

1 A revised northern European Turonian (Upper Cretaceous)
2 dinoflagellate cyst biostratigraphy: integrating palynology and carbon
3 isotope events

4 Kate Olde ^a, Ian Jarvis ^{a*}, Martin Pearce ^b, David Uličný ^c, Bruce Tocher ^d,

5 João Trabucho-Alexandre ^{e,f}, Darren Gröcke ^e

6 ^a *Kingston University London, Centre for Earth and Environmental Sciences Research,*

7 *School of Geography, Geology and Environment, Kingston upon Thames KT1 2EE, UK*

8 ^b *Evolution Applied Ltd, 50 Mitchell Way, Upper Rissington, Cheltenham GL54 2PL, UK*

9 ^c *Institute of Geophysics, Academy of Sciences of the Czech Republic, 141 31 Prague, Czech Republic*

10 ^d *Statoil, 2103 CityWest Blvd Ste 800, Houston TX 77042-2834, USA*

11 ^e *Department of Earth Sciences, University of Durham, Durham DH1 3LE, UK*

12 ^f *Institute of Earth Sciences Utrecht, Budapestlaan 4, 3584 CD Utrecht, Netherlands*

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21 * Corresponding author at: School of Geography, Geology and Environment, Kingston University
22 London, Penrhyn Road, Kingston upon Thames Surrey KT1 2EE, UK.

23 Tel: +44 208 4172526.

24

25 *E-mail addresses:* kateolde@gmail.com (K.J. Olde), i.jarvis@kingston.ac.uk (I. Jarvis),
26 info@evolutionapplied.com (M.A. Pearce), ulicny@ig.cas.cz (D. Uličný), bruce@statoil.com (B.A.
27 Tocher), j.trabucho@uu.nl (J. Trabucho-Alexandre), d.r.grocke@durham.ac.uk (D.R. Gröcke).

28 ABSTRACT

29 Organic walled dinoflagellate cyst (dinocyst) assemblage data are presented for a new
30 Turonian regional reference core (Bch-1) drilled at Běchary in the Bohemian Cretaceous
31 Basin, east-central Czech Republic. The detailed stratigraphic framework for the section is
32 summarised based on calcareous nannofossil and macrofossil biostratigraphy, regional e-log
33 correlation, sequence stratigraphy and carbon isotope chemostratigraphy. Dinocyst results
34 obtained for 196 samples from the 405 m long core offer the highest resolution (~22 kyr)
35 stratigraphically well-constrained data set available to date for the Turonian Stage, 93.9 – 89.8
36 Ma. A dinocyst biostratigraphic framework is presented based on the evolutionary first and
37 last occurrence, first common occurrence, and acmes of key species. Published dinocyst data
38 from English Turonian Chalk successions in East Sussex, Berkshire, Kent and Norfolk are
39 reviewed within a stratigraphic framework provided by macrofossil records and carbon
40 isotope event (CIE) chemostratigraphy. Critical analysis of existing published Turonian
41 dinocyst zonation schemes shows them to be untenable. Correlation of the English Chalk
42 data to Bch-1 provides a basis for defining a regional dinocyst event stratigraphy with 22
43 datum levels, and a revised dinocyst zonation scheme constrained within a chemostratigraphic
44 framework of 10 major CIEs. The new zones consist of a Cenomanian *Litosphaeridium*
45 *siphoniphorum* Zone, followed by the *Cauveridinium membraniphorum* Zone spanning the
46 uppermost Cenomanian to Lower Coniacian. This is subdivided into: *Senoniasphaera*
47 *turonica* (Lower – mid-Middle Turonian); and *Raetiaedinium truncigerum* (mid-Middle
48 Turonian – mid-Lower Coniacian) subzones. The *Oligosphaeridium pulcherrimum* Zone
49 (*Senonisphaera rotundata* Subzone) characterises the Lower Coniacian. The new
50 stratigraphy offers a basis for improved correlation and dating of Upper Cretaceous
51 successions.

52 **1. Introduction**

53 Over the last 40 years, a substantial amount of work has been undertaken on the
54 biostratigraphy of Turonian organic walled dinoflagellate cysts (dinocysts) from the English
55 and French Chalk and its correlatives in the Anglo-Paris Basin (Clarke and Verdier, 1967;
56 Foucher, 1974, 1975, 1976a, 1980, 1981, 1983; Tocher, 1984; Tocher and Jarvis, 1987, 1994,
57 1995; Jarvis et al., 1987, 1988a, b; FitzPatrick, 1992, 1995, 1996; Pearce, 2000, 2010; Pearce
58 et al., 2003, 2009; Prince et al., 2008; Lignum, 2009). However, to our knowledge, little has
59 been published previously on the Turonian – Coniacian dinocyst biostratigraphy of Central
60 Europe, notable exceptions being the work of Prössl (1990), Kirsch (1991) and Svobodová et
61 al. (1998, 2002).

62 Here, new dinocyst data are presented from an expanded (> 300 m thick) Turonian
63 hemipelagic succession in a fully cored research borehole drilled recently in the Bohemian
64 Cretaceous Basin at Běchary, east-central Czech Republic. Dinocyst records from four well-
65 characterised English Chalk successions in East Sussex, Berkshire, Kent and Norfolk are
66 reviewed and integrated using macrofossil biostratigraphy, lithostratigraphy and carbon
67 isotope chemostratigraphy (Jarvis et al., 2006; Pearce et al., 2009) to provide a regional
68 framework for comparison with results from the Czech Republic. Despite marked latitudinal
69 provinciality that occurred in the Late Cretaceous (see Lentin and Williams, 1980; Costa and
70 Davey, 1992), many of our marker taxa also occur to the north of the European Chalk
71 province, well into the siliciclastic-prone facies of the Shetland Group. It is a particular
72 strength of dinocysts to have a largely facies-independent preservation potential,
73 exemplifying their use as a powerful biostratigraphic tool. In this paper, a revised dinocyst
74 zonation for the northern European Turonian tied to the carbon isotope event (CIE)

75 stratigraphy of Jarvis et al. (2006) is proposed, based on integrating the English Chalk data
76 with new results from Bch-1.

77 **2. Geological framework**

78 The Bohemian Cretaceous Basin was an intra-continental basin formed during the
79 Cenomanian – Santonian (100.5 – 83.6 Ma) as a seaway between the Boreal Sea and Alpine
80 Ocean (Fig. 1). The basin originated by the reactivation of a fault system in the Variscan
81 basement of the Bohemian Massif, and combined features of an epeiric sea formed during
82 global transgression with those of a tectonically active setting that contains probably the
83 highest proportion of siliciclastics of all the European Cretaceous basins north of the Alps
84 (Uličný et al., 1997, 2009). During Turonian – Coniacian times, sedimentation in the
85 Bohemian Basin was dominated by the repeated progradation of coarse-grained deltas and
86 adjoining shorefaces, and was affected by redistribution of siliciclastics by strong along-shore
87 tidal currents (Uličný, 2001). A maximum water depth of around 100 m is estimated for the
88 basin interior (Mitchell et al., 2010).

89 During 2010, a 405 m research core, Bch-1, was drilled through a representative Lower
90 Coniacian to Upper Cenomanian succession of offshore marine sediments in the Bohemian
91 Cretaceous Basin, to investigate the responses of multiple proxies to sea-level change (Uličný
92 et al., 2014). The Bch-1 site (50.31506°N 15.29497°E), located in the village of Běchary,
93 east-central Czech Republic, is situated in the central basin between two depocentres (Fig. 1),
94 one adjacent to the Most-Tepllice High and Western Sudetic Island in the northwest, the other
95 bordering the Bohemian Massif in the southeast. These source areas contributed varying
96 amounts of sediment through the Turonian, but with the Western Sudetic Island being by far
97 the most prominent source area.

98 The dominant lithofacies in the Bch-1 core consist of very dark grey marlstones and
99 calcareous mudstones with a varying proportion of quartz silt (Fig. 2). The mean percentage
100 of CaCO₃ through the core is ~ 35 %, and carbonate is generally represented by a micritic
101 component, some mm-scale bioclasts, and calcite spar in horizons with concretionary cement.
102 Total organic carbon contents (TOC) average 0.42%. Turonian lithofacies show abundant
103 bioturbation throughout the core, dominated by a distal *Cruziana* ichnofacies (sensu
104 MacEachern et al., 2010).

105 **3. Stratigraphic framework**

106 Deposition in the Bohemian Cretaceous Basin has been split into a number of genetic
107 sequences, termed TUR1 – TUR7, CON1 and CON2 (Fig. 2), which were detailed by Uličný
108 et al. (2009). The sequences are based on the analysis of a basin-scale correlation grid,
109 developed using well-log data (gamma-ray, resistivity, neutron porosity logs) from >700
110 boreholes, in most cases supplemented by outcrop and core data. These genetic sequences,
111 bounded by maximum transgressive surfaces, form a hierarchy of nested, composite
112 sequences, interpreted to record a response to relative sea-level changes. The sequences
113 record major cycles of regression and subsequent transgression, within which smaller scale
114 cycles also occur. Correlation of the sequence boundaries to Bch-1, as presented here, has
115 been modified from Uličný et al. (2014) in the light of new stratigraphic data.

116 The macrofossil and calcareous nannofossil biostratigraphy, along with carbon isotope data
117 for the Bch-1 core, were published by Uličný et al. (2014). Key biostratigraphic datum levels
118 are plotted here against a lithological log and the carbon isotope profile for the core in Fig. 2.

119 3.1. Litho- and biostratigraphy

120 Sediments from the bottom of the Bch-1 core (404.6 – 402.4 m) yield a Cenomanian
121 nanofossil assemblage, including *Lithraphidites acutus* Verbeek & Manivit and *Corollithion*
122 *kennedyi* Crux. The base of the Turonian (Sequence TUR1) is marked by a burrowed
123 omission surface at 402.35 m, overlain by a 70 cm thick zone of glauconite-rich marlstone
124 with phosphate concretions, interpreted as a hiatus, followed by condensed deposition
125 (Valečka and Skoček, 1991; Uličný et al., 1993; Čech et al., 2005). A second, less prominent,
126 omission surface at 398.2 m, is overlain by a 20 cm thick, glauconite-rich, greenish-grey
127 marlstone (Fig. 2). Calcareous nanofossil zones UC 5a – b (Burnett et al., 1998; correlative
128 to the uppermost Cenomanian upper *Metoicoceras geslinianum* and *Neocardioceras juddii*
129 ammonite zones) are absent, confirming the interpretation of Uličný et al. (1993) of a major
130 hiatus at this time in the central part of the basin. The first occurrence (FO) of *Eprolithus*
131 *moratus* (Stover) at 400.0 m depth indicates that at least nanofossil zones UC 5c – 6a are
132 contained in the lowermost 2.35 m of the Turonian succession in Bch-1. The prominent
133 earliest Turonian condensation event is attributed to the major flooding near the Cenomanian
134 – Turonian boundary (CTB) that established hemipelagic conditions over most of the basin
135 (Klein et al., 1979; Uličný et al., 1997).

136 The first occurrence (FO) of the ammonite *Collignoceras woollgari* (Mantell), which
137 marks the base of the Middle Turonian, appears regionally together with *Inoceramus cuvieri*
138 (Sowerby) in the middle of Sequence TUR2. This datum level is placed at 374 m in Bch-1
139 (Fig. 2; Uličný et al., 2014), based on lithostratigraphic and e-log correlation to adjacent
140 sections. An acme of *Inoceramus perplexus* Whitfield occurs at the base of Sequence TUR5.
141 This level is distinctive due to a regional abundance of inoceramid prisms, identified at 246 m
142 in the core, and correlates to the “*costellatus-plana* Event” in NW Germany (Richardt and
143 Wilmsen, 2012). The base of the Upper Turonian, marked by the FO *I. perplexus*, is

144 correlated to the upper part of Sequence TUR4/3, at 252 m depth, immediately above the first
145 (rare) occurrence of the nannofossil *Marthasterites furcatus* (Deflandre) at 255 m. An
146 ammonite fauna typical of the *S. neptuni* Zone is recorded in the middle of TUR6, at 165 m.
147 This level is interpreted to represent the *Hyphantoceras* Event, a mid-Upper Turonian datum
148 level that can be recognised in England, parts of France, Germany, Poland and the Czech
149 Republic (e.g. Wiese et al., 2004).

150 The Upper Turonian – Lower Coniacian succession at Bch-1 is well constrained by
151 inoceramid bivalve and ammonite records from the core (Fig. 2), supplemented by e-log
152 correlation of FO datum levels from adjacent cores and outcrops. The uppermost Turonian
153 index taxon *Mytiloides scupini* (Heinz) is recorded at 134 m, while the position of its true FO
154 datum level is correlated to 140 m. *Prionocyclus germari* (Reuss) occurs at 121 m, with a
155 correlated FO at 130 m. The latest Turonian succession of three bivalve acme occurrences,
156 *Didymotis* Events 0, I and II (Wood et al., 1984, 2004; Čech, 1989; Walaszczyk and Wood,
157 1998; Wiese, 1999; Walaszczyk et al., 2010) is placed between 115 – 95 m; Events I and II
158 are recorded directly in the core and the position of Event 0 is inferred by correlation. An
159 acme of *Mytiloides herbichi* (Atabekjan) occurs from 108 – 99 m depth, between *Didymotis*
160 Events I and II, as seen also on northern Germany (Wood et al., 2004).

161 The base of the Coniacian is placed at the correlated first occurrence of *Cremnoceramus*
162 *deformis erectus* (Meek) at 94 m (cf. Walaszczyk et al., 2010), at the bottom of Sequence
163 CON1 and immediately above the top of *Didymotis* Event 2; *C. d. erectus* was recovered from
164 89 m in the core (Fig. 2). An acme of *M. furcatus* spans the Turonian – Coniacian boundary
165 interval.

166 The correlated FOs of *Cremnoceramus crassus inconstans* (Woods) at 45 m and *C. crassus*
167 *crassus* (Petrascheck) at 37 m depth, and records of the latter species from the core at 33 m,

168 enable the placement of the standard European Lower Coniacian inoceramid zones
169 (Walaszczyk and Wood, 1998) in the core. The base of the Middle Coniacian is tentatively
170 placed at the FO *Micula stauropora* (nannofossil Zone UC10), at 16 m depth, a short distance
171 above the highest dinocyst sample at 17.5 m.

172 *3.2. Carbon isotope chemostratigraphy*

173 Turonian sediments display consistent secular variation in carbon isotope profiles
174 throughout northern and southern Europe (Jarvis et al., 2006; Voigt et al., 2007, 2008;
175 Richardt et al., 2013; Sprovieri et al., 2013), and remarkably similar trends have been
176 documented from as far afield as Tibet and North America (e.g. Wendler, 2013; Joo and
177 Sageman, 2014). The Cenomanian – Coniacian carbonate carbon isotope ($\delta^{13}\text{C}_{\text{carb}}$) reference
178 curve for the English Chalk (Jarvis et al., 2006) and high-resolution $\delta^{13}\text{C}_{\text{carb}}$ curves from
179 Liencres, northern Spain (Wiese, 1999) and Saltzgitter-Salder (Voigt and Hilbrecht, 1997),
180 Oerlinghausen and Halle (Voigt et al., 2007) in northern Germany, have been correlated to the
181 organic carbon isotope profile ($\delta^{13}\text{C}_{\text{org}}$) for Bch-1 by Uličný et al. (2014). A $\delta^{13}\text{C}_{\text{org}}$ profile
182 was favoured for Bch-1 due to concerns over possible diagenetic alteration in carbonate-
183 carbon profiles generated from relatively low-carbonate mudrocks. Consistent relationships
184 were demonstrated between trends in the isotope profiles and the positions of key macrofossil
185 datum levels in the different sections (Uličný et al., 2014 fig. 3). A total of 20 peaks and
186 troughs in the profile from Bch-1 were correlated between the various sections, including the
187 major named CIEs of Jarvis et al. (2006).

188 The carbon isotope stratigraphy is consistent with an incomplete and attenuated
189 Cenomanian – Turonian boundary succession at Bch-1, and the occurrence of an expanded
190 Upper Turonian to Lower Coniacian section. The positions of the 9 most significant CIEs are
191 shown for the Bch-1 section in Fig. 2, together with the primary $\delta^{13}\text{C}_{\text{org}}$ isotope data and a

192 smoothed chemostratigraphic profile. Placement of the CIEs follows Uličný et al. (2014),
193 with minor revision following the acquisition of new stratigraphic data.

194 **4. Sampling and analysis**

195 The 404.86 m Bch-1 core was drilled as a new Turonian regional reference section. Samples
196 of approximately 50 g were taken every 2 m for elemental, isotopic and palynological
197 analysis (196 samples). Based on an average compacted sedimentation rate for the Middle
198 and Upper Turonian of 9 cm/kyr (Uličný et al., 2014), sampling resolution was on the order of
199 22 kyr. Additionally, smaller samples (20 g, total 610) were obtained at 0.5 m (5.6 kyr
200 resolution) intervals for carbon stable-isotope analysis of the organic fraction ($\delta^{13}\text{C}_{\text{org}}$).
201 Samples were cleaned, chipped to < 3 mm, and homogenised. Subsamples for isotopic and
202 elemental analysis were prepared and analysed following the methods described in Uličný et
203 al. (2014).

204 It was necessary to process 10 g splits of chipped samples to yield representative
205 assemblages of palynomorphs for quantitative analysis. Palynomorphs >15 μm were
206 concentrated by a commercial processing company (PLS Ltd, Holyhead, UK) using the HF-
207 HCl method of Lignum (2009) modified from Lignum et al. (2008, 'Company B'
208 methodology). All samples were spiked with tablets containing the modern spore
209 *Lycopodium* to allow statistically valid quantitative analysis of abundances (palynomorphs
210 per gram, ppg). Palynomorph identification and counting were undertaken using a light
211 microscope with a 400x objective. Three hundred dinocysts were identified per sample.
212 Broken or partial specimens were added to the count only if there was more than half of the
213 specimen present; unidentifiable specimens were recorded as 'indeterminate' and were not
214 included in the count of 300. Following this count, the remainder of the slide was scanned to

215 identify any additional species, which were marked as ‘present’, but in abundances too low to
216 be recorded among the 300.

217 **5. Dinocyst biostratigraphy of the Bch-1 core**

218 All samples yielded abundant and generally well-preserved dinoflagellate cysts, averaging
219 ~4000 dinocysts per gram (~7000 dpg when corrected for carbonate-dilution, cf. Pearce et al.,
220 2009). The occurrence and ranges of 76 common dinocyst species identified in the Bch-1
221 core are plotted in Fig. 3, and the relative abundances of dominant species are shown in Fig.
222 4. A complete list of taxa (92 species) is provided in Appendix A.

223 Dinocyst biostratigraphic datum levels identified at Bch-1 include the sequential first
224 occurrences (FOs) of *Cyclonephelium compactum* – *Cauveridinium membraniphorum* in the
225 uppermost Cenomanian, of *Senoniasphaera turonica* in the Lower Turonian, and of
226 *Oligosphaeridium poculum*, *Subtilisphaera pontis-mariae*, *Raetiaedinium truncigerum* and
227 *Florentinia buspina* in the Middle Turonian (Figs. 2, 3; Plate I). The last occurrences (LOs)
228 of *Stephodinium coronatum*, *Senoniasphaera turonica*, *C. compactum* – *C. membraniphorum*
229 and *Kiokansium unituberculatum* occur in the Upper Turonian. The first common occurrence
230 (FCO) of *Chatangiella ditissima* and the FO of *Surculosphaeridium belowii* occur towards the
231 top of the stage. The FO of *Cribroperidinium wilsonii* in the lowermost Coniacian is
232 followed by the FCO of *Oligosphaeridium pulcherrimum*, above. With the exceptions of *K.*
233 *unituberculatum*, *S. pontis-mariae* and *C. ditissima*, most of these taxa occur sporadically
234 (Fig. 3) and in low numbers (<1% of assemblage), limiting stratigraphic resolution. The last
235 common occurrence (LCO) and reoccurrence (RO) datum levels of some species are also
236 considered to have stratigraphic potential (discussed further in Section 5, below).

237 A number of distinctive dinocysts range patterns are observed in the Bch-1 data (Figs. 3,
238 4). A generally inverse relationship between the relative abundance curves of
239 *Palaeohystrichophora infusorioides* and *Spiniferites ramosus ramosus*, with a marked
240 minimum of the former and an acme of the latter in Upper Turonian Sequences TUR5 – 6/1
241 (Fig. 4), reflects the numerical dominance of these two taxa in the assemblages. A well-
242 defined acme of *Circulodinium distinctum distinctum* occurs from 185 – 190 m in mid-Upper
243 Turonian Sequence TUR6/1, with lesser floods of the species below, in the Middle Turonian
244 at 323.5 m (TUR3) and 271.5 m (TUR4/3).

245 Lower Turonian to basal Middle Turonian assemblages (Sequences TUR1 – 2) include
246 relatively high proportions of *Hystrichosphaeridium pulchrum* and *Surculosphaeridium*
247 *longifurcatum* (Fig. 4). *Downiesphaeridium armatum* is most common in Middle Turonian
248 Sequences TUR3 – 4/1 and an acme of *Circulodinium latoaculeum* occurs in TUR4/3. Other
249 notable events include the LO *Microdinium distinctum* and LCOs of *Hystrichosphaeridium*
250 *bowerbankii* and *Achomosphaera sagena* towards the top of the Middle Turonian (Sequence
251 TUR4/3).

252 A number of dinocyst species are more common within the regressive Upper Turonian
253 package of Sequences TUR5 – 6/1 (cf. Uličný et al., 2014), notably *Downiesphaeridium*
254 *aciculare*, *Oligosphaeridium prolixispinosum*, *Florentinia cooksoniae*, *Hystrichosphaeridium*
255 *tubiferum brevispinum*, *Kleithriasphaeridium loffreense*, *Kiokansium unituberculatum*, *S.*
256 *pontis-mariae*, *Tanyosphaeridium salpinx* (Figs. 3, 4). Common species that temporarily
257 disappear within this interval are *Florentinia mantellii* and *Downiesphaeridium armatum*.
258 The mutual exclusivity of a number of key taxa, points to palaeoenvironmental factors
259 limiting their stratigraphic distribution in the Bohemian Cretaceous Basin.

260 Several well-defined FOs of common species are apparent in the section (Figs. 3, 4),
261 notably, *Florentinia clavigera* towards the top of the Middle Turonian, and *Isabelidium*
262 *amphiatum* in the mid-Upper Turonian. *Surculosphaeridium belowii* and *Cribroperidium*
263 *wilsonii* first occur within the Turonian – Coniacian boundary interval, which from the upper
264 half part of Sequence TUR6/1 to mid-Sequence CON1, is characterised by assemblages
265 containing abundant *Sepispinula? ambigua*.

266 **6. Turonian dinocyst biostratigraphy: review**

267 Comparisons between dinocyst records from four key English Turonian Chalk sites (Fig.
268 1) and those obtained here from the Bohemian Cretaceous Basin (Figs. 3, 4) are illustrated in
269 Fig. 5, based on macrofossil biostratigraphic correlation and further constrained by key CIEs.
270 Carbon isotope data (Jarvis et al., 2006) are available to more precisely place the stratigraphic
271 levels of dinocyst records (FitzPatrick, 1995; Pearce, 2000, 2010; Pearce et al., 2003; Prince
272 et al., 2008) from Berkshire (Banterwick Barn borehole), Kent (Dover composite section) and
273 Norfolk (Trunch borehole), but limited carbon isotope data are available for the Turonian of
274 East Sussex. Here, the positions of the CIEs have been placed using bio- and
275 lithostratigraphic criteria derived from other southern English Chalk sections where isotope
276 data are available (Jenkyns et al., 1994; Pearce et al., 2003; Jarvis et al., 2006).

277 *6.1. Cenomanian – Turonian boundary interval*

278 No Cenomanian dinocyst marker species were recognised in the Bch-1 core. For example,
279 *Adnatosphaeridium tutulosum* and *Litosphaeridium siphoniphorum*, which have last
280 occurrences in the Upper Cenomanian *M. geslinianum* – *N. juddii* zones (Foucher, 1980,
281 1981; Courtinat et al., 1991; Costa and Davey, 1992; Dodsworth, 2000; Pearce, 2000;
282 Lignum, 2009; Pearce et al., 2009), are absent. However, calcareous nannofossil records

283 place the base Turonian at 402 m, indicated by the FO *Eprolithus octopetalus* at 401.2 m and
284 the LOs of Upper Cenomanian species *Lithraphidites acutus* at 402.4 m and *Corollithion*
285 *kennedyi* at 402.8.

286 *Cauveridinium* (formerly *Cyclonephelium*) *membraniphorum* and the *Cyclonephelium*
287 *compactum* – *Cauveridinium membraniphorum* ‘complex’ are important uppermost
288 Cenomanian and Turonian dinocyst markers in NW Europe (e.g. Clarke and Verdier, 1967;
289 Marshall and Batten, 1988; Pearce, 2000). The latter is found infrequently in Bch-1. The
290 taxon first occurs in the Upper Cenomanian near the core base at 403.6 m (Fig. 3), and is
291 recorded sporadically through the Lower and Middle Turonian, with a LO in the mid-Upper
292 Turonian *S. neptuni* Zone. Elsewhere, the LCO of *C. membraniphorum* is generally recorded
293 at or near the Turonian – Coniacian boundary (Prössl, 1990; Costa and Davey, 1992; Pearce,
294 2000; Pearce et al., 2003; Prince et al., 2008).

295 *Cauveridinium membraniphorum* ranges down into the Middle Albian (Foucher, 1981),
296 and has been recorded as high as the Santonian and Campanian (Foucher, 1979; Ioannides,
297 1986; Harker et al., 1990), but it is generally only a common component of assemblages in
298 the top Cenomanian and Turonian. An acme of *C. membraniphorum* has been identified as a
299 useful dinocyst marker in the uppermost Cenomanian (Dodsworth, 2000; Lignum, 2009), but
300 this acme is absent at Bch-1 and likely correlates to a hiatus in the section. The species has a
301 LO or LCO near the top of the Upper Turonian in most English Chalk sections (Fig. 5), and is
302 rare in post-Turonian sediments. Prince et al. (1999) suggested that many non-figured
303 specimens attributed by previous workers to *C. membraniphorum* in Santonian or younger
304 sediments might be *C. filoreticulatum*, leaving a probable true LO of *C. membraniphorum* in
305 the Lower Coniacian (Pearce, 2000; Pearce et al., 2003; Prince et al., 2008). The relatively

306 low LO of the species in Bch-1 in the mid-Upper Turonian, reflects the low abundance of the
307 species in the core.

308 *Heterosphaeridium difficile* and *Florentinia buspina* are biostratigraphic marker species
309 that have Lower Turonian bases in NW Europe (Davey and Verdier, 1976; Foucher, 1980,
310 1981; Tocher and Jarvis, 1987; Jarvis et al., 1988a; Costa and Davey, 1992; FitzPatrick, 1995;
311 Pearce et al., 2009). In the high northern latitudes, *H. difficile* has been recorded in the
312 Cenomanian (Bell and Selnes, 1997; Bloch et al., 1999) suggesting that it is a cold water
313 tolerant species that migrated southward with the predominant Late Cretaceous cooling.
314 *Heterosphaeridium difficile* is absent at Bch-1, and *F. buspina* first appears in the Middle
315 Turonian (Fig. 3). A mid-Turonian FO or FCO of *F. buspina* is also noted in most English
316 Chalk sections (Fig. 5), although the exact stratigraphic position is variable, and sporadic
317 occurrences range down into the Cenomanian (FitzPatrick, 1995; Pearce, 2000; Pearce et al.,
318 2009).

319 6.2. *Senoniasphaera* bioevents

320 The first occurrence of *Senoniasphaera rotundata*, originally described by Clarke and
321 Verdier (1967), has been widely regarded as being a marker for the Lower Turonian (Foucher,
322 1980, 1981; Tocher and Jarvis, 1987, 1994, 1995; Jarvis et al., 1988a, b; FitzPatrick, 1995;
323 Lamolda and Mao, 1999; Dodsworth, 2000; Pearce, 2000; Pearce et al., 2003, 2011). Recent
324 taxonomic revisions (Pearce et al., 2003, 2011), however, differentiate two main species of
325 *Senoniasphaera* in the Turonian: *S. turonica* (= *S. rotundata alveolata* of Pearce et al., 2003,
326 2009; Prince et al., 2008); and *S. rotundata* (= *S. rotundata rotundata*). *Senoniasphaera* spp.
327 are uncommon (Fig. 3) in Bch-1, but *S. turonica* first occurs within the *Mammites nodosoides*
328 Zone, between the Holywell and Lulworth CIEs.

329 Published FOs of *S. 'rotundata'* (interpreted here to be records of *S. turonica*; see Pearce et
330 al., 2011 for discussion) occur in the lower part of the Lower Turonian *Mytiloides labiatus*
331 Zone (equivalent to the *W. devonense* – *M. nodosoides* zones) in SE Devon (Jarvis et al.,
332 1988b) and East Sussex (FitzPatrick, 1995; Pearce et al., 2009), at the top of the zone in
333 Berkshire (Pearce et al., 2003), at the base of the Middle Turonian *Terebratulina lata* Zone
334 (= *C. woollgari* Zone) in Kent (FitzPatrick, 1995), and towards the top of that zone in Norfolk
335 (Pearce, 2000), where the Lower to basal Middle Turonian is barren of dinocysts (Fig. 5).
336 The observed diachroneity of the FO *S. turonica* is likely facies controlled, dinocysts being
337 less abundant in, and the index species absent from, coarser-grained condensed nodular chalk
338 facies that characterise the Lower Turonian in many areas.

339 The Lower Turonian in Bch-1 yielded abundant dinocysts throughout, but *S. turonica* was
340 recorded in only two samples (Fig. 3). Its FO in the lower *Mammites nodosoides* Zone is
341 consistent with published lowest records of the species in the English Chalk (e.g. Tocher and
342 Jarvis, 1987; Pearce et al., 2009). However, this cannot be regarded as being definitive.
343 Sporadic occurrences of *S. turonica* consistently range down into the Middle Cenomanian,
344 upper *Acanthoceras rhotomagense* Zone, at Culver Cliff, Isle of Wight England, at Wunstorf
345 Quarry, northern Germany, and at Vergons, SE France, indicating that this is the true FO of
346 the species (Lignum, 2009; Pearce et al., 2011). The FCO of *S. turonica*, however, typically
347 lies towards the base of the Lower Turonian (Pearce et al., 2011).

348 *Senoniasphaera* abundances vary considerably between sections, but an acme of *S.*
349 *turonica* occurs consistently in the Upper Turonian (*Sternotaxis plana* Zone; *Subprionocyclus*
350 *neptuni* Zone) of the English Chalk successions (Fig. 5). *Senoniasphaera rotundata* s.s. first
351 appears in the Upper Turonian, with a FCO around the stage boundary and an acme in the
352 Lower Coniacian (*Micraster cortestudinarium* Zone). *Senoniasphaera rotundata* was not

353 recorded from Bch-1. However, the LO *S. turonica* occurs in the lower *S. neptuni* Zone,
354 above the Hitch Wood CIE, which is correlative with the uppermost acme of the species
355 elsewhere (Fig. 5).

356 6.3. Middle Turonian dinocyst events

357 *Oligosphaeridium poculum* first occurs towards the base of the *C. woollgari* Zone at Bch-1
358 (Fig. 3). Its FO is recorded at a similar stratigraphic level in Berkshire and Kent (FitzPatrick,
359 1995; Pearce et al., 2003), but occurs lower in East Sussex, at the base of the *M. nodosoides*
360 Zone (Pearce et al., 2009). The FO of *O. poculum* in the Trunch borehole of eastern England
361 (see Pearce, 2010 for locality details) lies within the basal Coniacian, albeit based on only two
362 records from the core (Pearce, 2000), and these may not be *in situ* as that interval shows
363 evidence of intermittent sediment reworking. The datum level appears to be a consistent
364 Turonian marker, although the species has been recorded from the Hauterivian of Germany
365 (Prössl, 1990) and the Barremian – Albian, of Greenland, England and India (Jain, 1977;
366 Lister and Batten, 1988; Nøhr-Hansen, 1993), so the Turonian FO is in truth a reoccurrence
367 (RO) datum level, as indicated by Pearce et al. (2009, fig. 3).

368 The FO *Subtilisphaera pontis-mariae* is found within the lower *C. woollgari* zone in Bch-
369 1, marginally higher than the upper Lower Turonian placement of Hardenbol et al. (1998) for
370 the Tethyan realm. However, the species has a long stratigraphic range, from at least Upper
371 Albian (Davey, 1970; Lignum, 2009) to Lower Campanian (Prince et al., 1999; Pearce, 2000),
372 so its stratigraphic utility is limited.

373 The FO *Raetiaedinium truncigerum* lies in the mid-*C. woollgari* Zone at Bch-1, slightly
374 below the Glynde CIE. The FO of *R. truncigerum* has been previously recorded also from the
375 upper Middle Turonian by Prössl (1990), or slightly higher in the Upper Turonian (Foucher,
376 1976a; Marshall, 1983; Williams and Bujak, 1985; Williams et al., 1993; Hardenbol et al.,

377 1998) or Lower Coniacian (Kirsch, 1991), and so the FO appears to be a potential Middle
378 Turonian marker. The species ranges into the Campanian in England and Germany (Kirsch,
379 1991; Williams et al., 1993; Prince et al., 1999; and by our personal observations).

380 *Florentinia buspina* also first occurs in the mid-*C. woollgari* Zone at Bch-1 (Fig. 3). A
381 mid-Turonian FO or FCO of *F. buspina* is noted in most English Chalk sections (Fig. 5),
382 although the exact stratigraphic position is variable. This is again a RO, since the species
383 extends down into the Lower Cenomanian at Trunch (Pearce, 2000), at Culver Cliff Isle of
384 Wight, and at Vergons SE France (Lignum, 2009). The species ranges upwards into the
385 Campanian in Germany (Davey and Verdier, 1976; Kirsch, 1991; Pearce, 2000).

386 FitzPatrick (1995), Pearce (2000) and Pearce et al. (2003) recognised ‘acmes’ of
387 *Circulodinium distinctum* within the Middle Turonian *T. lata* Zone of the English Chalk.
388 Three main peaks of *C. distinctum* are found in the Bch-1 core (Figs. 4, 5): the first, in the
389 mid-*C. woollgari* Zone, between the Round Down and Glynde CIEs, is the highest amplitude
390 peak but is confined to a single sample; the second broader peak is towards the top of the *C.*
391 *woollgari* Zone, at the level of the ‘Pewsey’ CIE; the third peak is located in the mid-*S.*
392 *neptuni* Zone mid-way between the Bridgewick and the Hitch Wood CIEs. The first and
393 second peaks correspond stratigraphically to floods and acme intervals of *C. distinctum* found
394 in the English Chalk (Fig. 5). The final higher peak in the Upper Turonian may be of local
395 significance, or may not have been recognised (or preserved) in the lower resolution sampling
396 of the more attenuated, potentially less complete, English Chalk Upper Turonian successions
397 (e.g. see discussion in Uličný et al., 2014).

398 6.4. Upper Turonian dinocyst events

399 The Upper Turonian at Bch-1 is marked by a series of last occurrence datum levels (Figs.
400 3, 5). The LO of *Stephodinium coronatum* occurs in the lower *S. neptuni* Zone at Bch-1. The

401 LO of the species has been recorded marginally higher elsewhere in the area, in the *M. scupini*
402 Zone of the Úpohlavý section, located 25 km NNW of Prague (Svobodová et al., 2002). This
403 level correlates to a position just below the FO of *P. germari* in other Bohemian Cretaceous
404 Basin sections (cf. Fig. 2). This compares favourably to a top Upper Turonian LO of
405 *Stephodinium coronatum* at Trunch (Pearce, 2000). The LO *S. coronatum* has also been
406 recorded from the Turonian – Coniacian boundary interval elsewhere (Foucher, 1976b; Costa
407 and Davey, 1992; Williams et al., 1993).

408 Bujak and Williams (1978) and Williams and Bujak (1985) stated that *S. coronatum* occurs
409 in the Santonian, but without distribution data it is unknown whether this observation might
410 be based on reworked specimens; Ioannides (1986) also recorded *S. coronatum* from
411 Santonian to ?Maastrichtian sediments, but in samples that clearly contained reworked taxa.
412 We therefore discount these records in the light of overwhelming evidence, at least for NW
413 Europe, that the LO of *S. coronatum* occurs in the uppermost Turonian, close to the Turonian
414 – Coniacian boundary.

415 The coincident LOs of *S. turonica* and *C. compactum* – *C. membraniphorum* occur in the
416 mid-*S. neptuni* Zone, below the Hitch Wood CIE; the former is somewhat lower than the last
417 occurrence of *S. turonica* in the English Chalk (Fig. 5). The FCO of *Chatangiella ditissima*
418 occurs towards the base of the *M. scupini* Zone at Bch-1. The FO of *C. ditissima* has been
419 previously recorded from the lowermost Turonian (Costa and Davey, 1992), the Upper
420 Turonian (Sweet and McIntyre, 1988; Prössl, 1990; Scott, 2014) and the Lower Coniacian
421 (Williams et al., 1993). However, a high Upper Turonian (high *S. plana* Zone) FCO was
422 recorded at Trunch (Fig. 5) by Pearce (2000), at a comparable level to Bch-1, with lower
423 sporadic occurrences in the Lower Cenomanian. The FCO of the species offers, therefore, a
424 potential biostratigraphic datum level. *Chatangiella ditissima* is a common component of

425 Santonian – Campanian assemblages in many areas (e.g. McIntyre, 1975; Ioannides, 1986;
426 Costa and Davey, 1992; Skupien et al., 2009; Radmacher et al., 2014), with a likely LO in the
427 Maastrichtian (Kirsch, 1991; Williams et al., 1993; Lebedeva, 2006; Lebedeva et al., 2013).

428 6.5. Turonian – Coniacian dinocyst boundary events

429 The Turonian – Coniacian boundary interval is marked by a series of benthic macrofossil
430 events, particularly affecting the inoceramid bivalves (Walaszczyk, 2000), that enable the
431 development of a refined biostratigraphy at Bch-1 (Fig. 5). A number of dinocyst events are
432 also apparent. The FO *Surculosphaeridium belowii* occurs immediately below the stage
433 boundary and the Navigation CIE at Bch-1 (Fig. 3). This species has been recorded
434 previously largely from Coniacian – Maastrichtian sediments in England, Germany and
435 Austria (Yun, 1981; Kirsch, 1991; Pearce, 2000; Soliman et al., 2009; Mohamed and
436 Wagreich, 2013), but it has also been identified from the Barremian of the Slovak Carpathians
437 (Skupien, 2003); however, its Turonian reoccurrence (RO) datum level may be of
438 stratigraphic value.

439 The FO *Cribroperidinium wilsonii* occurs immediately above the base Coniacian and the
440 Navigation CIE at Bch-1 (Figs. 3, 5). A Turonian – Coniacian FO is consistent with records
441 from Germany and Denmark (Kirsch, 1991; Schiøler, 1992), although the species ranges from
442 Upper Albian – Campanian in southern England (Prince et al., 1999, 2008; Pearce, 2000;
443 Lignum, 2009). However, the FCO *C. wilsonii* is observed in the high Upper Turonian mid-
444 *S. plana* Zone above the Hitch Wood CIE at Trunch (Fig. 5), and here it becomes increasingly
445 common through the mid- to Upper Coniacian, confirming its importance as a significant
446 component of Coniacian dinocyst assemblages. Although *Palaeohystrichophora*
447 *infusorioides* is a major component of the dinocyst assemblages through most of the
448 succession at Bch-1, a prominent acme occurs in the lowest Coniacian *C. d. erectus* Zone

449 (Figs. 4, 5). A similar acme is recorded in the lowest Coniacian at Trunch (Pearce, 2000),
450 though it has not been identified in other Chalk sections studied to date.

451 The first common and consistent occurrence of *Oligosphaeridium pulcherrimum* occurs at
452 the top of the *Cremnoceramus deformis erectus* Zone at Bch-1, at the base of the Beeding
453 CIE; an acme of the species occurs a short distance above, at the base of the *C. c. crassus*
454 Zone. The FO of persistently occurring specimens, FCO and/or acme of the species are
455 observed around the Turonian/Coniacian boundary in Chalk sections throughout southern
456 England (Fig. 5). The oldest record of *O. pulcherrimum* is from the Upper Jurassic
457 (Brideaux, 1977), and it is a common component in the Lower Cretaceous (Prössl, 1990).
458 However, the species has been noted previously as becoming more common in the Coniacian
459 (Foucher, 1980; Pearce et al., 2003); in the zonation schemes of Williams (1975, 1977), *O.*
460 *pulcherrimum* is an important indicator species for the Coniacian *O. pulcherrimum* Zone.

461 *Pervosphaeridium truncatum* ranges through the Cenomanian – Coniacian succession
462 sampled at Bch-1. The species has a LO in the *M. coranguinum* Zone in Berkshire and
463 Norfolk (Marshall, 1983; Pearce et al., 2003), southern England (Fig. 5), indicating that the
464 top of Bch-1 probably lies below that stratigraphic level. However, records of the species
465 from the Campanian – Maastrichtian in Germany and Canada (Harker et al., 1990; Kirsch,
466 1991) may point to a younger true LO.

467 The FO *Heterosphaeridium verdieri* was proposed as a high Lower Coniacian marker by
468 Prince et al. (2008), based on records from Kent and the Isle of Wight. The species had
469 previously been reported from Santonian deposits in Germany (Yun, 1981; Kirsch, 1991).
470 The species has been recorded from the high-Middle Turonian in Berkshire (Pearce et al.,
471 2003) and as a very rare component (possibly misidentified?) from the Upper Cenomanian of
472 East Sussex (Pearce et al., 2009), but it has a FCO and acme in the low Middle Coniacian

473 (Fig. 5). The absence of *H. verdieri* and *Spinidinium echinoideum* (another Middle Coniacian
474 marker) at Bch-1 is consistent with the Early Coniacian age of the sampled section top
475 indicated by macrofossil and nannofossil records (*C. c. crassus* Zone, base UC10; Fig. 2).

476 **7. Turonian dinocyst zonation**

477 No generally accepted dinocyst zonation scheme exists for the Turonian Stage. Here,
478 previously published zonations are critically reviewed in the light of recent studies, including
479 the new data obtained from the Bch-1 core. The viability of individual zones is considered
480 and, following revision, a new composite scheme is proposed.

481 *7.1. Clarke and Verdier (1967) zonation*

482 The *Hystrichosphaeridium* (now *Litosphaeridium*) *siphoniphorum* Zone was created by
483 Clarke and Verdier (1967) to approximate the Cenomanian, from the stage base to a position
484 within the Plenus Marl of southern England, which at the time, was considered to be
485 questionably Turonian (cf. Jefferies, 1963). The stage boundary is now placed higher, within
486 the overlying Ballard Cliff Member (Gale et al., 2005; Pearce et al., 2009). *Litosphaeridium*
487 *siphoniphorum* tends to be common between its range base in the Upper Albian and the
488 Upper Cenomanian. The LCO of *L. siphoniphorum* occurs consistently within the Upper
489 Cenomanian (*M. geslinianum* Zone) throughout Europe and in North America, although rare
490 occurrences extend into the Lower Turonian (Davey, 1969; Foucher, 1979, 1980, 1982;
491 Marshall and Batten, 1988; Courtinat et al., 1991; Li Huan and Habib, 1996; Hardenbol et al.,
492 1998; Lamolda and Mao, 1999; Dodsworth, 2000; Pearce, 2000; Lignum, 2009; Pearce et al.,
493 2009). The absence of *L. siphoniphorum* at Bch-1 is consistent with an absence of low *M.*
494 *geslinianum* Zone and older Cenomanian sediments within the sampled interval.

495 Clarke and Verdier (1967) erected a *Scriniodinium* (previously *Endoscrinium*) *campanula*
496 Zone to represent the uppermost Cenomanian to the lower Turonian interval (Fig. 5), which
497 was characterised by the presence of *Xiphophoridium alatum* (now *Dinoptyrgium alatum*),
498 *Cometodinium obscurum* and *Cyclonephelium hughesii*. The base was defined by the top of
499 the *L. siphoniphorum* Zone, and the top by the LO of *S. campanula*. At Bch-1, *S. campanula*
500 was recorded only in two Lower Coniacian samples, and is absent from the Turonian. The
501 taxon occurs sporadically throughout the Cenomanian – Santonian at Trunch, with a LO here
502 and at Culver Cliff in the Upper Santonian, mid-*U. socialis* Zone (Prince et al., 1999, 2008;
503 Pearce, 2000), and it is never a common component of the assemblage. Furthermore, *D.*
504 *alatum* occurs through the Cenomanian to Upper Turonian (*S. plana* Zone), and *C. obscurum*
505 is only commonly recorded from the Upper Turonian (*S. plana* Zone), so the *S. campanula*
506 Zone as defined previously is not viable.

507 *Cauveridinium membraniphorum* is a very distinctive component of uppermost
508 Cenomanian and Turonian dinocyst assemblages throughout Europe (Section 6.1, above). A
509 *Cyclonephelium* (now *Cauveridinium*) *membraniphorum* Zone, of Turonian to Coniacian /
510 Santonian age, was erected by Clarke and Verdier (1967) based on limited sampling from the
511 Isle of Wight. The base of the zone was defined by the LO of *S. campanula*, and its top by
512 the LO of *C. membraniphorum* (Fig. 5). Subsequent records extending the range of *S.*
513 *campanula* into the Upper Santonian make the LO of this species untenable as a basal marker
514 for a largely Turonian zone. Accordingly, it is proposed here to redefine the base of the
515 *Cauveridinium membraniphorum* Zone by the LCO of *L. siphoniphorum*.

516 Clarke and Verdier (1967) erected a *Deflandrea echinoidea* (now *Spinidinium*
517 *echinoideum*) Zone to represent the ?lower – mid-Santonian, defined as the interval
518 immediately following the LO of *C. membraniphorum*, to immediately below the FO of

519 *Hystrichosphaeropsis ovum*, *Dinogymnium albertii* and *D. heterocostatum*. The FO of *S.*
520 *echinoideum* occurs in the Coniacian (Williams and Bujak, 1985); at Trunch and in Kent
521 (Pearce, 2000; Prince et al., 2008) its FO is in the mid-Coniacian, low *M. coranguinum* Zone
522 (Fig. 5). The index species has commonly low and varying abundance through the Coniacian
523 – Campanian in different sections, but it generally shows a FCO around the base Santonian,
524 making it a good Santonian marker (Foucher, 1976a; Heine, 1991; Kirsch, 1991; Prince et al.,
525 1999; Pearce, 2000).

526 Using the original definition of Clarke and Verdier (1967), beds above the LO of *C.*
527 *membraniphorum* at Bch-1 technically fall within their *S. echinoideum* Zone (Fig. 5).
528 However, in reality the FO of the zonal index species falls stratigraphically above the interval
529 represented in the Bch-1 core, and the zone is not considered to be relevant to the current
530 study.

531 7.2. Williams (1977) zonation

532 Williams (1977) ‘global’ Upper Cretaceous dinocyst zonation scheme, based largely on
533 assemblage data from southern England (Clarke and Verdier, 1967; Davey, 1969, 1970) and
534 offshore eastern Canada, employed *Kiokansium unituberculatum* (then referred to as
535 *Cleistosphaeridium polypes*) as a Cenomanian index species (Fig. 5). Subsequently, the LO
536 of *Kiokansium unituberculatum* has been recorded as Lower Turonian (Foucher, 1981), and
537 sporadic occurrences extend into the basal Lower Coniacian at Trunch (Pearce, 2000) but in
538 an interval with significant Cenomanian reworking, so this latter record may be unreliable.

539 Williams (1977) Turonian zonal index, *Surculosphaeridium? longifurcatum* (Fig. 5), is a
540 long-ranging species, from Upper Barremian (Prössl, 1990) to Campanian (Williams and
541 Bujak, 1985; Kirsch, 1991; Williams et al., 1993; Pearce, 2000). It is abundant in the Lower
542 Turonian to basal Middle Turonian and in the Lower Coniacian at Bch-1, but its abundance

543 records show little consistency between Chalk sections and it is considered to be of little
544 biostratigraphic value.

545 Williams (1977) recognised a *Callaiosphaeridium asymmetricum* – *Oligiosphaeridium*
546 *pulcherrimum* Zone within the Coniacian – Lower Santonian (Fig. 5). The first species is
547 long ranging, from Hauterivian (Davey and Williams, 1966a, b; Warren, 1967) to Campanian
548 (Foucher, 1979; Kirsch, 1991). By contrast, *O. pulcherrimum* has a consistent FCO in the
549 Lower Coniacian (Pearce, 2000; Pearce et al., 2003; Prince et al., 2008), and it is proposed
550 here as a Coniacian zonal index species (Fig. 5).

551 7.3. Foucher (1981) zonation

552 Foucher (1981) erected a *Senonisphaera rotundata* Zone, defined by the FO *S. rotundata*,
553 for the Turonian (top not considered), with an Upper Cenomanian – Lower Turonian
554 *Silicisphaera* (now *Florentinia*) *ferox* Zone, below (Fig. 5). The latter is long-ranging,
555 Hauterivian (Gocht, 1959) to Maastrichtian (Clarke and Verdier, 1967; Foucher, 1975, 1976a;
556 Foucher and Robaszynski, 1977; Kirsch, 1991), and is therefore of limited stratigraphic value.
557 By contrast, *Senonisphaera rotundata* sensu lato has proved to be a good biostratigraphic
558 marker (Section 5.2). The genus is used here to define a new Lower to Middle Turonian *S.*
559 *turonica* Subzone (*C. membraniphorum* Zone; Fig. 5) and a Lower Coniacian *S. rotundata*
560 sensu stricto Subzone (*O. pulcherrimum* Zone).

561 7.4. FitzPatrick (1995) zonation

562 A palynological zonation scheme for the uppermost Cenomanian to Turonian of the
563 southern English Chalk was proposed by FitzPatrick (1995). Three zones were erected:
564 Palynozones I to III. Palynozone I was considered to represent the Lower Turonian, with a
565 base defined by the FO of *Heterosphaeridium difficile*, *Senoniasphaera rotundata* sensu lato,

566 and *Florentinia buspina*. Another species thought to be an important index taxon was
567 *Litosphaeridium* sp. A of Marshall and Batten (1988), which was recorded as having a LO in
568 the lowest Turonian of East Sussex, immediately below the base of the *Mammites nodosoides*
569 Zone.

570 Palynozone II was considered to represent the mid-Turonian (*T. lata* Zone), and was
571 defined by the FO of *Florentinia? torulosa* to the LO of *S. campanula*. Acmes of *H. difficile*
572 and *C. distinctum* characterise the middle part of the zone. *Florentinia? torulosa* is absent in
573 the Turonian of Bch-1, and rare to absent in most English Chalk sections, so it is a rather poor
574 index species. More importantly, the LO of *S. campanula* is Santonian (Foucher, 1976a;
575 Kirsch, 1991; Costa and Davey, 1992; Prince et al., 1999; Pearce, 2000), so this zone cannot
576 be employed as a Turonian marker.

577 Palynozone III was erected to represent the Upper Turonian, and was defined as lying
578 directly above Palynozone II (i.e. above the LO of *S. campanula*); the top of the zone was not
579 defined. An acme of *Senoniasphaera 'rotundata'* (considered here to be records of *S.*
580 *turonica*) occurring in the lower part of the zone was considered to be of correlative value. In
581 the light of the proven extended stratigraphic range of *S. campanula* in the English Chalk and
582 elsewhere, Palynozone III would represent uppermost Santonian or Campanian, not Turonian
583 strata. The Turonian palynozonation scheme of FitzPatrick (1995) is therefore fundamentally
584 flawed.

585 7.5. *A revised Turonian zonation*

586 Here, we propose a single *Cauveridinium membraniphorum* Interval Zone spanning the top
587 Cenomanian to basal Coniacian (Fig. 5). The base of the *C. membraniphorum* Zone is
588 marked by the LCO of *Litosphaeridium siphoniphorum* (top *L. siphoniphorum* Zone). The *C.*
589 *membraniphorum* Zone is subdivided into: *Senoniasphaera turonica* (Lower – Middle

590 Turonian) and *Raetiaedinium truncigerum* (Middle Turonian – basal Coniacian) subzones.

591 The top of the *C. membraniphorum* Zone is defined by the FCO *Oligosphaeridium*

592 *pulcherrimum* (*S. rotundata* Subzone; base *O. pulcherrimum* Zone).

593 The FO of *S. turonica* is lower Middle Cenomanian *Acanthoceras rhotomagense* Zone in

594 southern England, northern Germany and SE France (Pearce et al., 2011), but in northern

595 Europe the species is rare at its FO and it is commonly absent from the Upper Cenomanian.

596 However, it shows a widespread RO and FCO in the Lower Turonian (Foucher, 1980; Tocher

597 and Jarvis, 1987; Jarvis et al., 1988a; Lamolda and Mao, 1999; Pearce et al., 2003, 2009).

598 The FCO/RO *S. turonica* defines the base of our *S. turonica* Subzone; its top is placed at the

599 FO *Raetiaedinium truncigerum*.

600 The FO of *R. truncigerum* in Bch-1 occurs within the Middle Turonian *C. woollgari* Zone,

601 below the Glynde CIE, consistent with records of its lowest FO elsewhere (Section 5.3). It

602 defines the base of the *R. truncigerum* Subzone.

603 Despite ranging down into the Hauterivian, *O. pulcherrimum* shows a FCO and acme in

604 the basal Coniacian (*Cremonoceras deformis erectus* Zone; Beeding CIE) of Bch-1, which

605 is consistent with records from the basal Coniacian of the English Chalk (Fig. 5). The FCO

606 (in reality, a reoccurrence datum level; Section 5.5) is used here to mark the base of the *O.*

607 *pulcherrimum* Zone, the lower part of which includes the FCO and an acme of *S. rotundata*,

608 constituting the *S. rotundata* Subzone (top not defined).

609 **8. Conclusions**

610 An expanded Turonian cored succession (Bch-1) from Běchary in the Bohemian

611 Cretaceous Basin has yielded abundant and diverse assemblages of well-preserved dinocysts

612 throughout the Turonian – Lower Coniacian. Dinocyst records are constrained by calcareous

613 nanofossil, macrofossil and sequence stratigraphic data (Uličný et al., 2014). A high-
614 resolution (5.6 kyr) carbon isotope ($\delta^{13}\text{C}_{\text{org}}$) profile obtained from the core provides the basis
615 for identifying the Turonian carbon isotope events (CIEs) of Jarvis et al. (2006) in the
616 succession, and placing dinocyst datum levels directly within the CIE stratigraphy. To our
617 knowledge, these records offer the highest resolution, fully stratigraphically constrained,
618 Turonian dinocyst dataset published to date.

619 A succession of 18 dinocyst datum levels, considered to be of potential regional
620 biostratigraphic significance, are recognised in Bch-1. From bottom to top, these are (Fig. 5):
621 FOs of *C. compactum* – *C. membraniphorum* and then *S. turonica* in the Lower Turonian;
622 FOs of *O. poculum*, *S. pontis-mariae*, a flood of *C. d. distinctum*, the FOs of *R. truncigerum*
623 and *F. buspina*, and a second flood of *C. d. distinctum* in the Middle Turonian; LO *S.*
624 *coronatum*, a *C. d. distinctum* acme, the LOs *C. compactum* – *C. membraniphorum*, *S.*
625 *turonica* and *K. unituberculatum*, the FCO *C. ditissima* and FO *S. belowii* in the Upper
626 Turonian; FO *C. wilsonii* coincides with the base Coniacian, followed by an acme of *P.*
627 *infusorioides*, the FCO and then an acme of *O. pulcherrimum*. *Pervosphaeridium truncatum*
628 ranges to the top of the sampled section (high Lower Coniacian).

629 A review of published Turonian records from English Chalk sections in East Sussex,
630 Berkshire, Kent and Norfolk demonstrates the presence of several consistent dinocysts datum
631 levels. However, detailed stratigraphic comparison is hampered by lateral thickness variation,
632 by differences in sampling resolution and stratigraphic completeness, and by the presence of
633 barren intervals and poor recovery in some sections. Consistent Chalk datum levels are
634 provided by the FO *S. turonica* low in the Lower Turonian, an acme of *C. d. distinctum* in the
635 high Middle Turonian, an acme of *S. turonica* in the mid-Upper Turonian with the FO *O.*

636 *pulcherrimum* towards the top of the substage. The Lower Coniacian is marked by the FCO
637 or an acme of *O. pulcherrimum*, followed by an acme/FCO *S. rotundata*.

638 Critical review of published Turonian dinocyst zonation schemes shows them to be
639 untenable. A revised dinocyst zonation for the Turonian based on our review of the English
640 Chalk data and new results from Bch-1, tied to the carbon isotope event stratigraphy of Jarvis
641 et al. (2006), has been presented that is judged to be of likely wider geographic significance.
642 Correlation of the English Chalk data to Bch-1 provides a basis for defining a regional
643 dinocyst event stratigraphy with 22 datum levels, and a revised dinocyst zonation scheme
644 constrained within a chemostratigraphic framework of 10 major CIEs.

645 The proposed new dinocyst zones consist of a Cenomanian *Litosphaeridium*
646 *siphoniphorum* Zone, followed by the *Cauveridinium membraniphorum* Zone spanning the
647 uppermost Cenomanian to Lower Coniacian. This is subdivided into: *Senoniasphaera*
648 *turonica* (Lower – mid-Middle Turonian); and *Raetiaedinium truncigerum* (mid-Middle
649 Turonian – mid-Lower Coniacian) subzones. The *Oligosphaeridium pulcherrimum* Zone
650 (*Senonisphaera rotundata* Subzone) characterises the Lower Coniacian.

651 Key regional datum levels are (Fig. 6):

- 652 (1) within the Cenomanian – Turonian boundary CIE: LCOs *L. siphoniphorum* and *W.*
653 *cassidata* (Upper Cenomanian, *M. geslinianum* Zone), defining the base of the *C.*
654 *membraniphorum* Zone;
- 655 (2) FO *C. compactum* – *C. membraniphorum* and LO *A. tutulosum* followed by an acme of
656 *C. membraniphorum* in the uppermost Cenomanian (*Neocardioceras juddii* Zone);
- 657 (3) FO *S. turonica* below the Holywell CIE (Lower Turonian, *F. catinus* Zone), defining
658 the base of the *S. turonica* Subzone;
- 659 (4) RO *O. poculum* above the Holywell CIE;

- 660 (5) flood of *C. d. distinctum* in the mid-Middle Turonian *C. woollgari* Zone;
- 661 (6) FO *R. truncigerum* between the Round Down and Glynde CIEs (Middle Turonian, *C.*
662 *woollgari* Zone), defining the base of the *R. truncigerum* Subzone;
- 663 (7) acme of *H. difficile* coincident with the Glynde CIE;
- 664 (8) an acme interval of *C. d. distinctum* at the summit of the Middle Turonian *C. woollgari*
665 Zone, spanning the ‘Pewsey’ CIE;
- 666 (9) acme interval of *S. turonica* spanning the Hitch Wood CIE *S. neptuni* Zone, following
667 the LO *C. compactum* – *C. membraniphorum*;
- 668 (10) FCO *C. ditissima* in the higher Upper Turonian;
- 669 (11) RO *S. belowii*, then LCO *C. membraniphorum* immediately below the Navigation CIE
670 in the uppermost Turonian, with the LO *K. unituberculatum* immediately above in the
671 base Coniacian;
- 672 (12) acme of *P. infusorioides* in the Lower Coniacian between the Navigation and Beeding
673 CIEs;
- 674 (13) FCO *O. pulcherrimum* below the Beeding CIE (Lower Coniacian, *F. (H.)*
675 *petrocoriensis* Zone), defining the bases of the *O. pulcherrimum* Zone and *S. rotundata*
676 Subzone.
- 677 (14) acmes of *O. pulcherrimum* and then *S. rotundata* in the mid-Lower Coniacian, with the
678 FCO *H. verdieri* towards the top of the substage.

679 The new stratigraphy offers potential for improved correlation and dating of Upper
680 Cretaceous successions. However, additional high-resolution dinocyst datasets from multiple
681 sections are required to test and further refine the Turonian biostratigraphy.

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689 **Appendix A. Species list**

690 Complete list of dinoflagellate cyst species recorded in the Bch-1 core. Numbers correspond
691 to the order of species plotted in Fig. 3. Other taxa, found less commonly, are also listed
692 along with the genetic sequence(s) from which they have been identified (i.e. TUR1 – 7,
693 CON1 – 2, Figs. 2, 3). Taxonomic references are given in Fensome et al. (2008) and Pearce
694 et al. (2011).

- 695 26 *Achomosphaera ramulifera ramulifera* (Deflandre 1937) Evitt 1963
- 696 33 *Achomosphaera regiensis* Corradini 1973
- 697 1 *Achomosphaera sagena* Davey and Williams 1966
- 698 2 *Callaiosphaeridium asymmetricum* (Deflandre and Courteville 1939) Davey and
699 Williams 1966
- 700 41 *Cassiculosphaeridia reticulata* Davey 1969
- 701 22 *Cauveridinium membraniphorum* – *Cyclonephelium compactum* Complex of
702 Marshall and Batten 1988
- 703 58 *Chatangiella ditissima* (McIntyre 1975) Lentin and Williams 1976
- 704 3 *Circulodinium distinctum distinctum* (Deflandre and Cookson 1955) Jansonius
705 1986
- 706 39 *Circulodinium latoaculeum* (Yun Hyesu 1981) Islam 1993
- 707 TUR3 *Cometodinium obscurum* Deflandre and Courteville 1939
- 708 59 *Cometodinium whitei* (Deflandre and Courteville 1939) Stover and Evitt 1978
- 709 CON1, 2 *Conosphaeridium* Cookson and Eisenack 1969

- 710 CON1 *Conosphaeridium striatoconum* (Deflandre and Cookson 1955) Cookson and
711 Eisenack 1969
- 712 4 *Coronifera oceanica* Cookson and Eisenack 1958
- 713 5 *Cribroperidinium orthoceras* (Eisenack 1958) Davey 1969
- 714 70 *Cribroperidinium* sp. Neale and Sarjeant 1962
- 715 76 *Cribroperidinium wilsonii* (Yun Hyesu 1981) Poulsen 1996
- 716 74 *Cyclonephelium filoreticulatum* (Slimani 1994) Prince et al. 1999
- 717 TUR6/1, CON2 *Cyclonephelium hughesii* Clarke and Verdier 1967
- 718 31 *Dapsilidinium laminaspinosum* (Davey and Williams 1966) Lentin and Williams
719 1981
- 720 72 *Dinogymnium acuminatum* Evitt et al. 1967
- 721 27 *Dinopterygium cladoides* Deflandre 1935
- 722 40 *Disphaeria macropyla* Eisenack and Cookson 1960
- 723 23 *Downiesphaeridium aciculare* (Davey 1969) Islam 1993
- 724 42 *Downiesphaeridium armatum* (Deflandre 1937) Islam 1993
- 725 37 *Ellipsodinium rugulosum* Clarke and Verdier 1967
- 726 24 *Exochosphaeridium arnace* Davey and Verdier 1973
- 727 43 *Exochosphaeridium bifidum* (Clarke and Verdier 1967) Clarke et al. 1968
- 728 60 *Exochosphaeridium phragmites* Davey et al. 1966
- 729 67 *Florentinia buspina* (Davey and Verdier 1976) Duxbury 1980
- 730 71 *Florentinia clavigera* (Deflandre 1937) Davey and Verdier 1973

- 731 28 *Florentinia cooksoniae* (Singh 1971) Duxbury 1980
- 732 47 *Florentinia laciniata* Davey and Verdier 1973
- 733 7 *Florentinia mantellii* (Davey and Williams 1966) Davey and Verdier 1973
- 734 34 *Florentinia* sp. Davey and Verdier 1973
- 735 8 *Hystrichodinium pulchrum* Deflandre 1935
- 736 TUR4/1 *Hystrichosphaeridium* sp. Deflandre 1937
- 737 32 *Hystrichosphaeridium bowerbankii* Davey and Williams 1966
- 738 49 *Hystrichosphaeridium conispiniferum* Yun Hyesu 1981
- 739 9 *Hystrichosphaeridium recurvatum* (White 1842) Lejeune-Carpentier, 1940
- 740 50 *Hystrichosphaeridium salpingophorum* Deflandre 1935
- 741 10 *Hystrichosphaeridium tubiferum tubiferum* (Ehrenberg 1838) Deflandre 1937
- 742 63 *Hystrichosphaeridium tubiferum brevispinum* (Davey and Williams 1966) Lentin
743 and Williams 1993
- 744 52 *Hystrichostrogylon membraniphorum* Agelopoulos 1964
- 745 69 *Impletosphaeridium clavulum* (Davey 1969) Islam 1993
- 746 74 *Isabelidinium? amphiatum* (McIntyre 1975) Lentin and Williams 1977
- 747 TUR4/1 *Kallosphaeridium? ringnesiorum* (Manum and Cookson 1964) Helby 1987
- 748 54 *Kiokansium unituberculatum* (Tasch in Tasch et al. 1964) Stover & Evitt 1978
- 749 35 *Kleithriasphaeridium loffreense* Davey and Verdier 1976
- 750 11 *Kleithriasphaeridium readei* (Davey and Williams 1966) Davey and Verdier 1976

- 751 TUR6/1, CON2 *Litosphaeridium arundum* (Eisenack and Cookson 1960) Davey 1979;
752 emend. Lucas-Clark 1984
- 753 36 *Membranilarnacia polycladiata* Cookson and Eisenack in Eisenack 1963
- 754 29 *Microdinium distinctum* Davey 1969
- 755 55 *Nematosphaeropsis denseradiata* (Cookson and Eisenack 1962) Stover and Evitt
756 1978
- 757 45 *Odontochitina costata* Alberti 1961; emend. Clarke and Verdier 1967
- 758 12 *Odontochitina operculata* (Wetzel 1933a) Deflandre and Cookson 1955
- 759 53 *Odontochitina singhii* Morgan 1980
- 760 TUR4/1 *Odontochitinopsis molesta* (Deflandre 1937) Eisenack 1961
- 761 13 *Oligosphaeridium complex* (White 1842) Davey and Williams 1966
- 762 48 *Oligosphaeridium poculum* Jain 1977
- 763 14 *Oligosphaeridium prolixispinosum* Davey and Williams 1966
- 764 46 *Oligosphaeridium pulcherrimum* (Deflandre and Cookson 1955) Davey and
765 Williams 1966
- 766 15 *Palaeohystrichophora infusorioides* Deflandre 1935
- 767 CON1 *Pareodinia ceratophora* Deflandre 1947
- 768 TUR2 *Pervosphaeridium* sp. Yun Hyesu 1981
- 769 TUR2 – 4/1, 4/3 *Pervosphaeridium cenomaniense* (Norvick 1976) Below 1982
- 770 TUR3 – 4/1, CON1 *Pervosphaeridium monasteriense* Yun Hyesu 1981
- 771 64 *Pervosphaeridium pseudhystrichodinium* (Deflandre 1937) Yun Hyesu 1981

- 772 16 *Pervosphaeridium truncatum* (Davey 1969) Below 1982
- 773 17 *Prolixosphaeridium granulosum* (Deflandre 1937) Davey et al. 1966
- 774 18 *Pterodinium “crassimuratum”* (Davey and Williams 1966) Thurow et al. 1988
- 775 68 *Raetiaedinium truncigerum* (Deflandre 1937) Kirsch 1991
- 776 CON1 *Scriniodinium campanula* Gocht 1959
- 777 44 *Senoniasphaera turonica* (Prössl, 1990 ex Prössl, 1992) Pearce et al. 2011
- 778 62 *Sentusidinium* sp. Sarjeant and Stover 1978
- 779 6 *Sepispinula? ambigua* (Deflandre 1937) Masure in Fauconnier and Masure 2004
- 780 38 *Spiniferites membranaceus* (Rossignol 1964) Sarjeant 1970
- 781 25 *Spiniferites ramosus granosus* (Davey and Williams 1966) Lentin and Williams
782 1973
- 783 19 *Spiniferites ramosus ramosus* (Ehrenberg 1838) Mantell 1854
- 784 51 *Stephodinium coronatum* Deflandre 1936
- 785 56 *Subtilisphaera pontis-mariae* (Deflandre 1936) Lentin and Williams 1976
- 786 TUR3, 4/1 *Surculosphaeridium? basifurcatum* Yun Hyesu 1981
- 787 75 *Surculosphaeridium belowii* Yun Hyesu 1981
- 788 20 *Surculosphaeridium longifurcatum* (Firtion 1952) Davey et al. 1966
- 789 21 *Tanyosphaeridium salpinx* Norvick 1976
- 790 61 *Tanyosphaeridium variecalamum* Davey and Williams 1966
- 791 65 *Tenua hystrix* Eisenack 1958
- 792 30 *Trichodinium castanea* Deflandre 1935

- 793 57 *Wrevittia cassidata* (Eisenack and Cookson 1960) Helenes and Lucas-Clark 1997
- 794 TUR4/1 *Wrevittia helicoidea* (Eisenack and Cookson 1960) Helenes and Lucas-Clark 1997
- 795 TUR4/3 – 6/2 *Xenascus ceratioides* (Deflandre 1937) Lentin and Williams 1973
- 796 66 *Xiphophoridium asteriforme* Yun Hyesu 1981

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1141

Figure and Plate Captions

1142

Fig. 1. Location and Turonian palaeogeography of the Bohemian Cretaceous Basin study section. (A) Simplified palaeogeography of the European epicontinental sea showing the location of the Bch-1 well. Adapted from Mitchell et al. (2010). (B) Detail of the Bohemian Cretaceous Basin, location shown by grey rectangle in A. Main siliciclastic source areas and sub-basins are shown: NW, Lužice-Jizera sub-basin; SE, Orlice-Ždár sub-basin. TUR2 – CON1 indicate regressive limits of nearshore strata in genetic sequences. Modified from Uličný et al. (2014)

1149

Fig. 2. Biostratigraphy and carbon isotope chemostratigraphy of the Bch-1 well. Calcareous nannofossil, dinocyst, inoceramid bivalve and ammonite datum levels are plotted against lithology and carbon isotope ratios of bulk organic matter ($\delta^{13}\text{C}_{\text{org}}$), and regional genetic sequences. Dinocyst datum levels from this study; other data from Uličný et al. (2014). Upper Cretaceous (UC) calcareous nannofossil zones after Burnett et al. (1998). Carbon isotope events (CIE) of Jarvis et al. (2006) are identified following Uličný et al. (2014). Minor revision of datum levels, genetic sequences and the placement of CIEs incorporates results from new unpublished stratigraphic work. Abbreviations used here and in text: FO = first occurrence; LO = last occurrence; FCO = first common occurrence; LCO = last common occurrence; RO = reappearance datum level. *Cci* = *Cremonoceras crassus inconstans*.

1159

Fig. 3. Dinocyst ranges and datum levels plotted against the macrofossil biostratigraphy and lithology of the Bch-1 well. ‘Floods’ are short-term abundance spikes; ‘acmes’ are medium- to long-term abundance maxima. The positions of major CIEs and the location of regional genetic sequences are shown. A complete list of species identified and their taxonomic assignments is provided in Appendix A. The ranges of biostratigraphically significant species (in bold) are emphasised by the vertical yellow bars; examples of these are illustrated in Plate

1165 I. Species displaying intervals of consistent common occurrence that may be of
1166 palaeoenvironmental or local biostratigraphic significance are highlighted by the vertical blue
1167 bars. See Fig. 2 for biostratigraphy and lithological key.

1168 **Fig. 4.** Relative abundance of common dinocyst species in the Bch-1 well. Values derived
1169 from counts of 300 identified dinocysts per sample. Note the different scales used to enhance
1170 stratigraphic trends. Red fills indicate peridinioid (P-cysts) and blue fills gonyaulacoid (G-
1171 cysts) species. Assemblages are dominated by *P. infusorioides* and *S. ramosus ramosus*, and
1172 in the Turonian – Coniacian boundary interval, *S. ambigua*. See Fig. 2 for biostratigraphy and
1173 lithological key.

1174 **Fig. 5.** Biostratigraphic and chemostratigraphic correlation of Bch-1 with English Chalk
1175 Turonian sections, showing key dinocyst datum levels. Inset map (modified from Rawson,
1176 1992) shows locations of English sections. Traditional Chalk macrofossil zones based on
1177 inoceramid bivalves, brachiopods and irregular echinoids; ammonite zones are also shown for
1178 the East Sussex composite section. Carbon isotope events in East Sussex based on
1179 interpretation of lithostratigraphic and biostratigraphic data (Mortimore, 1986; FitzPatrick,
1180 1995; Gale, 1996; Mortimore et al., 2001; Jarvis et al., 2006), and Pearce et al. (2009) for the
1181 Cenomanian – Turonian boundary interval.

1182 **Fig. 6.** Revised dinocyst zonation for the Turonian Stage, key dinocyst biostratigraphic
1183 markers, and their correlation to major carbon isotope events. Symbols as in Fig. 5. CTBE =
1184 Cenomanian – Turonian Boundary Event.

1185 **Plate I** Biostratigraphic marker species identified in the Turonian – Coniacian of the Bch-1
1186 core.

1187 1 *Pervosphaeridium truncatum* (Davey 1969) Below 1982, sample 335.5 m

- 1188 2 *Oligosphaeridium pulcherrimum* (Deflandre and Cookson 1955) Davey and Williams
1189 1966, sample 33.5 m
- 1190 3 *Palaeohystrichophora infusorioides* Deflandre 1935, sample 351.5 m
- 1191 4 *Cribroperidinium wilsonii* (Yun Hyesu 1981) Poulsen 1996, sample 57.5 m
- 1192 5 *Surculosphaeridium belowii* Yun Hyesu 1981, sample 51.5 m
- 1193 6 *Chatangiella ditissima* (McIntyre 1975) Lentin and Williams 1976, sample 33.5 m
- 1194 7 *Kiokansium unituberculatum* (Tasch in Tasch et al. 1964) Stover & Evitt 1978, sample
1195 197.5 m
- 1196 8 *Stephodium coronatum* Deflandre 1936, sample 215.5 m
- 1197 9 *Circulodinium distinctum distinctum* (Deflandre and Cookson 1955) Jansonius, 1986,
1198 sample 187.5 m
- 1199 10 *Florentinia buspina* (Davey and Verdier 1976) Duxbury 1980, sample 285.5 m
- 1200 11 *Raetiaedinium truncigerum* (Deflandre 1937) Kirsch 1991, sample 55.5 m
- 1201 12 *Subtilisphaera pontis-mariae* (Deflandre 1936) Lentin and Williams 1976, sample
1202 219.5 m
- 1203 13 *Oligosphaeridium poculum* Jain 1977, sample 43.5 m
- 1204 14 *Senoniasphaera turonica* (Prössl, 1990 ex Prössl, 1992) Pearce et al. 2011, sample
1205 389.5 m
- 1206 15 *Cyclonephelium compactum* complex of Marshall and Batten 1988, sample 398.6 m

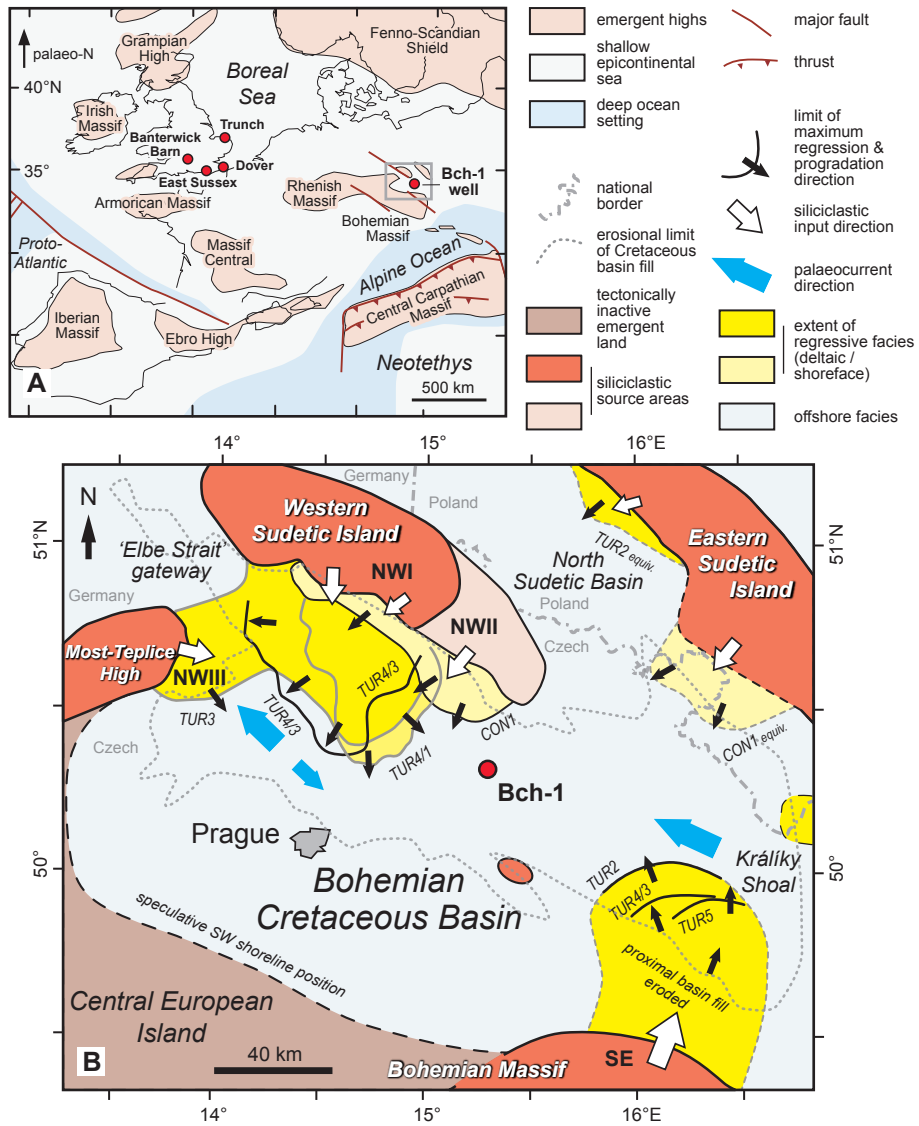


Fig. 1

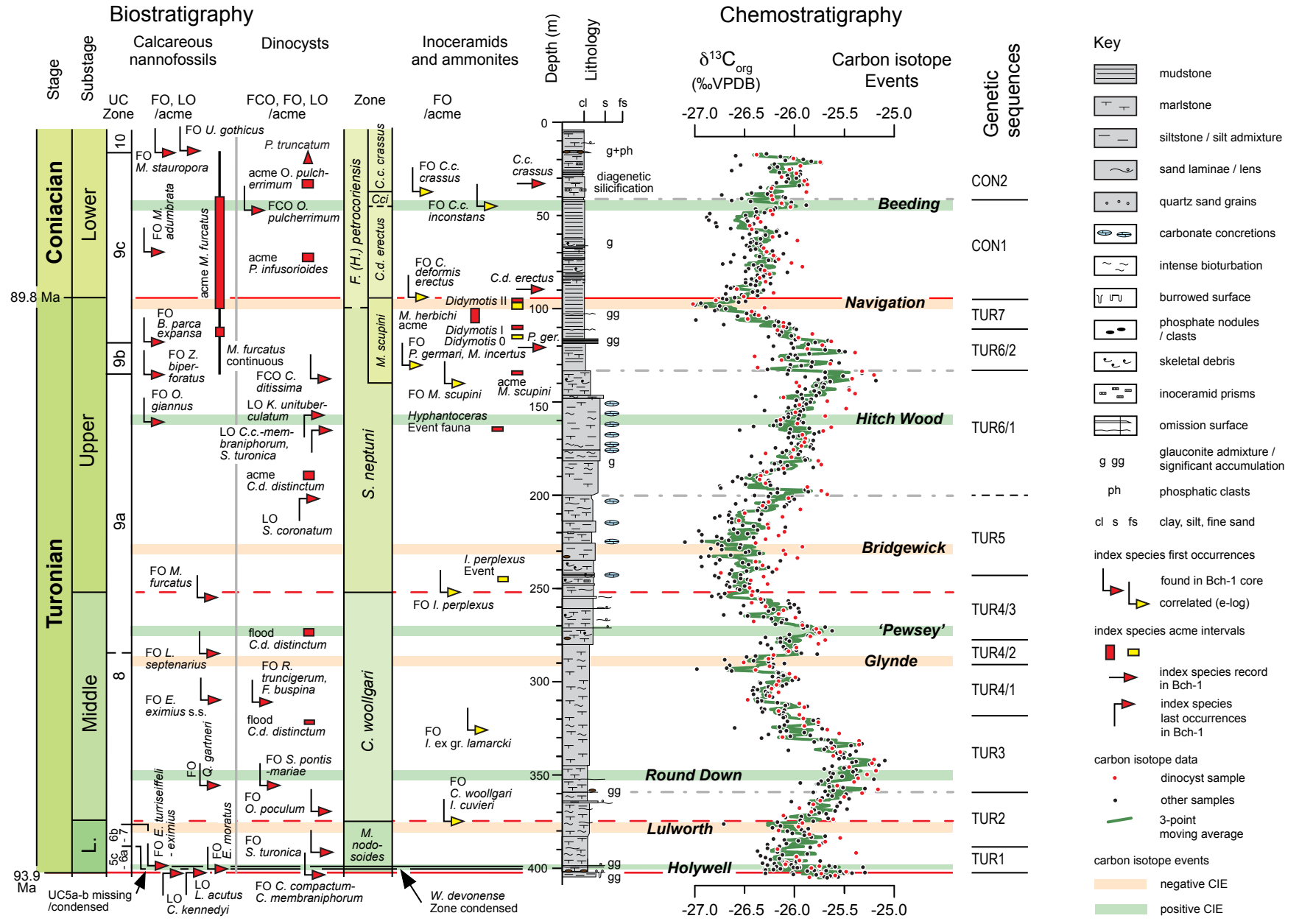


Fig. 2

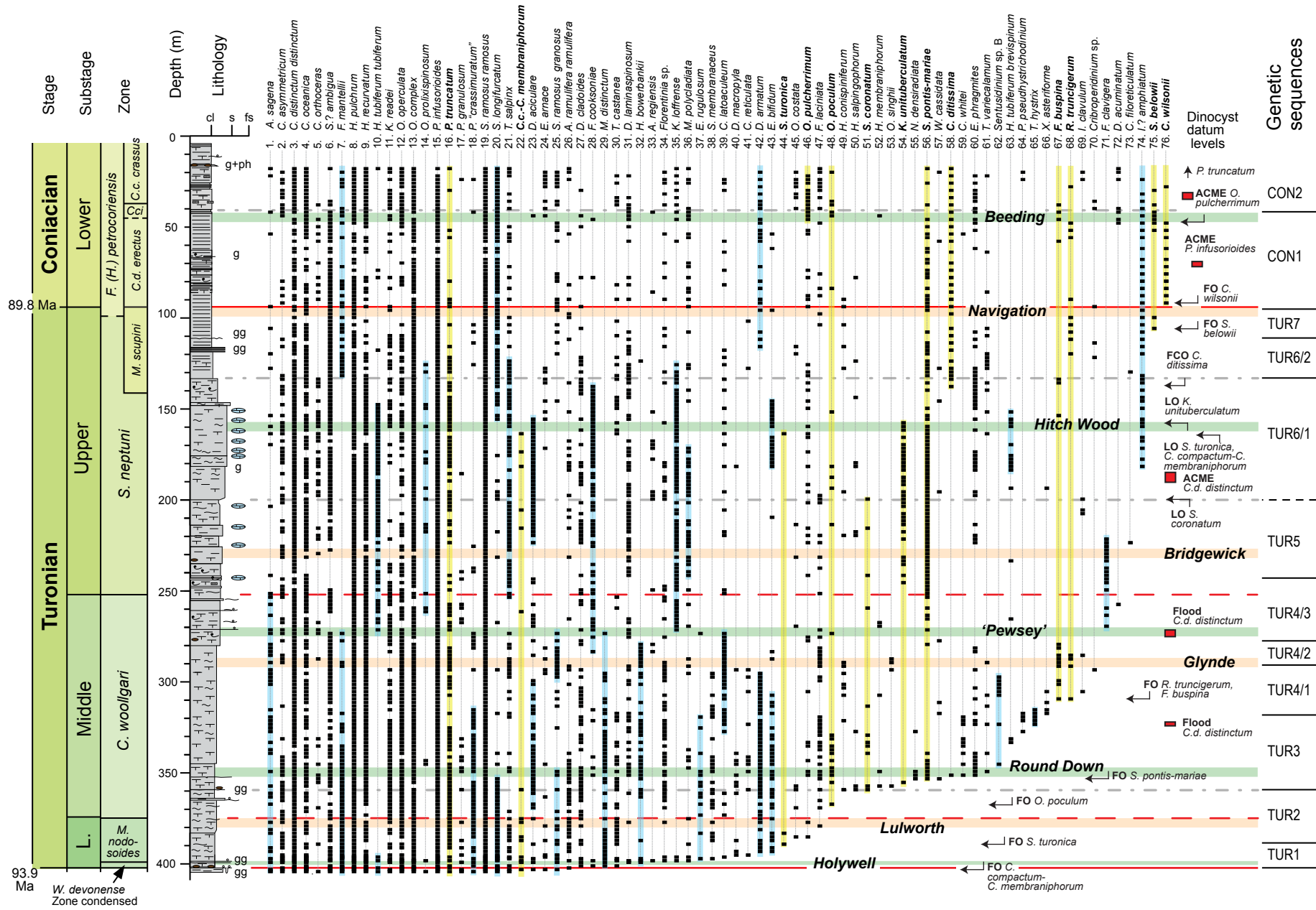


Fig. 3

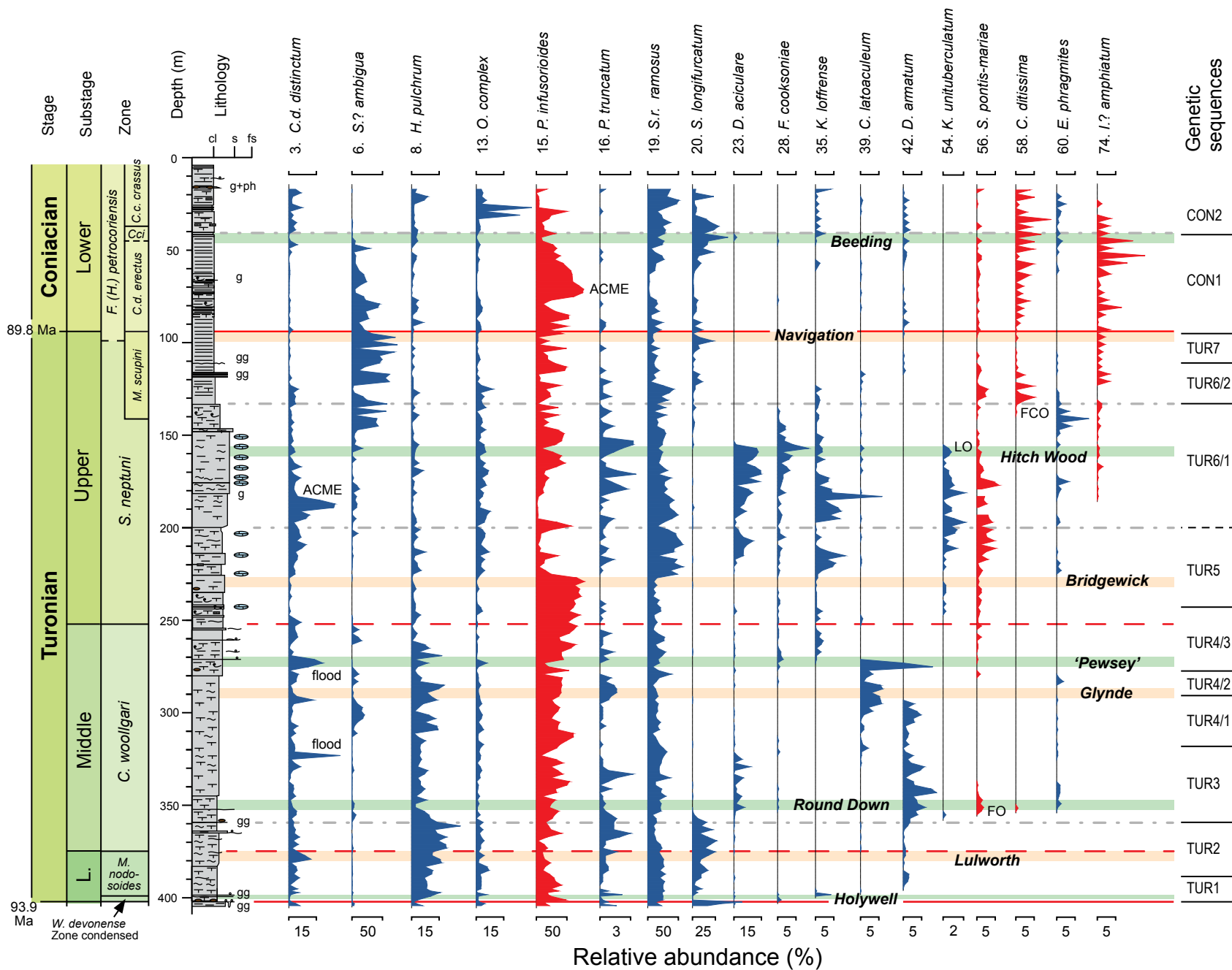
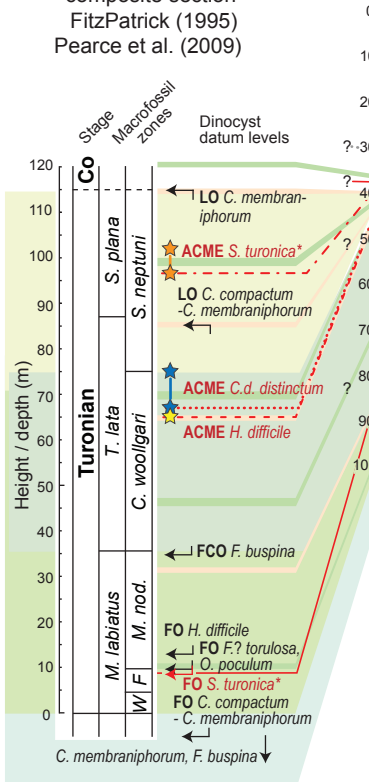


Fig. 4

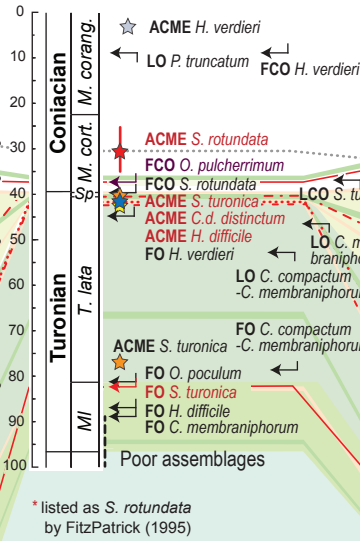
English Chalk

Ca-Op, *Callaiosphaeridium asymmetricum*-*Oligosphaeridium pulcherrimum*
 Cci, *Cremerceramus crassus inconstans*; Ec, *Endoscrinium campanula*; F, *Fagesia catinus*;
 Ku, *Kiokansium unituberculatum*; Ls, *Litosphaeridium siphoniphorum*;
 M. corang., *Micraster coranguinum*; M. cort., *Micraster cortestudinarium*;
 Ml, *Mytiloides labiatus*; Mn, *Mammites nodosoides*; W, *Watinoceras devonense*.

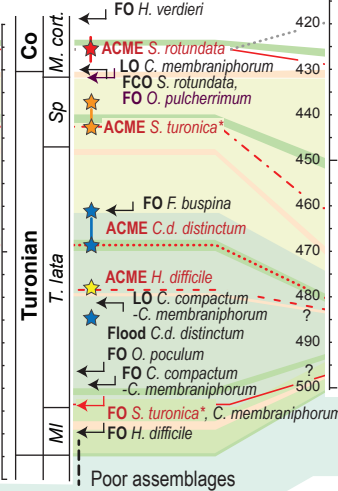
1. East Sussex composite section FitzPatrick (1995) Pearce et al. (2009)



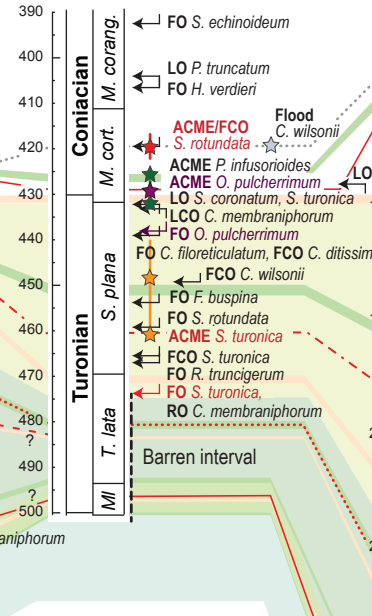
2. Berkshire Banterwick Barn Borehole Pearce et al. (2003)



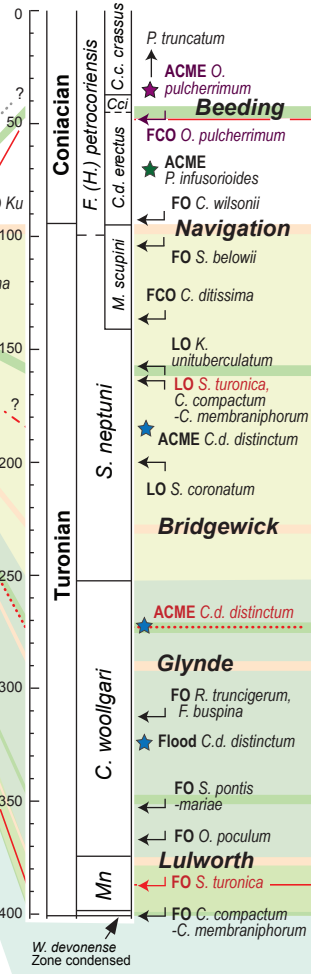
3. Kent Dover composite section FitzPatrick (1995) Prince et al. (2008)



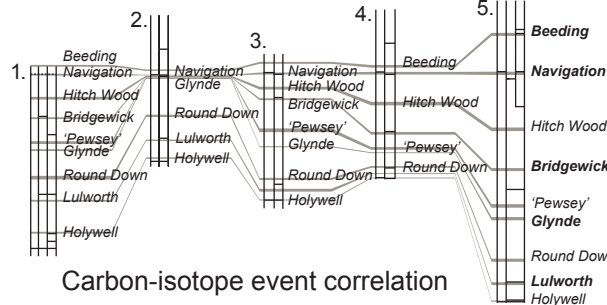
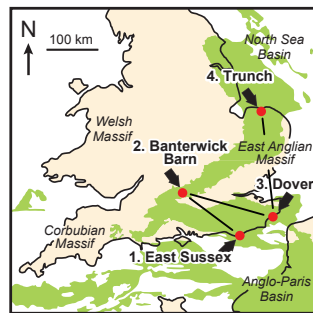
4. Norfolk Trunch Borehole Pearce (2000)



5. Czech Republic Běchary Borehole This study



Chalk localities



- Acmes / floods
- ★ *P. infusorioides*
 - ★ *S. rotundata*
 - ★ *S. turonica*
 - ★ *C. d. distinctum*
 - ★ *H. difficile*
 - ★ *O. pulcherrimum*
 - ★ others
- Cretaceous outcrop

| Zone | Subzone | Foucher (1981) | Williams (1977) | Clarke and Verdier (1967) | Dinocyst zonation |
|-----------|--|----------------|-----------------|---------------------------|----------------------------|
| Oligocene | <i>O. pulcherrimum</i> | | | | Ca-Op |
| | <i>S. rotundata</i> | | | | |
| Turonian | <i>Cauveridium membraniphorum</i> | | | | Spindinium echinoideum |
| | <i>Raetiaedinium truncigerum</i> | | | | |
| Turonian | <i>Senoniasphaera rotundata</i> | | | | Spindinium echinoideum |
| | <i>Surculosphaeridium? longifurcatum</i> | | | | |
| Turonian | <i>Cauveridium membraniphorum</i> | | | | Cauveridium membraniphorum |
| | <i>F. ferox</i> | | | | |
| Ls | <i>F. ferox</i> | | | | Cauveridium membraniphorum |
| | <i>Ku</i> | | | | |
| Ec | <i>Ku</i> | | | | Cauveridium membraniphorum |
| | <i>Ec</i> | | | | |

Fig. 5

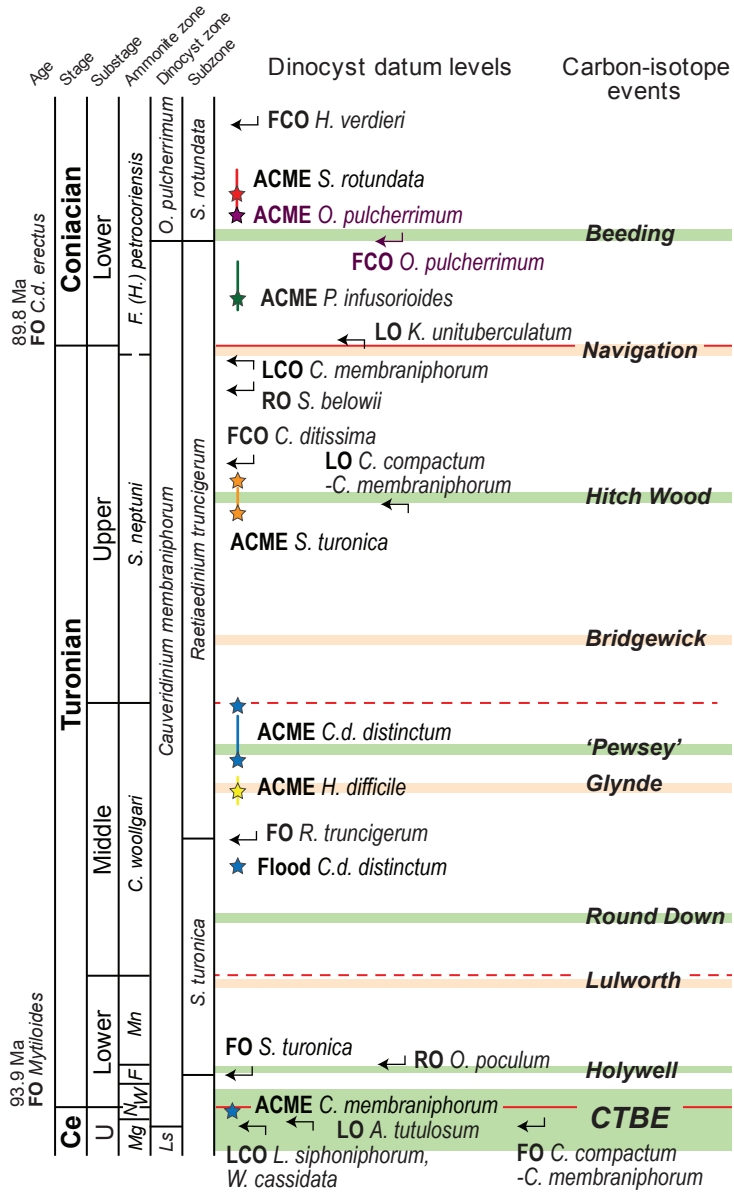
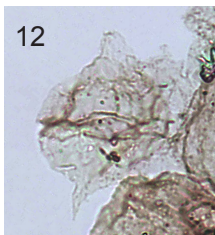
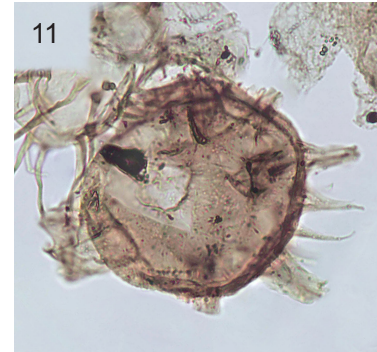
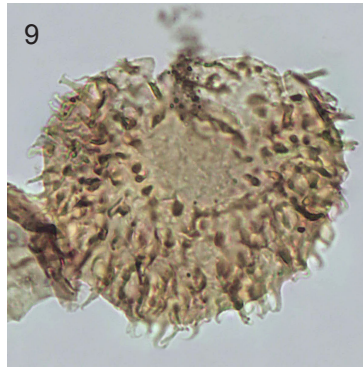
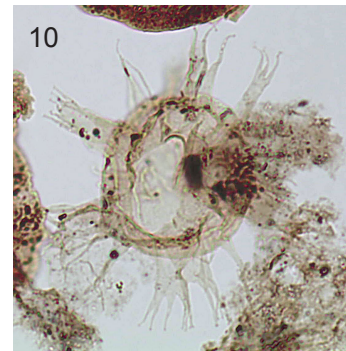
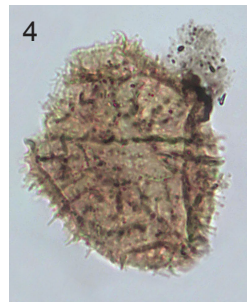
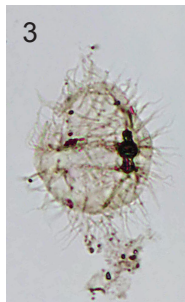
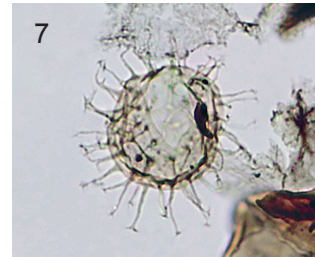
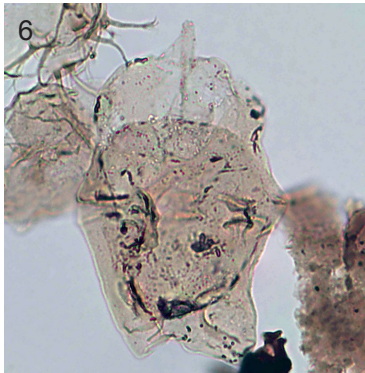
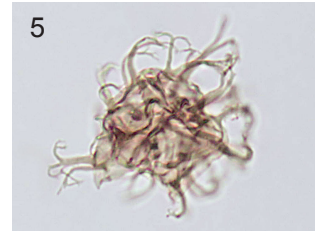
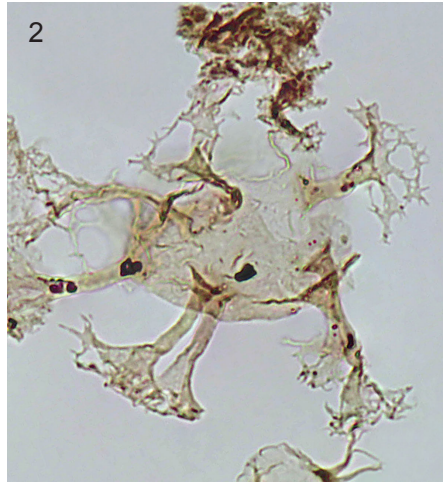
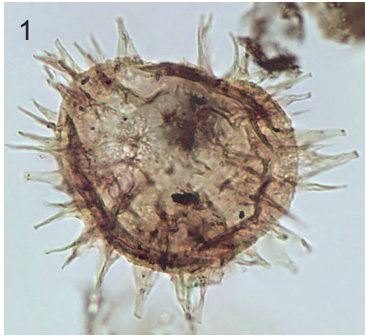


Fig. 6



25 μ m

