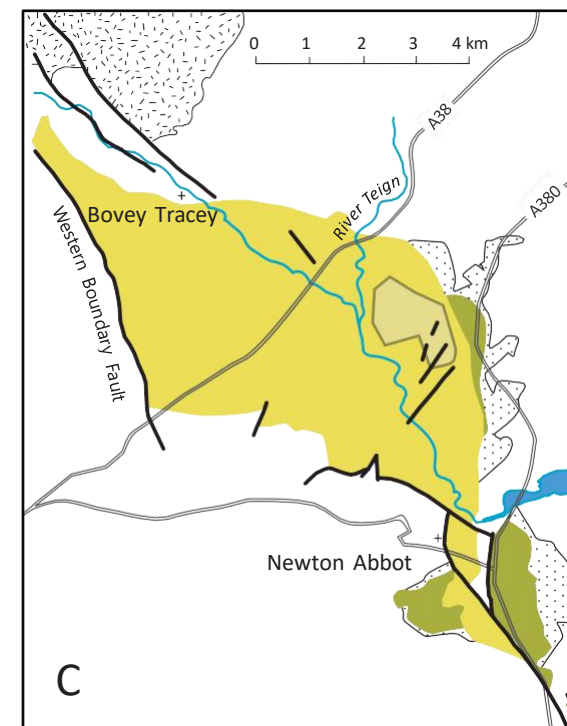
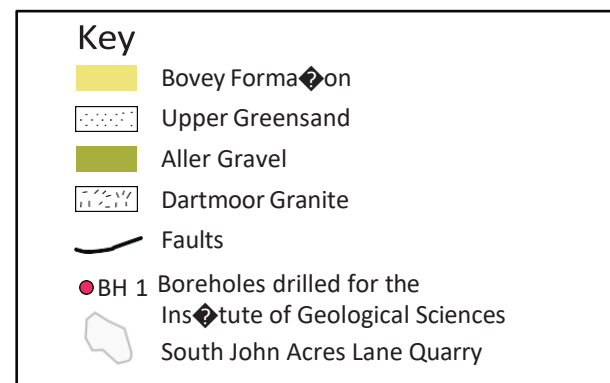
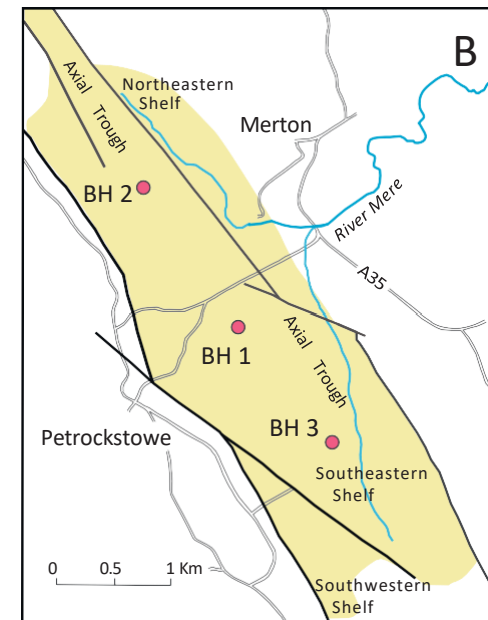
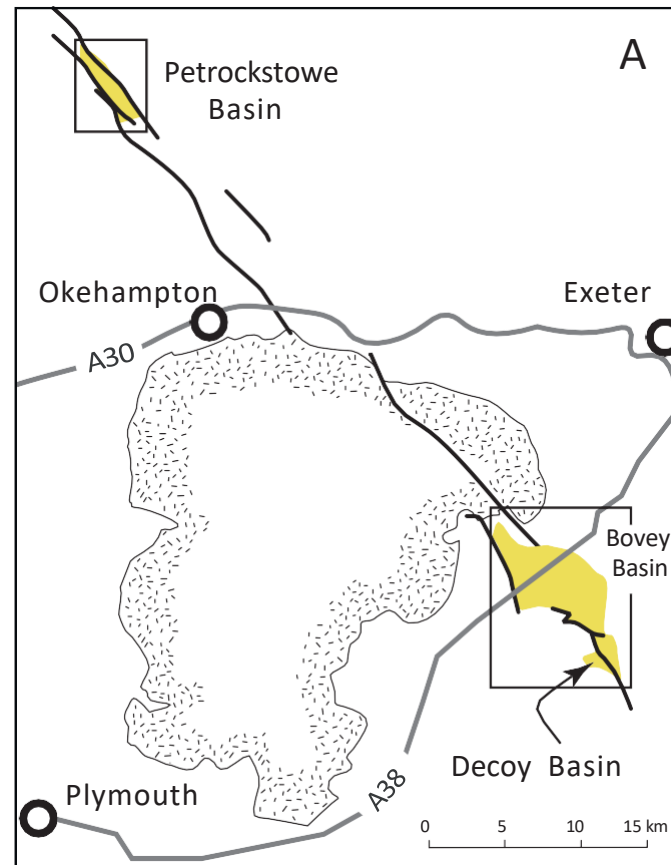
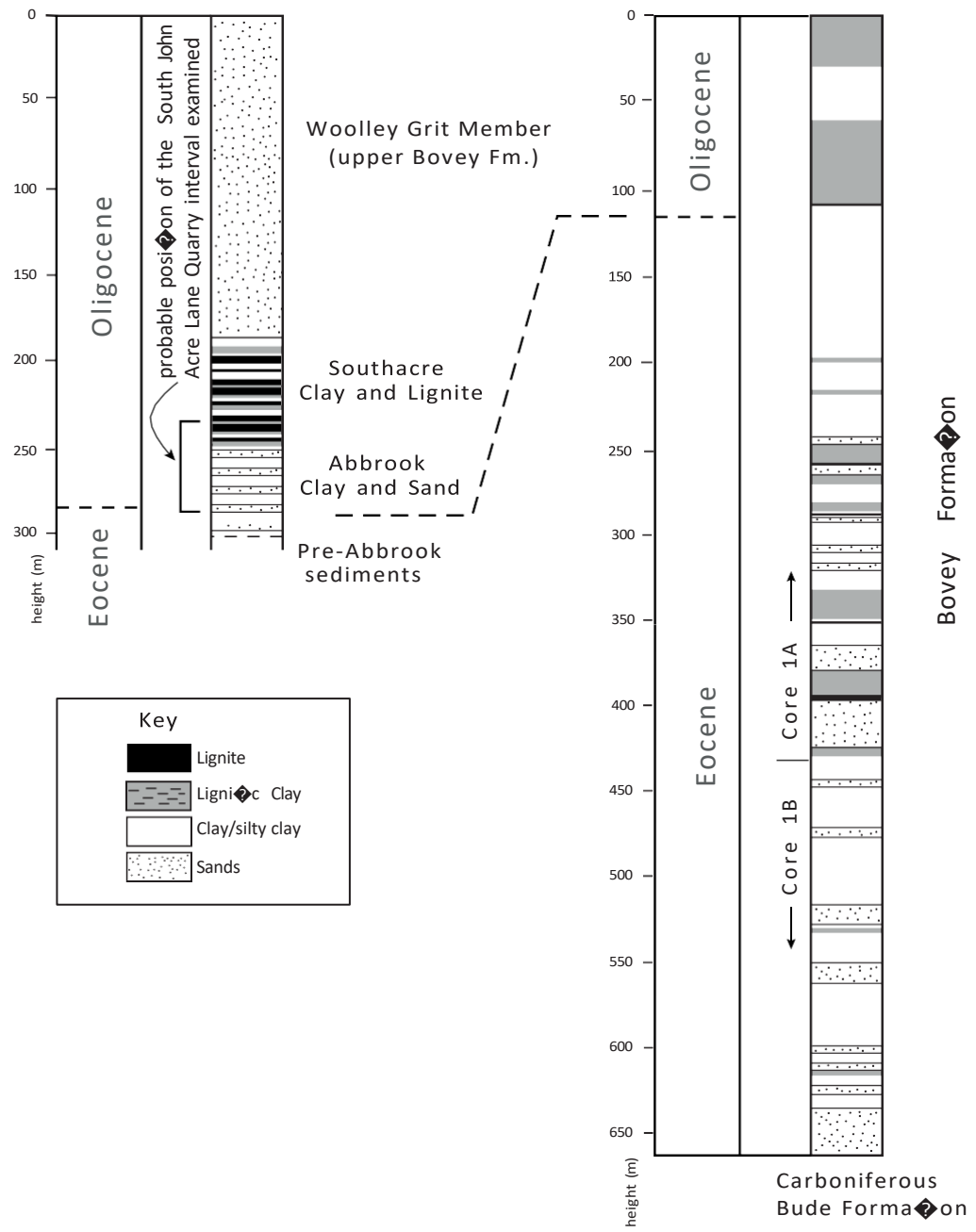


Fig 3



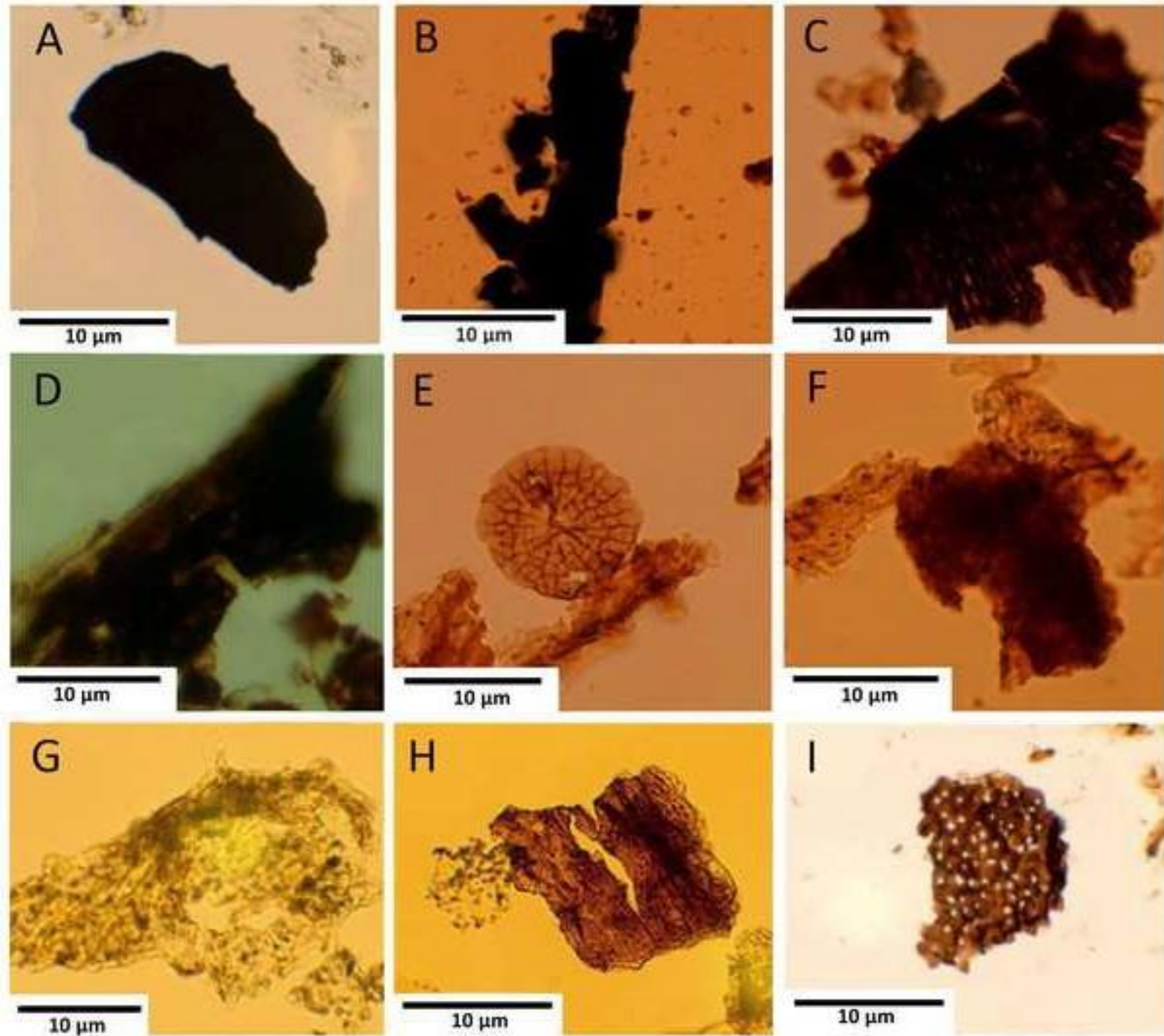


Fig 5

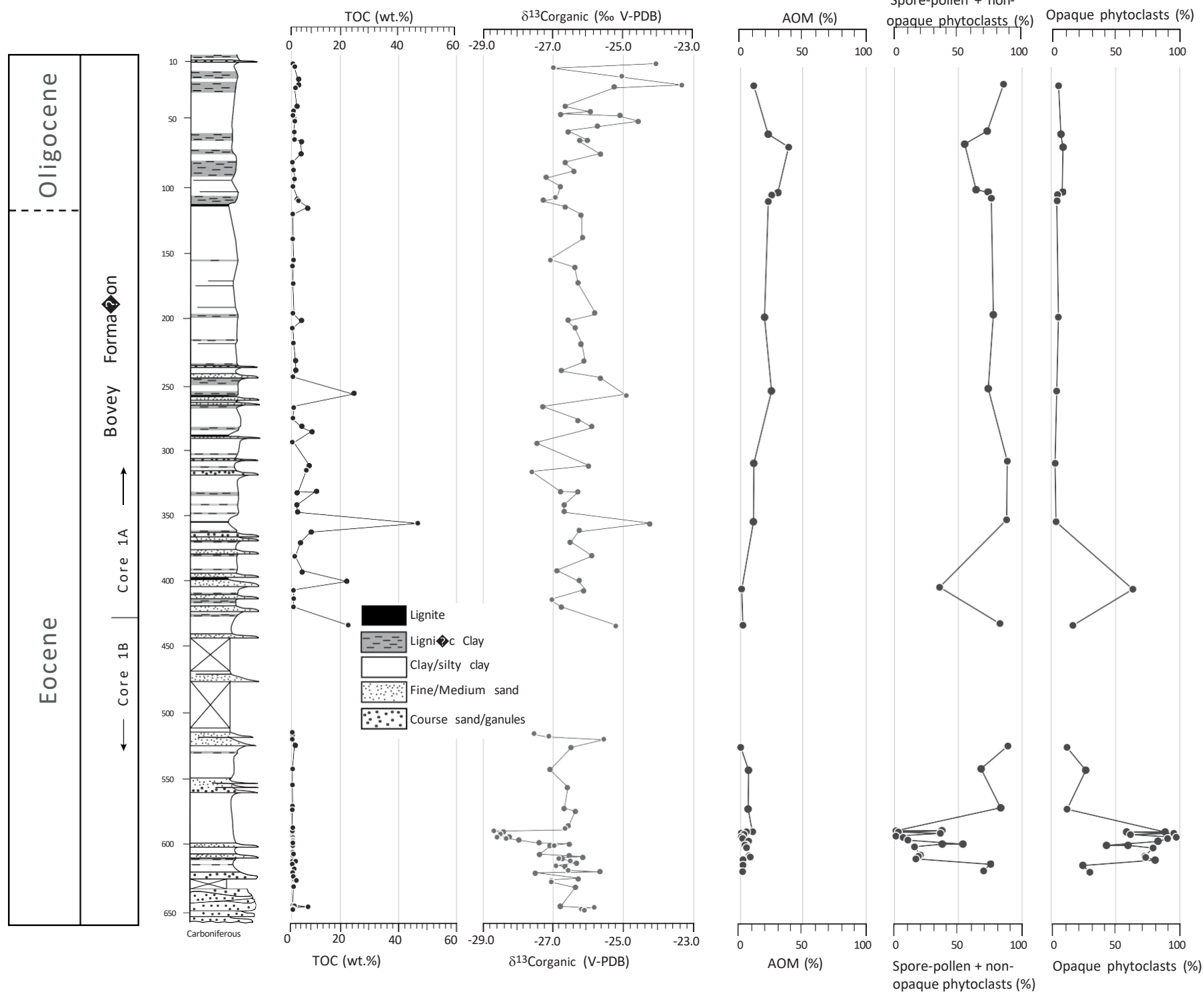
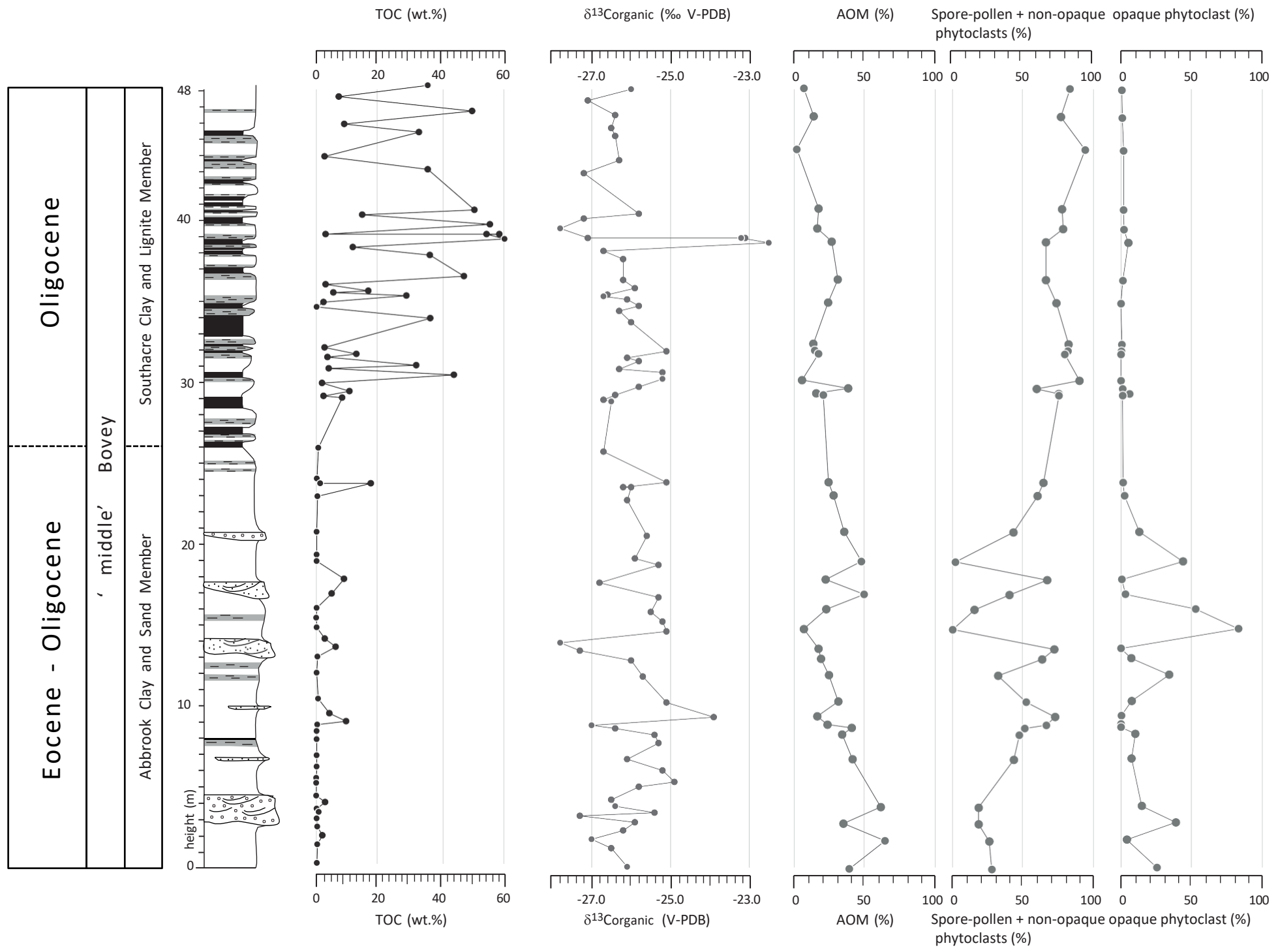
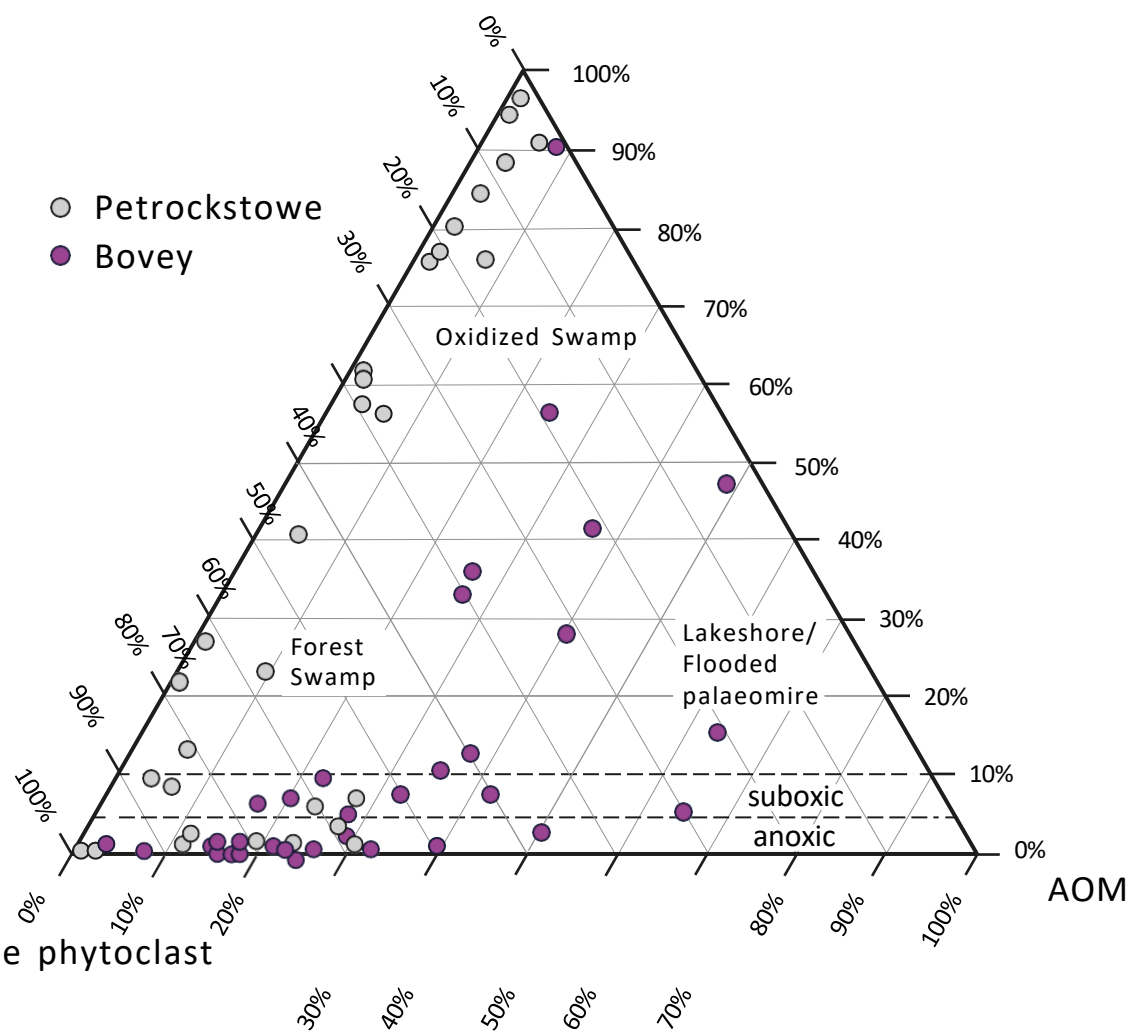


Fig 6



### opaque phytoclast

- Petrockstowe
- Bovey





Our m/s has not been published previously (except in the form of an abstract) and it is not under consideration for publication elsewhere. The publication is approved by all authors.

