

1 The palynology of the Middle Jurassic (Bajocian-Bathonian) *Wanaea verrucosa*
2 dinoflagellate cyst Zone of the North West Shelf of Australia

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4 Daniel J. Mantle ^{a*}, James B. Riding ^b

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6 ^a *Geoscience Australia, GPO Box 378, Canberra ACT 2601, Australia*

7 ^b *British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham NG12*
8 *5GG, United Kingdom*

9

10 * *Corresponding author.*

11 *E-mail address: daniel.mantle@ga.gov.au (D.J. Mantle).*

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13

14 ABSTRACT

15

16 The marine and terrestrial palynology of the Middle Jurassic *Wanaea verrucosa* Zone
17 from the Perseus-3A, Sunrise-2 and Sunset West-1 wells of the North West Shelf of
18 Australia was studied in detail. These three wells represent brackish and shallow
19 marine successions from the Northern Carnarvon and Bonaparte basins respectively.

20 The palynological data derived from these three wells constitute the basis for the
21 formal definition of this important dinoflagellate cyst biozone and its three constituent
22 subzones. The base of the Lower *Wanaea verrucosa* Subzone is defined by the
23 inception of the index species and is a relatively sparse, low diversity
24 microphytoplankton assemblage; species richness increases up-section. The base of
25 the succeeding Middle *Wanaea verrucosa* Subzone is defined by the range base of
26 *Valvaeodinium spinosum*, and the Upper *Wanaea verrucosa* Subzone is defined by the
27 incoming of the large and distinctive species *Endoscrinium kempiae*. Other
28 stratigraphically-important datums include the inceptions of *Bradleyella adela* in the
29 lower subzone, *Leptodinium* spp. and *Wanaea lacuna* in the middle subzone, and
30 *Endoscrinium* spp. and *Ternia balmei* within the upper subzone. Important range tops
31 include *Mancodinium semitabulatum* and *Phallocysta granosa* in the middle subzone,
32 and *Nannoceratopsis deflandrei* in the upper subzone. These and other datums are
33 compared with European ranges to assign a Late Bajocian to Early Bathonian age to
34 the *Wanaea verrucosa* Zone.

35 The dinoflagellate cyst associations are dominated by cosmopolitan taxa,
36 particularly at the generic level. Endemic Australasian forms such as *Phallocysata*
37 *granosa* and *Ternia balmei* are relatively minor in significance. However, two new
38 species, *Meiourogonyaulax straussii* sp. nov. and *Valvaeodinium cookii* sp. nov. are
39 established and are unknown from other localities. The species *Jansonia scarffei* is
40 reattributed as *Fostericysta scarffei* (Tykoezinski et al. 2001) comb. nov. Taxa with
41 epicystal and multiplate precingular archaeopyles are prominent; this represents the
42 coeval evolutionary explosion of the gonyaulacacean dinoflagellate cysts observed in
43 the latest Early to Late Bajocian of Europe. By contrast, the succeeding Callovian to
44 Oxfordian interval in Australasia and Europe is dominated by endemic taxa. This may
45 be an indication of the development of forms with specific environmental preferences
46 during the Callovian and Oxfordian and/or the establishment of barriers to the passive
47 dispersal of dinoflagellates within Tethys. However, this phenomenon may be
48 partially an artefact of further diversification.

49 The associated spore-pollen assemblages are transitional from the upper
50 *Dictyosporites complex* to the lower *Contignisporites cooksoniae* zones. The latter
51 zone is defined by the first appearance of the index species, but considerable care is
52 required to separate this species from the many intermediate forms of *Striatella-*
53 *Contignisporites* that occur through this interval. The palynofloras are dominated by
54 araucariacean monosaccates (particularly *Callialasporites*
55 spp.), corystospermibisaccates (mostly *Alisporites* spp.) and moderately diverse
56 bryophyte-lycophyte-pteridophyte spore assemblages.

57

58 *Keywords:* biostratigraphy; dinoflagellate cysts; *Wanaea verrucosa* Zone; Middle
59 Jurassic (Bajocian-Bathonian); North West Shelf; Australia.

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61

62 **1. Introduction**

63

64 The North West Shelf of Australia is a passive continental margin comprising
65 the Northern Carnarvon, Roebuck, Offshore Canning, Browse and Bonaparte basins
66 (Fig. 1). These five depocentres collectively make up the extensive Westralian
67 Superbasin and represent the most important hydrocarbon province in Australia.
68 Longley et al. (2002) reviewed the petroleum geology of this region that includes

69 multiple source, reservoir and seal units of Early Carboniferous to Late Cretaceous
70 age. These include the fluvio-deltaic and marginal marine sandstones of the Legendre
71 and Plover formations that form important Middle Jurassic reservoir units in the
72 Northern Carnarvon and Bonaparte basins respectively. This interval is represented by
73 the *Nannoceratopsis deflandrei*, *Wanaea verrucosa* and *Wanaea indotata*
74 dinoflagellate cyst zones.

75 Microfossil-based biostratigraphy has been extensively used during both the
76 hydrocarbon exploration and production phases across the North West Shelf. The
77 standard Mesozoic palynomorph zonation for the North West Shelf is Helby et al.
78 (1987). This is an integrated dinoflagellate cyst and spore-pollen biozonation scheme
79 for the Late Permian (Changshingian) to the Palaeocene (Danian) interval. The
80 dinoflagellate cyst zonal component generally provides substage level resolution from
81 the Middle Triassic (Anisian) to Palaeocene. Further taxonomic work chiefly on the
82 Jurassic (Toarcian-Tithonian) by Helby and Partridge (2001) and Riding and Helby
83 (2001a-h) established many key marine microphytoplankton taxa that significantly
84 increased the biostratigraphical resolution across this interval. These index species
85 have allowed the definition of many dinoflagellate cyst subzones, some of which were
86 illustrated, but not defined, by Helby et al. (1987, fig. 47) and Foster (2001, fig. 2).
87 Further revisions were figured by Helby et al. (2004) and Partridge (2006) on
88 chart/poster-style publications along with the bioevents that define each zone and
89 subzone. Subsequently, the ranges of many of the important dinoflagellate cyst index
90 taxa for the Mid Triassic to earliest Cretaceous (Ladinian-Berriasian) zones were
91 provided by Riding et al. (2010a), who reviewed and revised the chronostratigraphical
92 ages for the zones in this interval. However, the new zones and subzones listed by
93 Helby et al. (2004) and Partridge (2006) remained unformalized. These zones can
94 nevertheless be used in applied petroleum geology studies because their parameters in
95 terms of the defining bioevents were clearly illustrated.

96 This contribution is focussed on the Late Bajocian to Early Bathonian *Wanaea*
97 *verrucosa* dinoflagellate cyst Zone and its three constituent subzones. In this paper we
98 formally define the zone, and the three subzones, and provide detailed palynological
99 documentation of this interval in three important reference sections. The successions
100 studied are from the Perseus-3A well in the Northern Carnarvon Basin, and the
101 Sunrise-2 and Sunset-West-1 wells in the Bonaparte Basin (Fig. 1; Appendix 1).

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103

104 **2. The *Wanaea verrucosa* Zone - background**

105

106 The *Wanaea verrucosa* Zone was first illustrated by Foster (2001, fig. 2) for
107 the Bathonian (Middle Jurassic) of the North West Shelf of Australia. This
108 dinoflagellate cyst zone replaced the upper part of the *Caddasphaera halosa* Zone of
109 Helby et al. (1987). The *Wanaea verrucosa* Zone was subsequently illustrated, with
110 defining bioevents, by Helby et al. (2004, figs. 1, 4) and Partridge (2006). Its base and
111 top are delimited by the range bases of *Wanaea verrucosa* and *Wanaea indotata*
112 respectively. The base of the zone was also defined by the apparent extinction of
113 *Nannoceratopsis deflandrei*, but the current study considerably extends this range.
114 The zone was subdivided into three subzones defined on the range bases of *Wanaea*
115 *verrucosa*, *Valvaeodinium spinosum* and *Endoscrinium kempiae* (Helby et al., 2004;
116 Partridge, 2006). The only other biostratigraphical data depicted was the range base of
117 *Ternia balmei* within the youngest of these subzones (Helby et al., 2004, fig. 4).
118 Riding et al. (2010a, p. 562) revised the Bathonian age of the zone to Late Bajocian to
119 Early Bathonian based on key dinoflagellate cyst datums established in Europe (Fig.
120 2).

121 According to Riding et al. (2010a), the *Wanaea verrucosa* Zone is
122 characterised by high diversity assemblages of largely undescribed species with
123 species richness increasing up-section. The described taxa within this zone were noted
124 to include *Endoscrinium kempiae*, *Nannoceratopsis* spp., *Pareodinia ceratophora*,
125 *Pareodinia halosa*, *Phallocysta granosa*, *Ternia balmei*, *Valvaeodinium spinosum*,
126 *Wanaea enoda*, *Wanaea lacuna* and *Wanaea verrucosa* (see Riding et al., 2010a, p.
127 562).

128

129

130 **3. The palynology of the *Wanaea verrucosa* Zone in the Perseus-3A, Sunrise-2** 131 **and Sunset West-1 wells**

132

133 In this study, 64 conventional core samples from the Perseus-3A, Sunrise-2
134 and Sunset West-1 wells (Fig. 3) were investigated for palynology. In the Northern
135 Carnarvon Basin, 14 samples were selected from the fluvio-deltaic Legendre
136 Formation in the Perseus-3A well; this succession consists of a series of coarsening-

137 upward cycles deposited in low energy, non-marine and brackish environments
138 through to marginal and shallow marine settings. The remaining 50 samples from the
139 Sunrise-2 and Sunset West-1 wells, in the Bonaparte Basin, are from shallow marine
140 deposits in the uppermost Plover Formation. The samples largely produced abundant,
141 terrestrial palynofloras with a lower proportion of marine microphytoplankton. The
142 latter includes a moderately diverse dinoflagellate cyst assemblage that forms the
143 principal focus of this contribution due to their stratigraphical utility across the North
144 West Shelf.

145 In the majority of the samples investigated, low diversity associations of
146 gymnospermous pollen dominate, including abundant *Araucariacites* spp.,
147 *Callialasporites* spp. and undifferentiated bisaccate pollen (mostly the corystosperm
148 genus *Alisporites*). Common *Classopollis* spp. represent cheirolepidacean conifers,
149 whilst the frequently co-occurring taxodiacean species *Exesipollenites tumulus* and
150 *Perinopollenites elatoides* were also sporadically recorded. Further pollen species
151 recorded in low numbers included *Cycadopites* spp., *Vitreisporites pallidus* and rare
152 trisaccate types.

153 There is also a moderate diversity and abundance of pteridophyte, bryophyte
154 and lycodpod spores throughout the intervals studied; these assemblages are
155 commonly dominated by *Cyathidites* spp., *Dictyophyllidites* spp., *Gleicheniidites* spp.,
156 *Ischyosporites/Klukisporites* spp., *Neoraistrickia* spp., *Osmundacidites* spp. and
157 *Retitriletes* spp. Common accessory species included *Antulsporites saevus*,
158 *Annulispora* spp., *Coronatispora* spp., *Dictyotosporites complex*, *Foveosporites*
159 *canalis*, *Sestrosporites pseudoalveolatus* and *Staplinisporites caminus*. There is also a
160 stratigraphically significant transition from *Striatella* to *Contignisporites* through the
161 zone, with common intermediate forms.

162 Reworked pollen and spores were noted throughout the successions in all three
163 wells. These allochthonous forms are largely of Permian age and include highly
164 distinctive types such as *Diatomozonotriletes townrowii*, *Didecitriletes ericianus*,
165 *Dulhuntyispora dulhuntyi*, *Granulatisporites trisinus*, *Indotriradites* spp.,
166 *Microbaculispora villosa*, *Plicatipollenites* spp., *Praecolpatites sinuosus*,
167 *Protohaploxylinus* spp., *Pseudoreticulatispora pseudoreticulata*, *Striatoabieites*
168 *multistriatus* and *Striatopodocarpidites* spp.

169 However, the main focus of the study was on the moderately diverse marine
170 microphytoplankton assemblages that are present in the three selected wells. The

171 relative proportions of dinoflagellate cysts are highly variable across the *Wanaea*
172 *verrucosa* Zone, but they generally represent 15-40% of the palynofloras in the two
173 Bonaparte Basin wells and 1-20% of the palynofloras in the Perseus-3A well in the
174 Northern Carnarvon Basin. The significantly sparser dinoflagellate cyst assemblages
175 in the Perseus-3A well reflect the more marginal marine and brackish or even
176 nonmarine environments across the Bajocian-Bathonian interval in the Northern
177 Carnarvon Basin compared to the dominantly shallow marine successions across
178 much of the northern Bonaparte Basin. These dinoflagellate cyst associations are
179 dominated by *Ctenidodinium* spp., the *Dissiliodinium-Durotrigia* group,
180 *Escharisphaeridia* spp., *Meiourogonyaux* spp., *Pareodinia* spp. and *Wanaea*
181 *verrucosa*. Other common or stratigraphically significant forms include ?*Bradleyella*
182 *adela*, *Kallosphaeridium hypornatum*, *Leptodinium* spp., *Mancodinium*
183 *semitabulatum*, *Nannoceratopsis deflandrei*, *Phallocysta granosa*, *Ternia balmei*,
184 *Valvaeodinium cookii* sp. nov., *Valvaeodinium spinosum* and *Wanaea enoda*.
185 Miscellaneous palynomorphs such as acritarchs (largely *Micrhystridium* spp.),
186 *Botryococcus*, foraminiferal test linings and prasinophytes (e.g. *Pterospermella*
187 *australiense*) are present in relatively minor proportions, and appear to be of limited
188 stratigraphical significance.

189 The dinoflagellate cyst systematics, including the establishment of
190 *Meiourogonyaux straussii* sp. nov. and *Valvaeodinium cookii* sp. nov., are presented
191 as Appendix 2. The non-dinoflagellate cyst palynomorphs are simply listed in
192 Appendix 3 whilst the quantitative counts of both terrestrial and marine palynomorphs
193 are given in Appendix 4 (Tables 1-6). Selected dinoflagellate cyst specimens are
194 illustrated in Plates I-X, and all the figured material is housed in the Commonwealth
195 Palaeontological Collection (CPC) of Geoscience Australia, Canberra, ACT,
196 Australia. A register of figured specimens is included as Appendix 5.

197

198

199 3.1. The Perseus-3A well

200

201 The Perseus-3A well was drilled in the Northern Carnarvon Basin (Fig. 1;
202 Appendix 1) to a total depth of 3915 m to the Upper Triassic Mungaroo Formation.
203 Fourteen conventional core samples were examined from the Middle Jurassic *Wanaea*
204 *verrucosa* Zone; the quantitative distribution of palynomorphs in these samples is

205 depicted in Tables 1 and 4 of Appendix 4. The samples generally produced relatively
206 abundant, fair- to well-preserved palynomorph associations. The organic residues are
207 consistently dominated by terrestrially-derived palynomorphs, with subordinate
208 marine microphytoplankton (Tables 1, 4). In seven of the 14 samples, dinoflagellate
209 cysts represent less than 10% of the palynofloras. This relative sparsity of marine
210 microplankton is consistent with a brackish water depositional setting. This contention
211 is supported by the consistent, albeit rare, occurrences of the freshwater/brackish alga
212 *Botryococcus* (Table 4). A further 15 samples from this interval were not studied in
213 detail; these samples contained extremely sparse dinoflagellate cyst assemblages
214 (<1% of total palynomorphs) and are probably representative of brackish to non-
215 marine environments.

216

217 3.2. *The Sunrise-2 well*

218

219 The Sunrise-2 well is located immediately northeast of the Sunset West-1 well
220 in the Bonaparte Basin (Fig. 1; Appendix 1). It penetrated 2350 m into the fluvial-
221 deltaic Lower-Middle Jurassic Plover Formation. Twenty-nine samples from the
222 upper, more marine, sections of the Plover Formation were examined herein. The
223 quantitative distribution of palynomorphs in these samples is illustrated in Tables 2
224 and 5 of Appendix 4. The samples yielded moderately diverse terrestrial and marine
225 palynomorphs with dinoflagellate cysts commonly making up 20-50% of the total
226 assemblages. The preservation ranged from poor- to well-preserved. However, the
227 thermal alteration index is moderately higher in this well than the other two wells
228 examined; most spores and pollen are dark orange to brown and are at peak maturity
229 for oil generation.

230

231 3.3. *The Sunset West-1 well*

232

233 The Sunset West-1 well was drilled to a total depth of 2505 m in the Lower
234 Jurassic, fluvially dominated sections of the Plover Formation in the northern
235 Bonaparte Basin (Fig. 1; Appendix 1). Twenty-one samples from the *Wanaea*
236 *verrucosa* Zone in the shallow marine, upper Plover Formation were studied herein;
237 the quantitative distribution of palynomorphs in these samples is depicted in Tables 3
238 and 6 of Appendix 4. They generally produced abundant and poor- to well-preserved

239 palynomorph associations. However, the uppermost three samples yielded relatively
240 sparse, poorly-preserved palynofloras. The organic residues in the lower and middle
241 subzones are mostly dominated by terrestrially derived pollen and spores, with
242 subordinate marine microphytoplankton (9-29% dinoflagellate cysts of the total
243 palynofloras). However, the upper subzone is substantially more marine, with
244 dinoflagellate cysts accounting for 21% to 76% of the total palynomorphs.

245

246

247 3.4. Palaeoecological palynology

248

249 The palynomorph assemblages are largely dominated by pollen and spores
250 with a low to moderate diversity marine microphytoplankton component.
251 Gymnosperm pollen, particularly araucariacean types, are abundant throughout all
252 three wells together with moderately diverse and abundant bryophyte-lycophyte-
253 pteridophyte spore communities. The predominance of the araucariacean pollen, and
254 to a lesser extent corystosperm bisaccates, is suggestive of warm, largely non-seasonal
255 and temperate to moderately humid environments (Reyre, 1980; Mohr, 1989; Abbink
256 1998). This increase in abundance of araucariacean pollen and the marked decrease in
257 cheirolepidacean pollen, such as *Corollina* and *Exesipollenites*, reflects the change
258 from the drier and possibly warmer conditions that prevailed in the Early Jurassic
259 (Filatoff, 1975; McKellar, 1996; Sajjadi and Playford, 2002) and marks a prolonged
260 period of relative climate stability. These moister conditions in the Middle Jurassic are
261 also reflected in the moderate diversity of filicalean fern, and bryophytic moss and
262 liverwort spores.

263 The predominance of gymnosperm pollen over spores in the *Wanaea*
264 *verrucosa* Zone in both the Sunrise-2 and Sunset West-1 wells probably reflects the
265 transport time to shallow marine environments in the Bonaparte Basin, as opposed to
266 proximity to suitable habitats; araucariacean trees are more likely to occur away from
267 deltaic and most coastal environments, but their pollen is readily transported to such
268 settings. Similarly, the comparable abundances of pollen to spores and the much
269 reduced marine microphytoplankton abundance in Perseus-3A reflects the shorter
270 transport distances into the marginal marine to brackish and intermittently non-marine
271 environments in parts of the Northern Carnarvon Basin. These coastal plain to very
272 nearshore environments, possibly in a somewhat restricted basin, are considered

273 analogous with the Bathonian Great Estuarine Group of northwest Scotland. This unit
274 represents shallow water, paralic conditions where the salinity was largely brackish
275 and is characterised by dinoflagellate cyst assemblages with low species richness
276 (Riding et al., 1991, figs. A4-A10); the composition of these assemblages is broadly
277 comparable to those of the North West Shelf.

278 In the two Bonaparte Basin wells studied herein, the greater diversity and
279 abundance of marine microphytoplankton allows some inferences to be made
280 regarding the fluctuating marine depositional environments. There is a moderate
281 increase in abundance and diversity of dinoflagellate cysts through the Middle and
282 Upper *Wanaea verrucosa* subzones, which suggests a shift from a very nearshore
283 setting in the Lower subzone to shallow marine (though still nearshore)
284 palaeoenvironments in the overlying subzones. This is reflected in the overall
285 progression from a fluvially-dominated/tide-influenced succession for the Lower
286 *Wanaea verrucosa* Subzone and underlying sections to a wave-dominated/tide-
287 influenced interval that covers the Middle-Upper *Wanaea verrucosa* Subzones as
288 indicated by integrated studies of the sedimentology, ichnology and wireline log
289 profiles for these wells (Ainsworth et al., 2008; fig. 4.6).

290 A nearshore depositional environment is not only suggested by the dominance
291 of pollen and spores to marine microphytoplankton, but also by the relative abundance
292 of certain dinoflagellate cyst groups. *Meiourogonyaulax* are thick-walled, robust,
293 dinoflagellate cysts considered typical of nearshore environments (Harris and Tocher,
294 2003) and are likely to preserve well with minimal damage in differing environments
295 and after variable laboratory preparations (Mantle 2009b); their abundance through
296 the *Wanaea verrucosa* Zone should thus be relatively free from preservational or
297 processing artefacts. The prominence of *Meiourogonyaulax* in the Middle and Upper
298 subzones probably reflects normal salinity, shallow marine conditions, as is also
299 reflected by the increase in foraminiferal test linings and spiny acritarchs. *Ternia*
300 *balmei* is another species that is thought have been largely nearshore in occurrence; it
301 first occurs in the Upper *Wanaea verrucosa* Subzone.

302

303

304 **4. The definition of the *Wanaea verrucosa* Zone**

305

306 In this section, the *Wanaea verrucosa* Zone of Foster (2001), Helby et al.
307 (2004) and Partridge (2006) is formally defined.
308
309 *Wanaea verrucosa* Zone
310
311 Definition: The interval between the range base of *Wanaea verrucosa* and the range
312 base of *Wanaea indotata*.
313
314 Age: Late Bajocian to Early Bathonian (Riding et al., 2010a).
315
316 Type sections: The shallow marine successions in the Sunrise-2 (2155.74-2107.42m)
317 and Sunset West-1 (2247.05-2200.17m) wells in the northern Bonaparte Basin are
318 proposed as reference sections for the *Wanaea verrucosa* Zone and its constituent
319 subzones.
320
321 Accessory forms: The *Wanaea verrucosa* Zone is characterised by low to moderate
322 diversity dinoflagellate cyst assemblages dominated by the genera *Ctenidodinium*,
323 *Dissiliodonium-Durotrigia*, *Escharisphaeridia*, *Pareodinia* and *Wanaea*.
324 *Batiacasphaera* and *Nannoceratopsis* are also consistently present in relatively low
325 proportions.
326
327 Associated spore-pollen zones: upper *Dictyotosporites complex* to lower
328 *Contignisporites cooksoniae* zones (insert reference here)
329
330 Remarks: The base of the *Wanaea verrucosa* Zone is marked by the range base of the
331 important Middle-Late Jurassic genus, *Wanaea* (see Riding and Helby, 2001b, figs.
332 11, 12). In Australia, *Wanaea enoda* and *Wanaea verrucosa* have their inceptions at
333 this point, as observed in the three wells studied herein (Fig. 4). The range base of this
334 distinctive and large genus is an ideal biostratigraphical marker. Although the *Wanaea*
335 *verrucosa* Zone assemblages are typically dominated by pollen and spores, the index
336 species is consistently present, often in significant proportions.
337
338 Subzones: The Sunrise-2 and Sunset West-1 wells in the Bonaparte Basin are
339 subdivided into Lower, Middle and Upper subzones along similar lines to those

340 illustrated by Helby et al. (2004). However, alternative marker species are also noted,
341 and general assemblage trends may be as useful in identifying these subzones. The
342 Perseus-3A well has yielded considerably sparser and lower diversity dinoflagellate
343 cyst assemblages; it cannot be confidently subdivided as in the Bonaparte Basin
344 wells. Hence the comments on the subzones below may only apply to the Bonaparte
345 Basin rather than the whole of the North West Shelf.

346

347 Lower *Wanaea verrucosa* Subzone

348

349 Definition: The interval between the range base of *Wanaea verrucosa* and the range
350 base of *Valvaeodinium spinosum*.

351

352 Remarks: The base of this subzone is formally defined as the first occurrence of
353 *Wanaea verrucosa*. The lower half of the subzone is characterised by an abundance of
354 *Dissiliodinium/Durotrigia*-type cysts (20-66% of dinoflagellate cysts) in an otherwise
355 low diversity assemblage (Fig. 4; Tables 1-6). Important accessory forms include
356 *Nannoceratopsis deflandrei* subsp. *deflandrei*, ?*Egmontodinium* sp. A. and
357 *Phallocysta granosa*. The rare occurrence of *Mancodinium semitabulatum* subsp.
358 *semitabulatum* is an important stratigraphical tie to Bajocian assemblages in Europe;
359 there are no previously published records of this genus for the southern hemisphere. It
360 is restricted to the Lower Subzone, with only one specimen recorded from the base of
361 the Middle Subzone in the Sunset West-1 well (Table 3). Another potential marker
362 species is *Meiourogonyaulax* sp. B; it occurs consistently towards the top of the
363 Lower Subzone with only record in the Middle Subzone.

364

365 Middle *Wanaea verrucosa* Subzone

366

367 Definition: The interval between the range base of *Valvaeodinium spinosum* and the
368 range base of *Endoscrinium kempiae*.

369

370 Remarks: The base of this subzone is formally defined as the first occurrence of
371 *Valvaeodinium spinosum*. However, this species is uncommon towards the base of its
372 range and is best used in conjunction with the first appearance of *Valvaeodinium*
373 *cookii* sp. nov (Fig. 4). The latter species first appears at the same level, but is

374 marginally commoner in both the Sunrise-2 and Sunset West-1 wells. It does not
375 appear to range above the Middle Subzone. Another key species is ?*Bradleyella adela*
376 which first occurs in the uppermost Lower Subzone but is present as a notable acme in
377 the Middle Subzone (Fig. 4) where it accounts for 12-37% of the total palynomorphs
378 before abruptly disappearing at or immediately above the base of the Upper Subzone.
379 There is also a restricted acme of *Phallocysta granosa* in two samples (2121.63 and
380 2117.06 m, where it represents 15% and 5% of the dinoflagellate cysts, respectively)
381 in the Sunrise-2 well (Table 2) and high abundances of *Meiourogonyaulax* throughout
382 most of the subzone. The latter genus first occurs in the Lower Subzone, but the
383 abundance and diversity increases substantially in the Middle Subzone. However,
384 subdividing many of the forms is impractical as there is clearly a high degree of
385 intraspecific variability.

386 Overall, the microphytoplankton diversity is considerably higher than in the
387 underlying subzone, including such short ranging species as *Wanaea lacuna* that
388 appears to be restricted to a narrow interval within the Middle Subzone. Other marker
389 events include the inception of several dinoflagellate cyst genera with single-plate
390 precingular archaeopyles, such *Aldorfia*, *Endoscrinium* and *Leptodinium*, towards the
391 top of the subzone. Important final appearance datums include *Mancodinium*
392 *semitabulatum* subsp. *semitabulatum* at the base of the zone and *Nannoceratopsis*
393 *deflandrei* subsp. *senex* and *Valvaeodinium cookii* sp. nov. towards the top of the
394 subzone. Notable accessory species include *Evansia* sp. A, *Kallosphaeridium*
395 *hypornatum*, *Pareodinia* sp. A and *Wanaea verrucosa*.

396

397 Upper *Wanaea verrucosa* Subzone

398

399 Definition: The interval between the range base of *Endoscrinium kempiae* and the
400 range base of *Wanaea indotata*.

401

402 Remarks: The base of this subzone is formally defined as the first occurrence of
403 *Endoscrinium kempiae* (Fig. 4). This large and distinctive species is a good
404 biostratigraphical marker, but it can be rare in the lower parts of its range. The
405 subzone is characterised by a marked increase in the abundance and diversity of
406 *Ctenidodinium*, particularly spinose forms, and the consistent presence, albeit in low
407 numbers, of dinoflagellate cysts with single-plate precingular archaeopyles. The

408 Upper Subzone can also be distinguished from the underlying subzones by the general
409 absence of *Nannoceratopsis deflandrei* and ?*Bradleyella adela*; both these
410 morphotypes occur as extremely rare components at the base of the subzone.
411 *Valvaeodinium spinosum* is also notably commoner throughout this subzone with a
412 minor acme towards the base. The range base of *Ternia balmei* is a further important
413 bioevent that occurs within the Upper Subzone.

414

415 **5. The age of the *Wanaea verrucosa* Zone**

416

417 The dinoflagellate cyst assemblages recovered from the *Wanaea verrucosa*
418 Zone largely comprise cosmopolitan genera such as *Ctenidodinium*, *Dissiliodinium*,
419 *Durotrigia*, *Meiourogonyaulax*, *Pareodinia* and *Wanaea* (Tables 1-3). This
420 association is characteristic of the Late Bajocian to Bathonian using comparisons
421 elsewhere in the world, principally Europe (see section 6).

422 The *Wanaea verrucosa* Zone, or its equivalents, was assigned a Middle-Late
423 Bathonian age by Helby et al. (1987, fig. 12) that was later revised to an Early-Middle
424 Bathonian age by Helby et al. (2004, fig. 4) and Partridge (2006); this assignation was
425 not based on any independent stratigraphical evidence. Riding et al. (2010a, fig. 8)
426 reassessed the age as Late Bajocian to Early Bathonian following a review of
427 previously reported dinoflagellate cyst occurrences. This revised age is based upon
428 dinoflagellate cyst evidence from Europe, for example the range base of
429 *Valvaeodinium spinosum*, which is placed close to the Early-Late Bajocian transition.
430 The present study, however, represents the most comprehensive published account on
431 the palynofloras of the *Wanaea verrucosa* Zone and these data are used here to further
432 investigate the age of this interval. This section is subdivided into discussion of the
433 maximum and minimum ages of the zone, followed by a brief overview.

434

435 *5.1. The maximum age of the *Wanaea verrucosa* Zone*

436

437 There are several forms present in the material studied which have intra-
438 Bajocian range bases in Europe. These comprise *Acanthaulax crispera*, *Aldorfia* spp.,
439 *Atopodinium* spp., *Ctenidodinium* spp., *Endoscrinium* spp., *Meiourogonyaulax* spp.,
440 *Nannoceratopsis* sp. cf. *N. spiculata*, *Rhynchodiniopsis* spp., *Valensiella ovulum*,
441 *Valvaeodinium spinosum*, *Valvaeodinium vermicylindratum* and simple (i.e. non-

442 flanged) species of *Wanaea*. These genera and species all have inceptions during the
443 ‘mid’ Bajocian in Europe. Their range bases are all within the *Stephanoceras*
444 *humphriesianum* and *Strenoceras subfurcatum* zones which straddle the Early/Late
445 Bajocian transition (Prauss, 1989; Gowland and Riding, 1991; Riding et al., 1991;
446 Feist-Burkhardt and Wille, 1992; Feist-Burkhardt, 1994; Feist-Burkhardt and Monteil,
447 1997). Hence this is consistent with the Late Bajocian age suggested by Riding et al.
448 (2010a) as the maximum age for the *Wanaea verrucosa* Zone.

449

450 5.2. *The minimum age of the Wanaea verrucosa* Zone

451

452

453 *Nannoceratopsis deflandrei* occurs as a common accessory species in the
454 Lower-Middle *Wanaea verrucosa* subzones (Tables 2-3); these occurrences help
455 provide a minimum age for the zone as the consistent range top of this species (as
456 *Nannoceratopsis gracilis*) is close to the Early-Late Bajocian transition (i.e. the
457 *Stephanoceras humphriesianum* and *Strenoceras subfurcatum* zones) in Europe
458 (Gowland and Riding, 1991; Riding et al., 1991; Feist-Burkhardt and Wille, 1992;
459 Feist-Burkhardt and Monteil, 1997). Isolated occurrences have, however, been
460 reported from the Bathonian and Callovian (Riding et al., 1985; Prauss, 1989). These
461 records are sporadic and extremely sparse, and hence may represent reworking.
462 Therefore, the consistent presence of *Nannoceratopsis deflandrei* in the two
463 Bonaparte Basin wells is strongly suggestive of the Bajocian of Europe. This
464 contention is strengthened by the absence of *Nannoceratopsis pellucida sensu stricto*
465 Deflandre 1938, which normally has an intra-Bathonian range base in Europe (Riding
466 et al., 1985; 1991; Feist-Burkhardt and Wille, 1992). Importantly *Mancodinium*
467 *semitabulatum* subsp. *semitabulatum* also has a similar last appearance datum (the
468 *Stephanoceras humphriesianum* zone) in Europe (Riding 1984), thus providing further
469 strong evidence of a pre-Bathonian age. The occurrence of *Acanthaulax crispa* is also
470 suggestive of the ‘mid’ to Late Bajocian interval by comparison with Europe (Prauss,
471 1989; Feist-Burkhardt and Wille, 1992; Feist-Burkhardt and Monteil, 1997).
472 However, individual dinoflagellate cyst ranges should be noted with caution whilst
473 fully considering the overall composition of the assemblage. For example, the
474 apparent extinction of *Valvaeodinium spinosum* is Late Bathonian in Europe (Riding
475 et al., 1985; Prauss, 1989; Feist-Burkhardt and Wille, 1992; Riding and Thomas,

476 1992), but it is commonly recorded up to at least the Early Oxfordian *Ctenidodinium*
477 *ancorum* Zone in Australia (Mantle, 2009b).

478

479 5.3. Overview

480

481 The *Dissiliodinium caddaense* and *Nannoceratopsis deflandrei* zones are the
482 two immediately subjacent zones to the *Wanaea verrucosa* Zone. The *Dissiliodinium*
483 *caddaense* Zone is considered to be of Early Bajocian age (*Witchellia laeviuscula*
484 Zone) on the basis of ammonite and strontium isotope evidence (Riding et al., 2010b).
485 The *Nannoceratopsis deflandrei* Zone was assigned to the Early-Late Bajocian by
486 Riding et al. (2010a) based on calcareous nannofossil evidence.

487 The unit succeeding the *Wanaea verrucosa* Zone is the *Wanaea indotata*
488 Zone. Based on calcareous nannofossil and dinoflagellate cyst evidence, the *Wanaea*
489 *indotata* Zone was assigned to the Early-Late Bathonian by Riding et al. (2010a).
490 Hence, the maximum Late Bajocian and the minimum Early Bathonian ages assigned
491 to the *Wanaea verrucosa* Zone by Riding et al. (2010a) are entirely credible given the
492 independent evidence used to assign the ages of the adjacent zones.

493 However, the biostratigraphical evidence derived from ranges established in
494 Europe implies that the *Wanaea verrucosa* Zone may be latest Early to Late Bajocian
495 in age (i.e. the *Stephanoceras humphriesianum* to *Strenoceras Parkinsonia parkinsoni*
496 zones). Riding et al (2010a, p. 562) acknowledged this situation and stated that
497 “assemblages from the *Wanaea verrucosa* Zone are far more characteristic of the Late
498 Bajocian than the Bathonian based on comparisons with Europe”. The presence of
499 *Nannoceratopsis deflandrei* and *Mancodinium semitabulatum* subsp. *semitabulatum*
500 present the strongest support of this older age.

501 However, contra this evidence for a predominantly pre-Bathonian age is the
502 prominence and relative diversity of *Ctenidodinium*, particularly in the Upper *Wanaea*
503 *verrucosa* Zone. This genus is not especially abundant or diverse in the Bajocian of
504 Europe (Riding et al., 1991; Feist-Burkhardt and Monteil, 1997), but is prominent in
505 the Bathonian (Riding et al., 1985; Feist-Burkhardt and Monteil, 1997; Riding et al.,
506 1999). An example is the Bathonian Great Estuarine Group of northwest Scotland,
507 where *Ctenidodinium* spp. are relatively abundant; this contrasts with the underlying
508 Bajocian strata where this genus is relatively sparse (Riding et al., 1991). Moreover,
509 the taxonomic spectrum and the diversity levels of dinoflagellate cysts in the

510 Bathonian Great Estuarine Group of Scotland are broadly similar to the floras from
511 the *Wanaea verrucosa* Zone (Riding et al., 1991, fig. A6). Significantly, both the
512 Australian and Scottish material are from successions deposited in marginal to
513 shallow marine settings.

514 In summary, the *Wanaea verrucosa* Zone is still considered most likely to be
515 Late Bajocian to Early Bathonian in age, following Riding et al. (2010a), but may
516 range as old as latest Early Bajocian.

517

518

519 **6. The palaeobiology of the *Wanaea verrucosa* Zone assemblages of the North** 520 **West Shelf and comparison with coeval palynofloras**

521

522 The palynofloras from the *Wanaea verrucosa* Zone from the three successions
523 studied here are markedly similar to associations from the Bajocian-Bathonian
524 transition reported elsewhere in the world. In this section the palynofloras from the
525 North West Shelf, with emphasis on dinoflagellate cysts, are discussed in terms of
526 various aspects of palaeobiology and compared to key reports from other continents.
527 This section is subdivided into marine and terrestrial palynofloras.

528

529 *6.1. Marine palynomorphs*

530

531 The dinoflagellate cyst associations recovered from the three wells studied are
532 largely composed of the following genera: *Batiacasphaera*, *Ctenidodinium*,
533 *Dissiliodinim*, *Durotrigia*, *Endoscrinium*, *Escharisphaeridia*, *Leptodinium*,
534 *Meiourogonyaulax*, *Nannoceratopsis*, *Phallocysta*, *Pareodinia*, *Valvaeodinium* and
535 *Wanaea* (Tables 1-3). These genera are all typical of the Late Bajocian to Bathonian
536 interval globally, specifically in Africa, the Americas, the Arctic, Asia and Europe.
537 Key publications for comparison include: Aboul Ela and Aly (1988a), Aboul Ela and
538 Mahrous (1990), Aboul Ela and El-Shamma (1997), Geleta (1998), El-Shamma et al.
539 (2001) and El Beialy et al. (2002) for Africa; Johnson and Hills (1973) and Bujak and
540 Williams (1977) for the Americas; Smelror (1987) for the Arctic; Thusu and Vigran
541 (1985), Kumar (1987), Thusu et al. (1988), Ilyina (1991), Riding and Ilyina (1996;
542 1998), Riding et al. (1999), Mau Shaozhi and Bian Lizeng (2000) for Asia; and (for
543 example) Gocht (1970), Fenton and Fisher (1978), Davey (1980), Fenton et al. (1980),

544 Fenton (1981), Riding et al. (1985; 1991), Prauss (1989), Dodekova (1990), Feist-
545 Burkardt and Monteil (1997; 2001) and Gedl (2008) from Europe.

546 The Aalenian and earliest Bajocian interval is characterised by relatively low
547 diversity dinoflagellate cyst floras. Forms such as *Mancodinium semitabulatum*
548 Morgenroth 1970, *Moiesiodinium raileanui* Antonescu 1974, *Nannoceratopsis*
549 *deflandrei*, *Nannoceratopsis dictyambonis* Riding 1984, *Nannoceratopsis gracilis*
550 Alberti 1961, *Phallocysta elongata* (Beju 1971) Riding 1994, *Scriniocassis priscus*
551 (Gocht 1979) Below 1990 and *Scriniocassis weberi* Gocht 1964 are typical (Feist-
552 Burkardt, 1990; Feist-Burkardt and Monteil, 1997; Feist-Burkardt and Pross, 2010).
553 However in the latest Early Bajocian (*Stephanoceras humphriesianum* Zone) and the
554 early-mid Late Bajocian (*Strenoceras subfurcatum* and *Strenoceras garantiana* zones),
555 gonyaulacacean dinoflagellate cysts underwent a major phase of explosive evolution
556 (Fensome et al., 1996, fig. 1). During this interval, gonyaulacacean taxa with epicystal
557 and multiplate precingular archaeopyles such as *Ctenidodinium*, *Dissiliodinium*,
558 *Durotrigia* and *Wanaea* were extremely prominent (Feist-Burkardt and Monteil,
559 1997; 2001). Multiplate precingular archaeopyles (as in *Dissiliodinium*) appeared in
560 the Aalenian, prior to the inception of epicystal archaeopyles (as in *Wanaea*) in the
561 Bajocian (Gowland and Riding, 1991). This transition probably involved the fusing of
562 plate sutures throughout the epicyst (Stover and Helby, 1987, figs. 4A-4D).
563 Furthermore, the single-plate (3'') precingular archaeopyle, for example in
564 *Acanthaulax crispera* in the latest Early Bajocian (*Stephanoceras humphriesianum*
565 Zone), was probably derived from the early mutiplate excystment apertures in
566 *Dissiliodinium* and/or *Durotrigia* (see Feist-Burkardt and Monteil, 1997, fig. 4). It
567 appears that these early gonyaulacacean genera were experimenting with archaeopyle
568 styles in order to discover the most effective modes of excystment. This
569 experimentation phase persisted into the Bathonian. However, by the Callovian, most
570 gonyaulacaceans have either apical or single-plate (3'') precingular archaeopyles.
571 These two excystment types then became stabilised, and they remain the predominant
572 gonyaulacacean archaeopyle styles throughout the remainder of the Mesozoic and
573 throughout the Cenozoic up to the present day.

574 As mentioned earlier, the Late Bajocian to Early Bathonian interval worldwide
575 is characterised by relatively low diversity dinoflagellate cyst associations dominated
576 by species of *Ctenidodinium*, *Escharisphaeridia*, *Meiourogonyaulax*, *Pareodinia*,
577 *Valvaeodinium* and *Wanaea*. The species *Ctenidodinium sellwoodii* (Sarjeant 1975)

578 Stover and Evitt 1978 (and its synonyms *Ctenidodinium? stauromatos* (Sarjeant 1976)
579 Stover and Evitt 1978 and *Ctenidodinium tenellum* Deflandre 1938) is especially
580 abundant and geographically widespread. This taxon was interpreted as being
581 euryhaline and/or eurythermal (Riding et al., 1985; 1991). There is significant
582 evidence of dinoflagellate cyst provincialism in the Bathonian (e.g. Riding and Ilyina
583 (1996; 1998; Riding et al., 1999), however widespread forms such as *Ctenidodinium*
584 *sellwoodii* and *Meiourogonyaulax* spp. are recorded throughout the northern
585 hemisphere and beyond.

586 The principal region in the northern hemisphere which exhibits significant
587 provincialism of Bathonian dinoflagellate cysts is the Arctic region. Here, presumed
588 cold-tolerant forms such as *Ambonosphaera calloviana* Fensome 1979, *Evansia*
589 *janae* Piasecki 2001, *Evansia wigginsii* (Smelror 1988) Below 1990, *Lacrymodinium*
590 *warreni* Albert et al. 1986, *Paraevansia brachythelis* (Fensome 1979) Below 1990,
591 *Paragonyaulacysta calloviensis* Johnson and Hills 1973 and *Paragonyaulacysta*
592 *retiphragmata* Dörhöfer and Davies 1980 are present (Smelror, 1988a,b; Piasecki et
593 al., 2004).

594 The dinoflagellate cyst floras documented here from the *Wanaea verrucosa*
595 Zone are hence entirely typical of the Late Bajocian-Early Bathonian interval.
596 Relatively few taxa are present which are confined to Australasia. These include
597 *Endoscrinium kempiae*, *Meiourogonyaulax straussii* sp. nov., *Phallocysta granosa*,
598 *Ternia balmei*, *Valvaeodinium cookii* sp. nov., *Wanaea enoda* and *Wanaea verrucosa*.
599 Notably, the only exclusively Austral genus is *Ternia*. This situation is highly unusual
600 for eastern Gondwanan Jurassic dinoflagellate cyst floras. The overlying Callovian to
601 Tithonian interval in Australasia is dominated by indigenous southern hemisphere
602 taxa (Helby et al., 1987; Riding and Helby, 2001b-g; Mantle, 2009a, b; Riding et al.,
603 2010).

604 One explanation for this phenomenon may be that the East African Seaway
605 (Mozambique Corridor) had not opened, and the Central American Seaway (Hispanic
606 Corridor) and the Viking (or North Sea) Corridor, were either narrow or highly
607 restricted respectively, during the Bajocian and Bathonian (Ager, 1975; Smith et al.,
608 1994; Moyne et al., 2004, fig. 1). This was due to both relatively low sea levels and
609 tectonic factors. The consequent enclosed aspect and smaller extent of Tethys at this
610 time may have significantly enhanced the strength of the principal oceanic gyres and
611 possibly the westerly-flowing Tethys circumglobal current (TCC), thereby enabling

612 the effective passive dispersal of dinoflagellate cysts across Tethys due to higher
613 oceanic energy levels. Dinoflagellate cysts can potentially traverse otherwise
614 inhospitable palaeoclimatic/palaeolatitudinal belts because they are resting cysts and
615 hence dormant. This means that they are potentially more mobile than, for example,
616 molluscs which were palaeoclimatically partitioned during the Middle Jurassic
617 (Callomon, 2003). When the three aforementioned major seaways opened during the
618 Callovian or Oxfordian (Irralde-Vinent, 2006; Riding et al., 2011), it is possible that
619 this new oceanic configuration meant that the northern and southern Tethyan gyres
620 became weaker and more partitioned, hence diminishing the potential for the passive
621 dispersal of dinoflagellate cysts. This contention is supported by the findings of
622 Riding et al. (2011), who reported that the dinoflagellate cyst assemblages from the
623 Callovian of south central Argentina are of European aspect and lack any
624 characteristically Austral taxa. This succession from the Neuquén Basin almost
625 exclusively comprises northern hemisphere (Euro-Atlantic) and cosmopolitan taxa.
626 Another factor may be that the low-diversity Bajocian-Bathonian forms may be more
627 euryhaline and/or eurythermal than their significantly more diverse Callovian-
628 Tithonian counterparts. However, Enay (1980) and Hallam (1983) have contended that
629 Jurassic biotic endemism was principally controlled by eustasy and tectonic factors,
630 and that palaeotemperature played a relatively minor role. Despite this, fluctuating
631 palaeotemperatures caused several ammonite migrations between the Boreal and
632 Tethyan realms during the Jurassic. For example, in the Bathonian, Tethyan
633 ammonites migrated northwards towards the Boreal Ocean, helped by the opening of
634 marine connections in the North Sea area (Poulsen and Riding, 2003, fig. 6). This
635 factor may indicate that at least some of the typical Bajocian-Bathonian dinoflagellate
636 cysts had a Tethyan origin, and migrated into northern Europe from the south.

637

638 6.2. *Terrestrial palynomorphs*

639

640 The pollen and spores recovered from the Perseus-3A, Sunrise-2 and Sunset
641 West-1 wells are mostly dominated by low-diversity assemblages of gymnospermous
642 pollen that often constitute over 50% of the entire palynofloras. *Araucariacites* spp.,
643 bisaccate pollen and *Callialasporites* spp. are consistently prominent, with lower
644 proportions of *Classopollis* spp., *Cycadopites* spp., *Perinopollenites elatoides*,
645 trisaccate pollen and *Vitreisporites pallidus* (Tables 4-6). Bryophyte-lycophyte-

646 pteridophyte spores were generally recovered in smaller proportions than pollen, and
647 they normally comprise 20-30% of the entire palynoflora. The spore floras are
648 dominated by *Baculatisporites/Osmundacidites* spp., *Cyathidites* spp.,
649 *Dictyophyllidites* spp., *Gleicheniidites senonicus*, *Ischyosporites/Klukisporites* spp.,
650 *Neoraistrickia* spp. and *Retitriletes* spp. Lesser numbers of *Antulsporites saevus*,
651 *Cibotiumspora* spp., *Concavissimisporites* spp., *Contignisporites* spp., *Coronatispora*
652 spp., *Leptolepidites* spp., *Sestrosporites pseudoalveolatus*, *Staplinisporites caminus*
653 and *Stereisporites* spp. were also observed (Tables 4-6). This pollen-spore palynoflora
654 indicates a hinterland vegetated by conifer forests (dominated by Araucariaceae and
655 Coniferales) with an understorey of relatively diverse stands of club mosses and
656 various types of ferns (largely Filicopsida, Lycopodiaceae, Osmundaceae and
657 Schizaeaceae).

658 The abundant levels of *Araucariacites* and *Callialasporites*, together with
659 relatively diverse spores such as *Baculatisporites/Osmundacidites* spp., *Cyathidites*
660 spp., *Dictyophyllidites* spp., *Ischyosporites/Klukisporites* spp. and *Neoraistrickia* spp.
661 are typical of the Late Bajocian to Bathonian interval worldwide. The major elements
662 of the floras compare extremely well with coeval reports from Africa (Helal, 1965;
663 Thusu and Vigran, 1985; Aboul Ela and Aly, 1988b; Thusu et al., 1988), Arabia
664 (Sajjadi et al., 2007), Australasia (Balme, 1964; Filatoff, 1975; Helby et al., 1987;
665 Thorn, 2001), Canada (Pocock, 1970a,b; Bujak and Williams, 1977), Europe
666 (Traulau, 1968; Guy-Ohlson, 1986; 1989; Srivastava, 1987; Boulter and Windle,
667 1993; Koppelhus and Nielsen, 1994; Nielsen et al., 2010), India (Vijaya, 2000; 2009),
668 Russia (Ilyina, 1985; 1986) and South America (Menendez, 1968; Volkheimer et al.,
669 2008).

670 The worldwide distribution of the Middle Jurassic araucariaceae-fern
671 dominated palynofloras confirm the extensive connections within Laurasia and
672 Gondwana, which were clustered around the Tethys Ocean (Smith et al., 1994, map
673 10). This would have allowed floras to potentially disperse/migrate long distances. It
674 is also evident that the principal floral elements, such as the parent plants of
675 *Callialasporites*, were relatively tolerant of variations in, for example, palaeolatitude.
676 Furthermore, the cosmopolitan nature of these floras indicates that the global
677 palaeoclimate was relatively uniform. Despite the overall similarities of the Middle
678 Jurassic terrestrial palynoflora, some forms largely endemic to the southern
679 hemisphere were recorded from the wells studied. These include *Anapiculatisporites*

680 *dawsonensis*, *Antulsporites saevus*, *Contignisporites cooksoniae*, *Dictyotosporites*
681 *complex*, *Foveosporites canalis*, *Sculptisporis moretonensis* and *Trachysporites*
682 *infirmus*.

683

684 **7. Conclusions**

685 The dinoflagellate cyst associations recorded from the *Wanaea verrucosa*
686 Zone in the three wells examined herein are dominated by cosmopolitan forms,
687 especially at the generic level. The assemblages are most reminiscent of the Late
688 Bajocian by comparisons with apparently coeval floras from Europe. The Bajocian
689 was an interval in which the cyst-forming dinoflagellates diversified rapidly, with an
690 explosion in gonyaulacacean forms. Bajocian and Bathonian dinoflagellate cyst
691 associations worldwide are dominated by taxa with epicystal and multiplate
692 precingular archaeopyles such as *Ctenidodinium*, *Dissiliodinium*, *Durotrigia*, and
693 *Wanaea*. Gonyaulacacean dinoflagellate cysts underwent further significant
694 diversification in the succeeding Callovian and Oxfordian stages. The Callovian to
695 Oxfordian interval in Europe and Australasia is characterised by endemic taxa. It is
696 possible that these further evolved Callovian/Oxfordian floras had more specific
697 environmental preferences than the Bajocian/Bathonian assemblages, however it may
698 be that there were new barriers to the dispersal of dinoflagellate cysts across the
699 Tethys in the Callovian/Oxfordian.

700 Quantitative palynological assessments of the shallow marine successions of
701 the upper Plover Formation in the northern Bonaparte Basin confirm a tripartite
702 subdivision of the *Wanaea verrucosa* Zone into Lower, Middle and Upper subzones.
703 However this subdivision cannot be confidently replicated for the lower diversity
704 assemblages and more marginal marine environments of the Northern Carnarvon
705 Basin; the marker species are rare or absent in this depocentre. The abundance of
706 *Dissiliodinium/Durotrigia*-type cysts in the Lower Subzone, followed by an
707 increasing diversity of *Meiourogoniaulax* and *Ctenidodinium* in the Middle and
708 Upper subzones respectively, is largely representative of the Bajocian to Bathonian
709 transition through this interval. The common occurrence of *Nannoceratopsis*
710 *deflandrei* and rare examples of *Mancodinium semitabulatum* subsp. *semitabulatum* in
711 the Lower and Middle subzones suggest the *Wanaea verrucosa* Zone may extend
712 down to the latest Early Bajocian.

713

714

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716

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729

730

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1167
1168

1169 **APPENDIX 1: LOCATION AND OPERATORS OF THE WELLS STUDIED**

1170

1171 Well name and number	1171 Latitude	1171 Longitude	1171 Operator
1172 Perseus-3A	19° 31' 27.580"S	116° 06' 20.635"E	Woodside
1173 Sunrise-2	09° 29' 57.931"S	128° 06' 12.397"E	Woodside
1174 Sunset West-1	09° 38' 06.806"S	127° 53' 57.840"E	Woodside

1175

1176

1177 **APPENDIX 2.SYSTEMATIC PALAEONTOLOGY OF DINOFLAGELLATE**
1178 **CYSTS**

1179

1180 In this section, taxonomic notes pertaining to the key dinoflagellate cyst taxa
1181 are presented. The genera are listed alphabetically. Where measurements are quoted,
1182 these are given in micrometres (µm) as minimum, (mean) and maximum respectively.

1183

1184

1185 *Acanthaulax* Sarjeant 1968 emend. Sarjeant 1982

1186

1187 *Acanthaulax crispera* (Wetzel 1967) Woollam & Riding 1983 (Plate VII, fig. 12)

1188

1189 Remarks: *Acanthaulax crispera* was recorded in one sample at xxx m (put this in) in the

1190 Upper *Wanaea verrucosa* Subzone in Sunrise-2 (Table 2). In Europe this species

1191 ranges from the Early-Late Bajocian (Prauss, 1989; Feist-Burkhardt and Wille, 1992;

1192 Riding and Thomas, 1992; Feist-Burkhardt and Monteil, 1997) with questionable

1193 Bathonian occurrences from Scotland (Riding et al., 1991).

1194

1195

1196 *Aldorfia* Stover & Evitt 1978

1197

1198 *Aldorfia* sp. A (Plate VII, fig. 11)

1199

1200 Remarks: A distinctive morphotype of *Aldorfia* was encountered sporadically and

1201 rarely in all three wells studied (Tables 1-3). This form lacks an apical horn or

1202 protuberance, hence has an ovoidal dorsoventral outline. It has a thin ectophragm,

1203 and the tabulation is normally exhibited only by the cingulum and the archaeopyle.

1204 The sparsity of *Aldorfia* sp. A means that it is not formally described herein.

1205

1206

1207 *Aldorfia* spp.

1208

1209 Remarks: *Aldorfia* spp., often small morphotypes, were recorded in low numbers

1210 from samples SW4-SW8 (2217.98-2211.11 m) in the Sunset West-1 well (Table 3).

1211

1212

1213 *Atopodinium* Drugg 1978 emend. Masare 1991

1214

1215 *Atopodinium* sp.

1216

1217 Remarks: A single specimen of *Atopodinium* was recorded from 3244.18 m in the
1218 Perseus-3A well (Table 1). It is an elongate, subpentagonal form with a flat,
1219 thickened, antapical plate. This form most closely resembles *Atopodinium haromense*
1220 Thomas & Cox 1988. It is too rare to erect as a new species.

1221

1222

1223 *Batiacasphaera* Drugg 1970 emend. Morgan 1975

1224

1225 *Batiacasphaera* spp.

1226

1227 Remarks: *Batiacasphaera* spp. were encountered throughout in the Sunrise-2 and
1228 Sunset West-1 wells (Tables 2, 3). *Batiacasphaera* spp. are herein distinguished from
1229 representatives of *Escharisphaeridia* in being subcircular to ovoidal in outline,
1230 slightly longitudinally elongate, and lacking prominent accessory archaeopyle sutures
1231 and a discernible cingulum (Erkmen and Sarjeant, 1980, p. 62). By contrast, forms of
1232 *Escharisphaeridia* spp. are typically wider than they are long. This genus is
1233 morphologically simple and extremely long-ranging. Hence, representatives of
1234 *Batiacasphaera* were not speciated herein.

1235

1236

1237 *Bradleyella* Woollam 1983

1238

1239 ?*Bradleyella adela* (Fenton et al. 1980) Woollam 1983 (Plate IV, figs. 1-12)

1240

1241 Dimensions (30 specimens measured):

1242 Length of cyst including operculum: 29 (40) 50 μm

1243 Equatorial width of cyst: 28 (34) 40 μm

1244 Thickness of autophragm: ca. 1 μm

1245

1246 Remarks: The cysts recorded herein as ?*Bradleyella adela* are small, subspherical to
1247 ovoidal, dorsoventrally flattened species that are easily overlooked because most
1248 specimens exhibit only the faintest degree of tabulation, an irregularly scabrate,
1249 coarsely granulate or irregularly microreticulate autophragm and no readily
1250 discernible archaeopyle. Better preserved specimens do exhibit some tabulation in the

1251 form of low, rounded ridges, particularly along the cingular and postcingular sutures.
1252 The tabulation on the epicyst is consistently more obscure; this is in contrast to the
1253 generic description in Woollam (1983, p. 194) that stated the 'parasutures are
1254 preferentially developed on the epicyst'. Furthermore, none of the specimens studied
1255 show the degree of tabulation as expressed on the holotype (Fenton et al., 1980, pl.
1256 14, fig. 3), although this specimen is also larger and more clearly marked than the
1257 figured paratypes (Fenton et al., 1980, pl. 14, figs. 1-2, 4). Rare specimens show
1258 apparent long thin spines (2-17 μm long), largely concentrated around the apex and/or
1259 antapex (Plate IV, figs. 7, 11).

1260 The archaeopyle of these specimens is also rather enigmatic. Many specimens
1261 show a split/splits along the anterior margin of the cingulum (Plate IV, figs. 3, 9, 12),
1262 and could be considered to be epicystal. However a similar proportion of specimens
1263 exhibit splits around a single precingular plate (Plate IV, figs. 1, 10), whilst others
1264 show an almost complete disintegration of the epicyst. This was also noted by Fenton
1265 et al. (1980) who considered the epicyst to be 'prone to break up along the
1266 parasutures'. It is this uncertainty of the epicystal nature of the archaeopyle, together
1267 with the better defined hypocystal sutures and more comprehensively granulate or
1268 locally microreticulate ornament, that preclude a definitive specific assignment. A
1269 thorough restudy of the type material is needed to fully resolve this issue.

1270 ?*Bradleyella adela* is an excellent and abundant marker species for the Middle
1271 *Wanaea verrucosa* Subzone, although it does occur, in much reduced numbers,
1272 immediately above and below this subzone (Fig. 4).

1273

1274

1275 *Chlamydophorella* Cookson & Eisenack 1958 emend. Duxbury 1983

1276

1277 *Chlamydophorella* spp.

1278

1279 Remarks: *Chlamydophorella* spp. was recorded in one sample at xxx m (put this in) in
1280 the Upper *Wanaea verrucosa* Subzone in the Sunrise-2 well (Table 2). Similar forms
1281 occur in the overlying *Wanaea indotata* Zone, and are common from the *Ternia*
1282 *balmei* Zone up to the Early Cretaceous.

1283

1284

1285 *Ctenidodinium* Deflandre 1938 emend. Benson 1985

1286

1287 *Ctenidodinium* sp. A (Plate IV, figs. 13-15)

1288

1289 Remarks: *Ctenidodinium* sp. A was recorded in all three successions studied but is
1290 moderately prominent in only the Upper *Wanaea verrucosa* Subzone in the Sunrise-2
1291 well (Table 2). It is a morphotype of *Ctenidodinium* which exhibits extremely sparse,
1292 frequently suppressed tabulation. The sutures are partially indicated by low,
1293 discontinuous sutural ridges or sporadic lineations of low-relief ornamentation
1294 (PlateIV, , fig. 14). Some specimens may have occasional short, slender, distally sharp
1295 sutural spines. The autophragm is moderately thick and robust, scabrate to locally
1296 microreticulate and highly prone to folding. *Ctenidodinium* sp. A can be elongate
1297 ovoidal to squat in shape and it normally lacks an apical horn or protuberance. The
1298 simple morphology and low sutural ridges make *Ctenidodinium* sp. A similar to the
1299 Callovian species *Ctenidodinium planocristatum* Riding & Helby 2001. However,
1300 *Ctenidodinium planocristatum* has a thinner, smooth autophragm, is fully tabulate and
1301 has a more uniform, subspherical outline (Riding and Helby 2001d, fig. 5). Although
1302 *Ctenidodinium* sp. A exhibits an epicystal archaeopyle, it may be difficult to
1303 distinguish badly-preserved specimens from representatives of *Dissiliodinium* or
1304 *Durotrigia*, especially if the epicyst is damaged.

1305

1306

1307 *Ctenidodinium* sp. B (Plate V, figs. 1-3, 5-6)

1308

1309 Remarks: *Ctenidodinium* sp. B is extremely prominent in the Upper *Wanaea*
1310 *verrucosa* Subzone of the Sunrise-2 and Sunset West-1 wells (Tables 2, 3). It is a
1311 relatively squat morphotype, often being significantly wider than it is long. This form
1312 is characterised by low sutural crests or ridges surmounted by short processes, most of
1313 which are expanded distally but may be blunt, capitate, or bifurcate and are commonly
1314 longest at the antapex. The bifid distal terminations are composed of short, often
1315 simple furcae but others form a distinct anchor-shaped tip. Some of the distal furcae
1316 are extremely short and are only identifiable at relatively high magnifications. The
1317 insertion density of the processes also varies significantly on a single specimen and
1318 across the population. *Ctenidodinium* sp. B is similar to other squat species of

1319 *Ctenidodinium* which have relatively short sutural spines. These include
1320 *Ctenidodinium sellwoodii* (Sarjeant 1975) Stover & Evitt 1978, *Ctenidodinium?*
1321 *stauromatos* (Sarjeant 1976) Stover & Evitt 1978 and *Ctenidodinium tenellum*
1322 Deflandre 1938. However, this form is clearly most similar to *Ctenidodinium*
1323 *ancorum* Riding & Helby 2001 from the Callovian of Australia due to the
1324 preponderance of distally-expanded spines. However, the majority of *Ctenidodinium*
1325 *ancorum* have bifurcate sutural processes which exhibit distinctly recurved furcae
1326 with narrow neck-like constrictions immediately below the bifurcation (Riding and
1327 Helby, 2001d, figs. 3G, J). These anchor or grapnel-shaped distal terminations so
1328 typical of *Ctenidodinium ancorum* are only occasionally present in *Ctenidodinium* sp.
1329 B which is used herein as a broader form-based concept. The scabrate to locally
1330 microreticulate autophragm of *Ctenidodinium* sp. B is also thicker and more robust
1331 than that of *Ctenidodinium ancorum sensu stricto*.

1332

1333

1334 *Ctenidodinium* sp. C (Plate V, figs. 7-9)

1335

1336 Remarks: *Ctenidodinium* sp. C is relatively prominent in the lower half of the *Wanaea*
1337 *verrucosa* Zone in the Perseus-3A well and irregularly common in the Upper *Wanaea*
1338 *verrucosa* Subzone of the Sunrise-2 and Sunset West-1 wells (Tables 2, 3). This
1339 morphotype is variable in shape, with both elongate and squat specimens observed
1340 (Plate V, figs 7, 9). It is characterised by a relatively thick, robust autophragm which
1341 is variably scabrate to spinose, locally microreticulate or comprehensively
1342 microreticulate. The tabulation is exhibited by low sutural ridges or crests which are
1343 surmounted by short, solid, distally-sharp spines which are longer at gonial points.
1344 These relatively inconspicuous crests are often finely fenestrate and along with the
1345 fine spines surmounting them, form the characteristic feature of this morphotype.

1346

1347

1348 *Ctenidodinium* spp. (Plate V, fig. 4)

1349

1350 Remarks: This grouping includes all other forms of the genus not attributable to
1351 *Ctenidodinium* sp. A, B or C.

1352

1353

1354 *Dissiliodinium* Drugg 1978 emend. Feist-Burkhardt & Monteil 2001

1355

1356 *Dissiliodinium* sp. A (Plate VI, figs. 1, 2, 4-6)

1357

1358 Remarks: *Dissiliodinium* sp. A was recorded throughout the three wells studied here;
1359 it is especially prominent in the Lower *Wanaea verrucosa* Subzone in the Sunrise-2
1360 well (Table 2). This morphotype is relatively large, with a scabrate to granulate
1361 autophragm. The only indications of tabulation are the archaeopyle, and the sparse,
1362 discontinuous sutural ridges present on some specimens. These partially tabulate
1363 specimens are invariably characterised by a cingulum (Plate VI, figs. 1, 5). Feist-
1364 Burkhardt and Monteil (2001; p.58) emended *Dissiliodinium* to include only weakly
1365 to non-tabulate specimens where any tabulation is 'expressed by negative structures'
1366 whilst retaining those specimens with obvious tabulation delimited by 'elevated
1367 parasutural features such as septa, crests or ridges' within *Durotrigia*. As the current
1368 specimens vary from non-tabulate to very faintly tabulate, the end-member
1369 morphotypes could be placed in different genera; in this study they are grouped
1370 together as *Dissiliodinium* sp. A. Some specimens of *Dissiliodinium* sp. A are
1371 comparable to *Dissiliodinium* sp. (no antapical node) of Helby et al. (1987, fig. 16E).

1372

1373

1374 *Dissiliodinium* spp. (Plate VI, fig. 3)

1375

1376 Remarks: This material includes all the other forms of *Dissiliodinium* which are not
1377 attributable to *Dissiliodinium* sp. A. These specimens are typically smaller than
1378 *Dissiliodinium* sp. A, and may be thick-walled and granulate or have a thin, psilate
1379 autophragm.

1380

1381

1382 *Durotrigia* Bailey 1987

1383

1384 *Durotrigia* spp. (Plate VI, figs. 7-10)

1385

1386 Remarks: Only morphotypes with a type 1P-5P archaeopyle, and with paratabulation
1387 consistently expressed by elevated sutural crests or ridges are included within
1388 *Durotrigia*. Morphotypes attributable to this genus occur throughout all three wells,
1389 and are intermittently common.

1390

1391

1392 *Egmontodinium* Gitmez & Sarjeant 1972

1393

1394 *?Egmontodinium* sp. A (Plate IX, figs. 1-3)

1395

1396 Remarks: *?Egmontodinium* sp. A was recorded rarely throughout the *Wanaea*
1397 *verrucosa* Zone of the Sunrise-2 and Sunset West-1 wells; it was consistently present
1398 in only the lower subzone of Sunset West-1 (Table 3). *?Egmontodinium* sp. A is a
1399 distinctive morphotype that is tentatively assigned to *Egmontodinium* as it is covered
1400 by numerous short (3-10 μ m), nontabular, relatively broad processes and appears to
1401 have an apical archaeopyle. These processes are parallel-sided, expanded distally with
1402 oblate, bi- or trifurcate distal extremities and are apparently hollow. The latter feature
1403 is not typical of *Egmontodinium*. No indications of tabulation are present.
1404 Furthermore most specimens do not show an archaeopyle, and the few specimens that
1405 may have apical archaeopyles are inconclusive. Hence, the generic assignment is
1406 tentative.

1407 *?Egmontodinium* sp. A is superficially similar to *Egmontodinium toryna*
1408 (Cookson & Eisenack 1960) Davey 1979 which has far fewer solid processes with
1409 simpler distal terminations and a definite apical archaeopyle. The present form was
1410 not recorded in sufficient numbers to be formally described.

1411

1412

1413 *Endoscrinium* (Klement 1960) Vozzhennikova 1967 emend. Riding & Fensome 2002

1414

1415 Remarks: Representatives of *Endoscrinium* first appear at the base of the Upper
1416 *Wanaea verrucosa* Zone. This range base appears to have regional stratigraphical
1417 significance.

1418

1419

1420 *Endoscrinium kempiae* (Stover & Helby 1987) Lentin & Williams 1989 (Plate VII,
1421 fig. 10)

1422

1423 Remarks. The large and distinctive species *Endoscrinium kempiae* first appears at the
1424 base of the Upper *Wanaea verrucosa* Subzone in the Sunrise-2 and Sunset West-1
1425 wells (Tables 2, 3), and in all but the lowest three samples of the unsubdivided
1426 *Wanaea verrucosa* Zone in Perseus 3A (Table 1). The range base of this taxon defines
1427 the base of the 7ciai Subzone as depicted by Helby et al. (2004, fig. 4) and the Upper
1428 *Wanaea verrucosa* Subzone herein (Fig. 2). *Endoscrinium kempiae* is normally
1429 present in low proportions in this upper subzone, however a minor acme is present in
1430 sample sample SR3, at the top of the subzone in the Sunrise-2 well (2107.52/.47 m).
1431 *Endoscrinium kempiae* ranges into and throughout the overlying *Wanaea indotata* and
1432 *Ternia balmei* zones and irregularly up to the *Ctenidodinium ancorum* Zone (Helby et
1433 al., 1987, fig. 15; Mantle, 2009b, fig. 6).

1434

1435

1436 *Endoscrinium luridum* (Deflandre 1938) Gocht 1970 (Plate VII, figs. 7, 9)

1437

1438 Remarks: This species was recorded sparsely in the uppermost Upper *Wanaea*
1439 *verrucosa* Subzone in the Sunrise-2 well (Table 2). The specimens recorded herein are
1440 slightly more angular than the holotype (Deflandre, 1938, pl. 5, figs. 4, 5) and may
1441 exhibit a significantly narrower pericoel and/or short apical horn. However, these
1442 minor differences are deemed to be within the scope of intraspecific variability.
1443 *Endoscrinium luridum* is a reliable marker for the Mid Oxfordian to Kimmeridgian
1444 interval of the northern hemisphere (Riding and Fensome, 2002, fig. 2), hence its
1445 range base in Australia appears to be significantly older. However, the genus
1446 *Endoscrinium* is well represented in the Bajocian-Bathonian interval in Europe
1447 (Riding et al., 1985; Feist-Burkhardt and Monteil, 1997; Riding et al., 2010a, pl. I, fig.
1448 6).

1449

1450

1451 *Endoscrinium* sp. cf. *E. luridum* (Deflandre 1938) Gocht 1970 (Plate VII, fig. 8)

1452

1453 Remarks: *Endoscrinium* sp. cf. *E. luridum* is present in low proportions in the Upper
1454 *Wanaea verrucosa* Subzone of the Sunrise-2 and Sunset West-1 wells (Tables 2, 3).
1455 Although it is closely comparable with the type of *Endoscrinium luridum* illustrated
1456 by Deflandre (1938, pl. 5, figs. 4, 5) from the Early Oxfordian of northern France, it
1457 differs in having a rounded subpentagonal outline without the distinctly angular
1458 hypocyst and protruding antapex of the type material. The hypocyst is broadly
1459 longitudinally symmetrical, hence it differs profoundly from *Endoscrinium*
1460 *asymmetricum* Riding 1987. This morphotype was not sufficiently abundant to be
1461 formally described.

1462

1463

1464 *Escharispharidia* Erkmen & Sarjeant 1980

1465

1466 Remarks: Representatives of *Escharispharidia* were recorded throughout all three
1467 wells studied (Tables 1-3). This genus is distinguished from *Batiacasphaera* in
1468 normally being wider than long, and having prominent accessory archaeopyle sutures
1469 which are typically widely separated; furthermore a cingulum is frequently present
1470 (Erkmen and Sarjeant, 1980, p. 62). The deep accessory archaeopyle sutures which
1471 'gape' emphasise the squat shape of isolated loisthocysts of this genus.

1472 Representatives of the similar genus *Batiacasphaera* are subcircular to ovoidal in
1473 outline and typically lack deep accessory archaeopyle sutures. In this study, forms of
1474 *Escharispharidia* spp. are not identified to species level because individual taxa are
1475 profoundly problematical to consistently recognise. Moreover, forms of this genus are
1476 not stratigraphically significant throughout the *Wanaea verrucosa* Zone.

1477

1478

1479 *Escharispharidia* sp. A (Plate II, fig. 3)

1480

1481 Remarks: *Escharispharidia* sp. A is characterised by a granulate autophragm, long
1482 'gaping' accessory archaeopyle sutures and frequent indications of a cingulum. This
1483 morphotype was illustrated as *Chytroeisphaeridia* (now *Escharispharidia*) *pocockii*
1484 Sarjeant 1968 by Filatoff (1975, pl. 29, figs. 5, 6) from the Middle Jurassic of the
1485 onshore Perth Basin. However the type material of *Escharispharidia pocockii*
1486 (Sarjeant 1968) Erkmen & Sarjeant 1980 (i.e. Sarjeant, 1968, pl. 3, fig. 9) lacks

1487 accessory archaeopyle sutures and has a much thicker autophragm than the specimens
1488 figured by Filatoff (1975), thus this name is not applied herein.

1489

1490

1491 *Escharispharidia* sp. B. (Plate II, fig. 3)

1492

1493 Remarks: This form, like *Escharispharidia* sp. A, has well-developed accessory
1494 archaeopyle sutures and it also sometimes exhibits vague indications of a cingulum.
1495 However, the autophragm is smooth to scabrate rather than comprehensively
1496 granulate. The specimen figured as *Chytroeisphaeridia chytroeides* (Sarjeant 1962)
1497 Downie & Sarjeant 1965 by Filatoff (1975, pl. 29, fig. 2) from the Middle Jurassic of
1498 Western Australia is apparently referable to *Escharispharidia* sp. B. This specimen
1499 cannot, however, be *Chytroeisphaeridia chytroeides* because the latter has a
1500 precingular and not an apical archaeopyle. It can be difficult to consistently
1501 distinguish *Escharispharidia* sp. B from specimens of *Escharispharidia* sp. A with
1502 extremely low-relief ornamentation.

1503

1504

1505 *Evansia* Pocock 1972 emend. Below 1990

1506

1507 *Evansia* sp. A (Plate IX, figs. 10-12)

1508

1509 Dimensions (10 specimens measured):

1510 Length of cyst including operculum: 52 (56) 62 μm

1511 Equatorial width of cyst: 36 (38) 43 μm

1512 Thickness of autophragm: 1-2 μm

1513

1514 Remarks: *Evansia* sp. A is a typically small member of this genus, with a thick, robust
1515 autophragm, a prominent cingulum marked by thick folds and a small to moderate
1516 apical horn surmounted by a short, solid apicular structure 1-2 μm long. The surface
1517 ornament is predominantly granulate to verrucate with some elements fusing to form
1518 short rugulae; the ornament becomes notably coarser towards the antapex. This
1519 morphotype is not formally described here or attributed to any existing species
1520 because insufficient material is available. However, it is broadly comparable with

1521 *Evansia zabros* (Davies 1983) Jansonius 1986 from the Bathonian to Oxfordian of
1522 North America. The latter species is characterised by uneven antapical bulges and
1523 adcingularly-aligned coarse grana. It is also larger, often more elongate and lacks the
1524 prominent folds delimiting the cingulum of *Evansia* sp. A. The latter feature, and the
1525 rugulate ornament are particularly reminiscent of *Pareodinia* sp. 1 of Feist-Burkhardt
1526 and Monteil (1997, pl. 5, figs. 6, 7) that was recorded from the Late Bajocian to Early
1527 Bathonian of northern France. *Evansia* sp. A is sparsely present in all three wells, and
1528 ranges from the upper Lower *Wanaea verrucosa* Subzone to the lower part of the
1529 Upper *Wanaea verrucosa* Subzone (Fig. 4; Tables 1-3).

1530

1531

1532 *Fostericysta* Riding 2005

1533

1534 *Fostericysta scarffei* (Tykoezinski et al. 2001) comb. nov. (Plate VIII, fig. 1)

1535

1536 *Jansonia scarffei* Tykoezinski et al. 2000, p. 84-86, pl. 1, figs. 1-5, pl. 4, figs. 10-13.

1537

1538 Dimensions (5 specimens measured):

1539 Length of cyst including operculum: 21 (23) 25 μm

1540 Equatorial width of cyst: 22 (23) 26 μm

1541 Thickness of autophragm: ca. 1-2 μm

1542

1543 Remarks: *Fostericysta* Riding 2005 was established for small, gonyaulacalean,
1544 proximate to proximochorate, acavate cysts with a 'prominent, incised paracingular
1545 region' and an apical archaeopyle (Riding and Helby, 2001e, p. 114). The type
1546 species, *Fostericysta eclipsiana* (Riding & Helby 2001) Riding 2005, has 'low
1547 parasutural ridges or low crests, which are surmounted by denticles and/or spines'.
1548 *Fostericysta scarffei* clearly shares the diagnostic, deeply incised, broad cingulum, as
1549 well as having a noticeably thick, dark-walled appearance and a similar tabulation
1550 pattern. Thus, the species is transferred to *Fostericysta*.

1551 *Fostericysta scarffei* is a rare component of the Upper *Wanaea verrucosa*
1552 Subzone in the Sunrise-2 and Sunset West-1 wells (Tables 2, 3), and was recorded at
1553 3195.10 m in the Perseus-3A well. The Australian specimens possess a slightly
1554 narrower cingulum and shorter denticles surmounting the sutural ridges, but are

1555 otherwise closely comparable to the type material. *Fostericysta scarffei* is slightly
1556 smaller than the Callovian-Oxfordian species, *Fostericysta eclipsiana*, lacks the very
1557 distinctive dark accumulation body and has a larger, more equant 1" plate.
1558 *Fostericysta scarffei* was originally recorded from the Middle-Late Bathonian of
1559 central England (Tykoezinski et al., 2000).
1560
1561
1562 *Jansonia* Pocock 1972 emend. Riding & Walton in Riding et al. 1991
1563
1564 *Jansonia* spp. (Plate VIII, figs. 2-5)
1565
1566 Remarks: *Jansonia* spp. were recorded sporadically in all three wells with a first
1567 appearance datum within the Lower *Wanaea verrucosa* Zone in Sunset West-1 (Table
1568 3). Most specimens are broadly similar to *Jansonia psilata* Martínez et al. 1999, but
1569 some exhibit a granulate autophragm and an adnate operculum; they are thus also
1570 comparable with *Jansonia manifesta* Riding & Walton in Riding et al. 1991. Although
1571 there is a minor acme at 2111.1 m in Sunrise-2 (5% of total palynomorphs; Table 2),
1572 this genus is otherwise rare, and individual specimens are not given specific status
1573 due to their variable surface ornament, wall thickness and outline.
1574
1575
1576 *Kallosphaeridium* de Coninck 1969 emend. Jan du Chêne et al. 1985
1577
1578 *Kallosphaeridium hypornatum* Prauss 1989 (Plate II, figs. 13-16)
1579
1580 Remarks: *Kallosphaeridium hypornatum* is present in low numbers throughout the
1581 *Wanaea verrucosa* Zone in all three wells studied, but is most prominent and
1582 consistent in the Middle Subzone (Tables 1-3). This is the first report of this species
1583 from the southern hemisphere. This taxon was first described from the Bajocian of
1584 northwest Germany by Prauss (1989).
1585
1586
1587 *Kalyptea* Cookson & Eisenack 1960 emend. Wiggins 1975
1588

1589 *Kalyptea stegasta* (Sarjeant 1961) Wiggins 1975

1590

1591 Remarks: *Kalyptea stegasta* was encountered extremely rarely at 3244.18 m (sample
1592 P29) in the Perseus-3A well (Table 1). This kalyptrate species has subequal apical and
1593 antapical horns (Sarjeant, 1961, pl. 15, fig. 15). In this study, weakly bicornate forms
1594 are referred to *Pareodinia* spp.

1595

1596

1597 *Leptodinium* Klement 1960 emend. Stover & Evitt 1978

1598

1599 *Leptodinium? ancoralium* Mantle 2005 (Plate VII, fig. 3)

1600

1601 Remarks: *Leptodinium? ancoralium* is a distinctive form with bifurcate, anchor-tipped
1602 spines surmounting prominent sutural crests. It is recorded from only one sample
1603 (SR3; 2107.52/.47 m) in Sunrise-2. This extends the range base below the first
1604 appearance datum in the *Ternia balmei* Zone (Mantle, 2009a, p. 57).

1605

1606

1607 *Leptodinium* spp. (Plate VII, fig. 6)

1608

1609 Remarks: Although first appearing in the uppermost part of the Middle *Wanaea*
1610 *verrucosa* Zone, representatives of *Leptodinium* first consistently occur in the Upper
1611 Subzone, and are potentially useful markers for this interval. *Leptodinium* is most
1612 typical of the Late Jurassic in Europe (Klement, 1960), but representatives have been
1613 reported from the Middle Jurassic (Bajocian-Bathonian) of the northern hemisphere
1614 (e.g. Riding et al., 1985; 1991).

1615 Most specimens referable to *Leptodinium* in this study were not speciated.

1616 This is because of the sparsity of material and the significant morphological
1617 variability observed. Many of the specimens encountered are large, and have a
1618 rounded subquadrangular to ovoidal dorsoventral outline (Plate 7, fig. 6). These
1619 forms are most similar to the Late Jurassic species *Leptodinium arcuatum* Klement
1620 1960, *Leptodinium eumorphum* (Cookson & Eisenack 1960) Sarjeant in Davey et al.
1621 1969 and *Leptodinium mirabile* Klement 1960. However, the specimens recorded
1622 herein have a more rounded outline than the distinctly angular, pentagonal species

1623 *Leptodinium arcuatum* and *Leptodinium eumorphum*; furthermore, they all lack the
1624 characteristically subdivided sulcal region of *Leptodinium mirabile* (see Cookson and
1625 Eisenack, 1960, pl. 37, figs. 1-3; Klement, 1960, pl. 6, figs. 5-7). The sulcal area in
1626 the material studied herein is relatively narrow. Moreover, the sutural crests on the
1627 *Wanaea verrucosa* Zone material are significantly variable in height.

1628

1629

1630 *Mancodinium* Morgenroth 1970 emend. Below 1987b

1631

1632 *Mancodinium semitabulatum* subsp. *semitabulatum* (Morgenroth 1970) Fensome et al.
1633 1993 (Plate X, figs. 11-15)

1634

1635 Remarks: *Mancodinium semitabulatum* subsp. *semitabulatum* was recorded rarely in
1636 the Lower and lowermost Middle *Wanaea verrucosa* subzones in the Sunrise-2 and
1637 Sunset West-1 wells (Tables 2, 3). These forms possess short, relatively thick, capitate
1638 spines or gemmae that are noticeably reduced in and around the sulcal area. These
1639 specimens are similar to those figured by Below (1987b; pl. 4, figs. 1-15). The
1640 precingular, anterior intercalary and apical plates may all be lost in archaeopyle
1641 formation, or any number of these plates may remain attached. In the latter case, the
1642 plates are normally partially separated. This is the first published record of this genus
1643 in the southern hemisphere; in Europe it ranges from the Late Pliensbachian to Early
1644 Bajocian (Morgenroth, 1970; Below, 1987b; Riding and Thomas, 1992).

1645

1646

1647 *Meiourogonyaulax* Sarjeant 1966

1648

1649 Remarks: Representatives of *Meiourogonyaulax* were recorded throughout the
1650 *Wanaea verrucosa* Zone (Tables 1-3). These forms are not referable to any existing
1651 species. Most of the observed morphotypes are thick-walled with strong
1652 ornamentation, have poorly-defined tabulation, and frequently have accumulation
1653 bodies and attached opercula .

1654

1655

1656 *Meiourogonyaulax straussii* sp. nov. (Plate I, figs. 1-16)

1657

1658 Description: A species of *Meiourogonyaulax* which is ellipsoidal in dorsoventral
1659 outline; an apical horn or protuberance is entirely lacking. The autophragm is robust,
1660 thick, comprehensively rugulate to irregularly reticulate and locally may bear
1661 elements of low-relief ornamentation such as baculae, denticles/echinae, tubercles,
1662 and verrucae. The density and type of this ornament is highly variable, ranging from
1663 largely spinose forms to comprehensively rugulate morphotypes. Locally, the
1664 coalescence of verrucae and rugulae gives rise to a pseudoreticulate texture. The
1665 spinose-baculate elements are typically irregularly distributed and are highly variable
1666 in form, for example they may be either distally blunt, sharp or oblate. These elements
1667 are consistently most well-developed on the hypocyst, and especially around the
1668 antapical (1''') plate, although some specimens are comprehensively spinose. The
1669 sexiform gonyaulaccean tabulation is indicated by the apical archaeopyle, the
1670 prominent crests which consistently mark the apparently undivided laevorotatory
1671 cingulum, and by low, frequently discontinuous sutural ridges or crests which
1672 delineate the remaining plate series. The tabulation is largely suppressed in the apical
1673 and antapical areas. Frequently, the crests/ridges in the precingular and postcingular
1674 plate series become lower and more discontinuous in a polar direction either side of
1675 the cingulum, becoming entirely suppressed towards the middle point of these series.
1676 The sutural crests/ridges, where developed, dominantly have irregular distal margins
1677 formed by denticles, but they can occasionally be distally smooth or fenestrate.
1678 Relatively large, dark accumulation bodies which are subspherical to ovoidal in
1679 outline are centrally attached to the cyst body on most specimens. The sulcus is
1680 apparently undivided, relatively narrow and longitudinal. The archaeopyle is apical;
1681 the simple operculum is nearly always attached. Minor accessory archaeopyle sutures
1682 may be developed in the precingular plate series.

1683

1684 Dimensions (30 specimens measured):

1685 Length of cyst including operculum: 45 (60) 75 μm

1686 Equatorial width of cyst: 58 (69) 82 μm

1687 Height of ornamentation: 0.5-4.0 μm

1688 Thickness of autophragm: 1-1.5 μm

1689

1690 Comments: *Meiourogonyaulax straussii* sp. nov. is easily recognised by its thick and
1691 robust, rugulate to irregularly reticulate autophragm, the prominent cingulum, its
1692 partially-developed sutural crests/ridges, the variable low-relief ornamentation which
1693 is best developed around the antapex, the frequently attached simple apical operculum
1694 and the prominent accumulation bodies. The morphology of the sutural crests/ridges
1695 is highly variable, they typically have irregularly denticulate distal margins, but these
1696 can also be distally smooth or fenestrate. This species is prominent, even when
1697 working at relatively low magnifications due to its thick autophragm, which imparts a
1698 strong body colour.

1699

1700 Comparison: *Meiourogonyaulax straussii* sp. nov. differs from all other species of
1701 *Meiourogonyaulax* in bearing significantly incomplete tabulation. Stover and Evitt
1702 (1978, p. 62) stated that the tabulation is 'generally complete'. The species which is
1703 most similar is *Meiourogonyaulax reticulata* Dodekova 1975, which has a thick,
1704 reticulate autophragm and a frequently attached operculum. However, the tabulation
1705 of *Meiourogonyaulax reticulata* is fully indicated by low, distally-smooth sutural
1706 ridges (Riding, 1983, pl. 1).

1707

1708 Holotype and type locality: Plate I, Figs. 5-6. Sunset West-1 well (2216.84 m),
1709 Bonaparte Basin, Timor Sea. Slide no. 2, EF T39/2, CPC no. 41142.

1710

1711 Stratigraphical distribution: *Meiourogonyaulax straussii* sp. nov. was observed
1712 commonly in the *Wanaea verrucosa* Zone in both the Sunrise-2 and Sunset West-1
1713 wells. It first appears in the middle part of the Lower Subzone, is common to
1714 abundant in the upper half of the Middle Subzone to the lower part of the Upper
1715 Subzone and ranges sporadically into the overlying *Wanaea indotata* Zone (Tables 2,
1716 3). *Meiourogonyaulax straussii* was also recorded in low to moderate numbers in the
1717 *Wanaea verrucosa* Zone of the Perseus-3A well (Table 1).

1718

1719

1720 *Meiourogonyaulax* sp. A (Plate II, figs. 1-2)

1721

1722 Dimensions (10 specimens measured):

1723 Length of cyst excluding operculum: 48 (53) 60 μ m

1724 Equatorial width of cyst: 44 (55) 61 μm
1725 Thickness of autophragm: > 1 μm
1726
1727 Remarks: *Meiourogonyaulax* sp. A is a simple form with a granulate to
1728 microreticulate autophragm, long accessory archaeopyle sutures and tabulation which
1729 is faintly delimited by aligned grana or low crests/ridges that may be finely fenestrate.
1730 It differs from most forms of *Meiourogonyaulax* in the *Wanaea verrucosa* Zone in
1731 lacking an adnate operculum and only rarely displaying an obvious accumulation
1732 body. *Meiourogonyaulax* sp. A is notably smaller than *Meiourogonyaulax viriosa*
1733 Riding & Helby 2001, and lacks the fully developed tabulation marked by continuous,
1734 slender crests. However, similar forms are present through the Callovian and early
1735 Oxfordian of Australia. In the present study, *Meiourogonyaulax* sp. A is uncommon
1736 in all three wells from the uppermost part of the Lower *Wanaea verrucosa* Subzone
1737 to the lowermost part of the Upper Subzone. This interval coincides with the peak
1738 density and diversity of *Meiourogonyaulax* in the *Wanaea verrucosa* Zone.
1739
1740
1741 *Meiourogonyaulax* sp. B (Plate II, figs. 5-8)
1742
1743 Dimensions (12 specimens measured):
1744 Length of cyst excluding operculum: 48 (53) 57 μm
1745 Equatorial width of cyst: 50 (54) 59 μm
1746 Thickness of autophragm: ca. 1 μm
1747 Length of processes: 1-4 μm
1748
1749 Remarks: This small to medium sized form of *Meiourogonyaulax* is relatively thick-
1750 walled, with a comprehensive cover of grana and short baculae or spines. The spines
1751 may be capitate, bifurcate or blunt-tipped; rarely the furcae coalesce to form finely
1752 fenestrate sutural crests or a localised reticulum. The tabulation is only weakly
1753 expressed by low, discontinuous ridges of coalescent grana; typically only the
1754 cingulum is discernible, but the pre- and postcingular plates may also be faintly
1755 evident. The archaeopyle margin is formed of deep accessory sutures and the
1756 operculum is free. *Meiourogonyaulax* sp. B is a rare but important marker with a
1757 restricted range in the upper part of the Lower *Wanaea verrucosa* Subzone in the

1758 Sunrise-2 and Sunset West-1 wells (Fig. 4; Tables 2, 3); one specimen was also
1759 recorded in the lowermost Middle *Wanaea verrucosa* Subzone in the Sunset West-1
1760 well. This form is not present in sufficient numbers to be formally described.

1761

1762

1763 *Meiourogonyaulax* sp. C (Plate II, figs. 9-12)

1764

1765 Dimensions (14 specimens measured):

1766 Length of cyst including operculum: 52 (57) 63 μm

1767 Equatorial width of cyst: 43 (52) 56 μm

1768 Thickness of autophragm: ca. 1 μm

1769

1770 Remarks: *Meiourogonyaulax* sp. C is a distinctive form with a thick, granulate to
1771 microreticulate autophragm, low sutural ridges, an adnate operculum and a thick, dark
1772 accumulation body. The low ridges often have denticulate margins and the cingulum
1773 is typically well-developed. *Meiourogonyaulax* sp. C is marginally darker and thicker-
1774 walled than *Meiourogonyaulax* sp. A but is readily differentiated by the usually
1775 attached operculum, obvious accumulation body and more prominent sutural ridges. It
1776 shares these first two features with *Meiourogonyaulax straussii* sp. nov., but should
1777 not be confused with this larger, more coarsely ornamented species. It is a notable
1778 feature of the *Wanaea verrucosa* Zone assemblages that the majority of forms with
1779 apical archaeopyles have an adnate operculum and a dark accumulation body. These
1780 accumulation bodies are mostly subcircular and are attached close to the cingulum.

1781

1782

1783 *Meiourogonyaulax* spp.

1784

1785 Remarks: This material includes all the other forms of *Meiourogonyaulax* which are
1786 not attributable to *Meiourogonyaulax straussii* sp. nov. or *Meiourogonyaulax* sp. A, B
1787 or C. There is large diversity of forms through the Middle and Upper *Wanaea*
1788 *verrucosa* subzones that cannot easily be grouped into consistent taxa. .

1789

1790

1791 *Mendicodinium* Morgenroth 1970 emend. Bucefalo Palliani et al. 1997

1792
1793 *Mendicodinium* spp.
1794
1795 Remarks: Squat ovoidal forms of *Mendicodinium* with a relatively thick, smooth
1796 autophragm and an attached epicystal archaeopyle were recorded throughout the
1797 *Wanaea verrucosa* Zone in low numbers (Tables 1-3). The preservation of these rare
1798 forms precludes a confident assignment to any existing species, so they are simply
1799 termed *Mendicodinium* spp.
1800
1801
1802 *Nannoceratopsis* Deflandre 1938 emend. Piel & Evitt 1980
1803
1804 *Nannoceratopsis deflandrei* Evitt 1961 subsp. *deflandrei* (autonym) (Plate X, figs. 16-
1805 18)
1806
1807 Remarks: *Nannoceratopsis deflandrei* subsp. *deflandrei* was recorded in low numbers
1808 throughout the *Wanaea verrucosa* Zone in the Sunrise-2 and Sunset West-1 wells
1809 (Tables 2, 3). The range top of the species is within the Upper *Wanaea verrucosa*
1810 Subzone. This subspecies has a relatively smooth to scabrate autophragm, a strongly
1811 developed dorsal antapical horn and a relatively weakly developed ventral antapical
1812 horn. The ventral horn is commonly reduced to little more than a prominent 'shoulder'
1813 (Plate X, fig. 18).
1814
1815
1816 *Nannoceratopsis deflandrei* Evitt 1961 subsp. *senex* (van Helden 1977) Ilyina in
1817 Ilyina et al. 1994 (Plate X, figs. 21-23)
1818
1819 Remarks: This distinctive subspecies was recorded consistently in the Middle *Wanaea*
1820 *verrucosa* Subzone in the Sunrise-2 and Sunset West-1 wells, but only rarely in the
1821 Lower Subzone (Tables 2, 3). The autophragm of *Nannoceratopsis deflandrei* subsp.
1822 *senex* is smooth to scabrate, and only the dorsal antapical horn is developed. The
1823 entire lack of a ventral antapical horn imparts a rounded subquadrangular shape to this
1824 subspecies.
1825

1826

1827 *Nannoceratopsis spiculata* Stover 1966 (Plate X, fig. 20)

1828

1829 Remarks: *Nannoceratopsis spiculata* was observed in one sample (SW8, 2217.98 m)
1830 in the Sunset West-1 well. This distinctive species has two subequal antapical horns.
1831 The right and left lateral surfaces are slightly different in size, giving the impression
1832 of cavation at the distal extremities of the antapical horns (Stover, 1966, fig. 1, pl. 8,
1833 figs. 1-5). *Nannoceratopsis spiculata* is typical of the latest Early Bajocian to Mid
1834 Callovian interval in Europe (Stover, 1966; Fenton et al., 1980; Riding et al. 1985;
1835 1991; Prauss, 1989; Feist-Burkhardt and Monteil, 1997).

1836

1837

1838 *Nannoceratopsis* spp. (Plate X, fig. 19)

1839

1840 Remarks: This material includes all other forms of *Nannoceratopsis* that are not
1841 attributable to *Nannoceratopsis deflandrei* or *Nannoceratopsis spiculata*.

1842

1843

1844 *Pareodinia* Deflandre 1947 emend. Below 1990

1845

1846 Remarks: Representatives of *Pareodinia* occur throughout the *Wanaea verrucosa*
1847 Zone in varying proportions in all three wells (Tables 1-3). A wide variety of forms
1848 were observed, many of which are difficult to consistently place into existing species
1849 and the vast majority of the specimens exhibit accumulation bodies (Plate IX, figs. 5,
1850 9). All the forms below include kalyprate and non-kalyprate forms.

1851

1852

1853 *Pareodinia halosa* (Filatoff 1975) Prauss 1989 emend. Prauss 1989 (Plate IX, fig. 8)

1854

1855 Remarks: This distinctive kalyprate species was recorded in significant proportions
1856 throughout in the Sunrise-2 and Sunset West-1 wells (Tables 2, 3) and as a rare
1857 component of the Perseus-3A assemblages (Table 1). Consistently common
1858 occurrences of *Pareodinia halosa* are mostly confined to the *Nannoceratopsis*
1859 *deflandrei* and *Wanaea verrucosa* zones (Mid Bajocian to Early Bathonian) in

1860 Australia, although this taxon is present in low to moderate proportions from the Early
1861 Bajocian to Early Cretaceous of Australia (Riding et al., 2010, fig. 12). Normally the
1862 kalyptra of *Pareodinia halosa* is broadly subcircular in outline, reflecting the outline
1863 of the cyst body. However, relatively small numbers of this species are characterised
1864 by extremely irregular kalyptras. In these forms, the periphery of the kalyptra has
1865 numerous irregular extensions which impart a spinose appearance (e.g. Plate IX, fig.
1866 8). These 'spinose' morphotypes are present throughout the *Wanaea verrucosa* Zone.

1867

1868

1869 *Pareodinia* sp. A (Plate IX, figs. 14-16)

1870

1871 Dimensions (10 specimens measured):

1872 Length of cyst including apical horn: 48 (58) 72 μm

1873 Equatorial width of cyst: 44 (51) 60 μm

1874 Thickness of autophragm: ca. 1 μm

1875

1876 Remarks: *Pareodinia* sp. A is a distinctive form with a thick, finely granulate
1877 autophragm; the cyst body is subspherical in shape and has a very short (4-9 μm)
1878 apical horn (Plate IX, fig. 16). There is insufficient material in the wells studied to
1879 erect a new species. This form is present in low numbers in all three wells from the
1880 upper part of the Lower *Wanaea verrucosa* Subzone to the lower part of the Upper
1881 *Wanaea verrucosa* Subzone (Fig. 4; Tables 1-3).

1882

1883

1884 *Pareodinia* spp. (Plate IX, figs. 5-7, 9, 13)

1885

1886 Remarks: The majority of representatives of *Pareodinia* were not subdivided, and are
1887 simply placed in *Pareodinia* spp. Included in this grouping are forms similar to
1888 *Pareodinia ceratophora* Deflandre 1947 emend. Gocht 1970, elongate forms, squat
1889 morphotypes with short apical horns, antapically granulate types, and kalyptrate and
1890 non-kalyptrate forms. This plexus is extremely difficult to subdivide consistently; the
1891 individual forms appear to represent members of a morphological continuum.

1892 *Pareodinia* spp. were recorded in moderate numbers throughout the *Wanaea*
1893 *verrucosa* Zone in all three wells (Tables 1-3).

1894

1895

1896 *Phallocysta* Dörhöfer & Davies 1980 emend. Riding 1980

1897

1898 *Phallocysta granosa* Riding and Helby 2001 (Plate X, figs. 1-4, 6-10)

1899

1900 Remarks: *Phallocysta granosa* was recorded in relatively low proportions throughout
1901 the Lower and Middle *Wanaea verrucosa* subzones in the Sunrise-2 and Sunset West-
1902 1 wells (Figure 4; Tables 2, 3). A significant acme is recorded in the Middle Subzone
1903 in Sunrise-2, where *Phallocysta granosa* consists of 7.3%, 0.7%, and 2.4% of the
1904 total palynomorphs in three consecutive samples from 2121.63 m to 2117.06m.

1905 The present work confirms that *Phallocysta granosa* has a densely granulate to
1906 spinulate periphragm as stated by Riding and Helby (2001c, p. 61). This phenomenon
1907 is clearly exhibited by the holotype (Riding and Helby, 2001c, figs. 1G-H). However,
1908 the latter authors figured six specimens of *Phallocysta granosa* from the Sunset-1
1909 well (not included in the present study) which clearly have a microgranulate to
1910 granulate periphragm (Riding and Helby, 2001c, figs. 1A-F). These microgranulate
1911 forms are considerably rarer end members of a morphological continuum in the
1912 Sunrise-2 and Sunset West-1 wells; most specimens recorded herein are
1913 comprehensively spinulate or coarsely granulate with at least some short, simple
1914 spines.

1915

1916

1917 *Phallocysta* spp. (Plate X, fig. 5)

1918

1919 Remarks: Rare, non-spinose forms of *Phallocysta* were recorded in all three wells.
1920 Included within this grouping are small, subspherical, scabrate to microgranulate
1921 forms (Plate X, fig. 5), and types that are broadly similar to *Phallocysta erregulensis*
1922 (Filatoff 1975) Stover & Helby 1987. The latter forms are marginally smaller, less
1923 prone to folding of the endo- and periphragm and with shorter apical horns than those
1924 figured by Stover and Helby 1987 (fig. 11).

1925

1926

1927 *Prolixosphaeridium* Davey et al. 1966 emend. Davey 1969

1928

1929 *Prolixosphaeridium* spp.

1930

1931 Remarks: *Prolixosphaeridium* spp. were only recorded in the uppermost part of the
1932 Upper *Wanaea verrucosa* Subzone in the Sunset West-1 well (Table 3). Forms similar
1933 to *Prolixosphaeridium capitatum* (Cookson & Eisenack 1960) Singh 1971 are
1934 included in this group; this species occurs as a common accessory species from the
1935 *Wanaea indotata* to *Dingodinium swanense* zones (Helby et al., 1987; Mantle,
1936 2009b).

1937

1938

1939 *Rhynchodiniopsis* Deflandre 1935 emend. Jan du Chêne et al. 1985

1940

1941 *Rhynchodiniopsis* sp. cf. *R? regalis* (Gocht 1970) Jan du Chêne et al. 1985

1942

1943 Remarks: Low numbers of a distinctive acavate gonyalacacean form were recorded
1944 from the Perseus-3A and Sunrise-2 wells (Tables 1, 2). It has an apical horn, thick
1945 autophragm, an ovoidal amb and proximally fenestrate/distally denticulate sutural
1946 crests. The cyst organisation and the distinctive morphology of the sutural crests are
1947 reminiscent of *Rhynchodiniopsis? regalis*. However, the type material has a distinctly
1948 angular (subpentagonal) outline, and higher, more ornate sutural crests (Gocht, 1970,
1949 fig. 10, pl. 33, figs. 5-7). The range of *Rhynchodiniopsis? regalis* in Europe is latest
1950 Early Bajocian to Late Bathonian (Gocht, 1970; Fenton et al., 1980; Riding, 1984;
1951 Riding et al. 1985; 1991; Riding and Thomas, 1992; Feist-Burkhardt and Monteil,
1952 1997).

1953

1954

1955 *Rhynchodiniopsis* spp. (Plate VII, figs. 1-2, 4-5)

1956

1957 Remarks: Forms attributable to *Rhynchodiniopsis* were observed in low proportions
1958 from all three wells (Tables 1-3). These morphotypes are acavate, ovoidal to
1959 subpentagonal in outline and with a variety of spinose ornamentation on the sutural
1960 crests. The spines may possess complex splayed or furcate tips (Plate VII, figs. 1, 4-5)
1961 and project directly from gonial points or surmount low simple or fenestrate crests.

1962 The fenestrae may be reduced (Plate VII, fig. 2) or well-developed (Plate VII, fig. 1).

1963 Some specimens are densely folded.

1964

1965

1966 *Sentusidinium* Sarjeant & Stover 1978

1967

1968 *Sentusidinium* spp.

1969

1970 Remarks: *Sentusidinium* spp. were encountered sporadically throughout the *Wanaea*

1971 *verrucosa* Zone in the Sunrise-2 and Sunset West-1 wells (Tables 2, 3).

1972

1973

1974 *Ternia* Helby & Stover 1987

1975

1976 *Ternia balmei* Helby & Stover 1987 (Plate IX, fig. 4)

1977

1978 Remarks: *Ternia balmei* is an extremely distinctive species that first appears in the

1979 Upper *Wanaea verrucosa* Subzone in the Sunrise-2 and Sunset West-1 wells (Fig. 4;

1980 Tables 2, 3). This agrees with the range base of *Ternia balmei* as depicted by Helby et

1981 al. (2004, fig. 4) and Partridge (2006) in their 7ciai subzone. However, it is only

1982 consistently present in the Upper *Wanaea verrucosa* Subzone in Sunrise-2 and is thus

1983 too rare to be a reliable marker species in all wells. *Ternia balmei* ranges into and

1984 throughout the overlying *Wanaea indotata* and *Ternia balmei* zones (Helby et al.,

1985 1987; 2004; Partridge, 2006)

1986

1987

1988 *Valensiella* Eisenack 1963 emend. Courtinat 1989

1989

1990 *Valensiella ovulum* (Deflandre 1947) Eisenack 1963

1991

1992 Remarks: *Valensiella ovulum* is present in low numbers in the Upper *Wanaea*

1993 *verrucosa* Subzone in the Sunrise-2 and Sunset West-1 wells (Fig. 4, Tables 2, 3), and

1994 throughout much of the undivided *Wanaea verrucosa* Zone in Perseus-3A (Table 1).

1995 This small species is prominent in the Late Bajocian and Bathonian of Europe (Gocht,
1996 1970; Riding et al., 1985; Feist-Burkhardt and Monteil, 1997).

1997

1998

1999 *Valvaeodinium* Morgenroth 1970 emend. Below 1987

2000

2001 *Valvaeodinium cookii* sp. nov. (Plate VIII, figs. 16-25)

2002

2003 Description: A small species of *Valvaeodinium* with a squat, subspherical outline and
2004 normally a flattened antapical margin. The autophragm is moderately thick (ca. 1-1.5
2005 μm) and dark brown; the surface is scabrate to granulate with a variable density and
2006 distribution of short processes. These elements may be baculate, short capitate spines
2007 or rarely spines with blunt, bifurcate tips. The latter features are only resolvable using
2008 high power objectives. Some specimens have a relatively dense covering of these fine
2009 processes (Plate VIII, fig. 16), but they are largely confined to gonal or intergonal
2010 positions on most individuals with only a few scattered intratabular elements (Plate
2011 VIII, figs. 17). Tabulation is indicated by the archaeopyle and low crests and ridges of
2012 variable thickness (0.5-2 μm) and distribution. These sutural features may be
2013 surmounted by short processes particularly at the gonal points and are most
2014 prominent on the hypocyst, particularly around the precingular plates. The
2015 archaeopyle is interpreted to be type AI, formed through the loss of a single apical and
2016 intercalary plate (assumed to be the 3' and 1a plates as is typical for the genus). This
2017 combination archaeopyle that leaves three apical plates in place leads to a rather
2018 pointed apex when the cyst is viewed laterally (Plate VIII, fig. 19); again, a common
2019 feature of the genus. The operculum may be free or one or both of the opercular plates
2020 may remain attached, albeit loosely. The full tabulation formula is frequently not fully
2021 resolvable, but is clearly consistent for *Valvaeodinium* i.e.: 4', 1a, 5'', ?6c, 5''', 1''''.

2022

2023 Dimensions (20 specimens measured):

2024 Length of cyst including operculum: 28 (33) 38 μm

2025 Equatorial width of cyst excluding spines: 29 (35) 40 μm

2026 Length of spines: 1-3 μm

2027 Thickness of autophragm: ca. 1-1.5 μm

2028

2029 Comments: *Valvaeodinium cookii* sp. nov. is characterised by short sutural spines,
2030 variable crests and ridges delimiting an incomplete tabulation, and a typically squat,
2031 subspherical outline. The sutural ridges vary from thin, short crests with an irregular
2032 notched to finely spinose margin (Plate VIII, figs. 17-18), to low, thick, granular
2033 ridges (Plate VIII, figs. 20, 23, 25). The tabulation is commonly best developed on the
2034 hypocyst where the precingular plates are typically prominent; the sutural ridges may
2035 appear as thick folds of the cyst wall.

2036

2037 Comparison: *Valvaeodinium cookii* sp. nov. is markedly less cylindrical and rather
2038 squatter and flatter-based than most other species of *Valvaeodinium*. The prominent
2039 tabulation is also a rare feature of the genus. *Valvaeodinium euareatum* Prauss 1989 is
2040 a closely comparable species from the Early to Middle Bajocian of northwest
2041 Germany. It is similarly squat with well-developed tabulation and a covering of fine,
2042 acuminate to capitate spines. However, *Valvaeodinium euareatum* has a much denser
2043 covering of these spines with a more even, intratabular distribution. The spines may
2044 also coalesce to form a fine reticulum; this is not a feature of *Valvaeodinium cookii*
2045 sp. nov. Furthermore, the well-defined sutural ridges of *Valvaeodinium euareatum*
2046 display a more complete tabulation.

2047

2048 Holotype and type locality: Plate VIII, fig. 25. Sunrise-2 well (2122.33 m), Bonaparte
2049 Basin, Timor Sea. Slide no. 2, EF P29/2, CPC no. 41198.

2050

2051 Stratigraphical distribution: *Valvaeodinium cookii* sp. nov. is an important marker
2052 species for the Middle *Wanaea verrucosa* Subzone. It first appears at the base of this
2053 subzone, together with *Valvaeodinium spinosum*, in both the Sunrise-2 and Sunset
2054 West-1 wells (Fig. 4; Tables 2, 3); it is a commoner, more consistent marker than the
2055 latter species in both wells, but its broader regional distribution is unknown.

2056 *Valvaeodinium cookii* sp. nov. is particularly prominent in the Sunrise-2 well, where it
2057 peaks at 3% of the total palynomorphs in sample SR10 (2117.06 m). The range top of
2058 *Valvaeodinium cookii* sp. nov. is close to the top of the Middle *Wanaea verrucosa*
2059 Subzone. It was not recorded in the Perseus-3A well.

2060

2061

2062 *Valvaeodinium spinosum* (Fenton et al. 1980) Below 1987 (Plate VIII, figs. 6-12)

2063

2064 Remarks: The range base of this distinctive, relatively small, species marks the base
2065 of the Middle *Wanaea verrucosa* Subzone (following the *7ciaii* subzone of Helby et
2066 al., 2004). However, it is relatively rare through this subzone in the Sunrise-2 and
2067 Sunset West-1 wells before a minor acme at the base of the Upper Subzone. This
2068 acme ranges from 2% of total palynomorphs in the Sunset West-1 well, up to 5% of
2069 total palynomorphs in the Sunrise-2 well (Fig. 4, Tables 2-3). The majority of
2070 individuals in the Middle Subzone are squat or subspherical (Plate VIII, figs. 7-10),
2071 and become more cylindrical up-section; most specimens in the Upper Subzone are
2072 notably more elongate (Plate VIII, figs. 6, 11-12). This morphological succession was
2073 noted for *Valvaeodinium spinosum* and other species of *Valvaeodinium* by Feist-
2074 Burkhardt and Monteil (1997, p. 48).

2075

2076

2077 *Valvaeodinium vermicylindratum* Below 1987 (Plate VIII, figs. 13-15)

2078

2079 Remarks: This species was encountered in the Perseus-3A and Sunset West-1 wells,
2080 and questionably in the Sunrise-2 well (Tables 1-3). This is the first southern
2081 hemisphere report of this Late Bajocian-Early Bathonian marker (Feist-Burkhardt and
2082 Monteil, 1997).

2083

2084

2085 *Valvaeodinium* sp. cf. *V. vermipellitum* Below 1987

2086

2087 Remarks: A form similar to *Valvaeodinium vermipellitum* was recorded in one sample
2088 (SW8, 2217.98m) in the Upper *Wanaea verrucosa* Subzone in the Sunset West-1 well
2089 (Table 3). The ornament is less dense, and fewer spines coalesce to form a finer, less
2090 complete reticulum than in the type material.

2091

2092

2093 *Wanaea* Cookson & Eisenack 1958 emend. Riding and Helby 2001

2094

2095 *Wanaea enoda* Riding & Helby 2001 (Plate III, fig. 3)

2096

2097 Remarks: Most specimens of *Wanaea enoda* observed in this study were irregularly
2098 scabrate, rather than possessing a completely psilate autophragm, and were often
2099 squatter than the distinctly subconical hypocysts of the type material from the
2100 Magobu-1 well in Papua New Guinea (Riding and Helby 2001b). *Wanaea enoda* was
2101 observed in extremely low proportions throughout the *Wanaea verrucosa* Zone in all
2102 three wells studied (Tables 1-3).

2103

2104

2105 *Wanaea indotata* Drugg 1978

2106

2107 Remarks: The inception of *Wanaea indotata* marks the base of the late Early to Late
2108 Bathonian *Wanaea indotata* Interval Zone.

2109

2110

2111 *Wanaea lacuna* Riding & Helby 2001 (Plate III, figs. 6, 9)

2112

2113 Remarks: This cavate species of *Wanaea* was recorded in small numbers from a
2114 restricted interval within the Middle *Wanaea verrucosa* Subzone in the Sunrise-2 and
2115 Sunset West-1 wells (Fig. 4; Tables 2, 3). This confirms the findings of Riding and
2116 Helby (2001b), who described this taxon from the equivalent 7ciaii subzone in the
2117 Sunrise-2 well between 2122.33 m and 2122.05 m.

2118

2119

2120 *Wanaea verrucosa* Riding & Helby 2001 (Plate III, figs. 1-2, 4-5, 7-8)

2121

2122 Remarks: *Wanaea verrucosa*, the index species of this zone, occurs throughout the
2123 three wells studied and is normally present in significant proportions (Tables 1-3).

2124 The thickness of the autophragm, ornamentation and size of the antapical horn are
2125 somewhat variable. Forms with a thin, granulate autophragm and a relatively small
2126 antapical horn (Plate III, figs. 2, 5, 7-8) are present throughout, but are most
2127 prominent in Lower and Middle *Wanaea verrucosa* subzones. By contrast,
2128 morphotypes with a significantly thicker and more robust autophragm and with
2129 relatively high relief ornamentation, comprising dense baculae, grana and/or pilae
2130 (Plate III, figs. 1, 4) are confined to the uppermost Middle and Upper *Wanaea*

2131 *verrucosa* subzones. The latter forms normally exhibit prominent antapical horns. The
2132 type material of Riding and Helby (2001b, fig. 9) appears to entirely comprise these
2133 younger morphotypes.

2134 The low-relief ornamentation of the older, purely granulate, forms can make
2135 the distinction between *Wanaea enoda* and *Wanaea verrucosa* difficult to make using
2136 low or medium power objectives. *Wanaea enoda* should be confined to forms which
2137 have a smooth to irregularly scabrate autophragm and no coarser ornament. The range
2138 bases of these two species are coeval (Riding and Helby, 2001b, figs. 11, 12).

2139

2140

2141 **APPENDIX 3. LIST OF THE NON-DINOFLAGELLATE CYST**

2142 **PALYNOMORPHS**

2143

2144 Appendix 3 lists all pollen, spores and miscellaneous palynomorphs recorded
2145 in this study with author citations for the species.

2146

2147 **Pollen:**

2148 *Araucariacites australis* Cookson 1947

2149 *Araucariacites* spp.

2150 *Callialasporites* spp.

2151 *Classopollis* spp.

2152 *Cycadopites* spp.

2153 *Exesipollenites tumulus* Balme 1957

2154 *Perinopollenites elatoides* Couper 1958

2155 *Plicatipollenites* spp. (reworked)

2156 *Praecolpatites sinuosus* (Balme & Hennelly 1956) Bharadwaj & Srivastava 1969

2157 (reworked)

2158 *Protohaploxylinus* spp. (reworked)

2159 *Striatoabieites multistriatus* (Balme & Hennelly 1955) Hart 1964 (reworked)

2160 *Striatopodocarpidites* spp. (reworked)

2161 *Vitreisporites pallidus* (Reissinger 1939) Nilsson, 1958

2162

2163 **Spores:**

2164 *Anapiculatisporites dawsonensis* Reiser & Williams 1969

- 2165 *Annulispora* spp.
- 2166 *Antulsporites saevus* (Balme 1957) Archangelsky & Gamarro 1966
- 2167 *Baculatisporites-Osmundacidites* spp.
- 2168 *Cibotiumspora juncta* (Kara-Murza 1956) Zhang 1978
- 2169 *Cibotiumspora* spp.
- 2170 *Concavissimisporites verrucosus* Delcourt & Sprumont 1955
- 2171 *Concavissimisporites* spp.
- 2172 *Contignisporites cooksoniae* (Balme 1957) Dettmann 1963
- 2173 *Contignisporites* spp.
- 2174 *Coronatispora telata* (Balme 1957) Dettmann 1963
- 2175 *Coronatispora* spp.
- 2176 *Cyathidites* spp.
- 2177 *Diatomozonotriletes townrowii* Segroves 1970 (reworked)
- 2178 *Dictyophyllidites* spp.
- 2179 *Dictyotosporites complex* Cookson & Dettmann 1958
- 2180 *Didecitriletes ericianus* (Balme & Hennelly 1956) Venkatachala & Kar 1965
- 2181 (reworked)
- 2182 *Dulhuntyispora dulhuntyi* Potonié 1956 emend. Price 1983 (reworked)
- 2183 *Foveosporites canalis* Balme 1957
- 2184 *Gleicheniidites senonicus* Ross 1949
- 2185 *Gleicheniidites* spp.
- 2186 *Granulatisporites trisinus* Balme & Hennelly 1956
- 2187 *Granulatisporites* spp. (reworked)
- 2188 *Indotriradites* spp. (reworked)
- 2189 *Ischyosporites-Klukisporites* spp.
- 2190 *Leptolepidites* spp.
- 2191 *Matonispurites* spp.
- 2192 *Microbaculispora villosa* (Balme & Hennelly 1955) Bharadwaj 1962 (reworked)
- 2193 *Neoraistrickia* spp.
- 2194 *Pseudoreticulatispora pseudoreticulata* (Balme & Hennelly 1956) Bharadwaj
- 2195 & Srivastava 1969 (reworked)
- 2196 *Retitriletes* spp.
- 2197 *Sculptisporis moretonensis* (de Jersey 1964) McKellar in press
- 2198 *Sestrosporites pseudoalveolatus* (Couper 1958) Dettmann 1963

- 2199 *Staplinisporites caminus* (Balme 1957) Pocock 1962
 2200 *Stereisporites* spp.
 2201 *Striatella* spp.
 2202 *Trachysporites infirmus* (Balme 1957) McKellar in press
 2203
 2204 **Miscellaneous palynomorphs:**
 2205 *Botryococcus* spp.
 2206 *Circulisporites* spp.
 2207 foraminiferal test linings
 2208 *Leiofusa* sp.
 2209 *Leiosphaeridia* spp.
 2210 *Micrhystridium* spp.
 2211 *Nummus apiculatus* Riding & Helby 2001
 2212 *Pterospermella australiense* (Deflandre & Cookson 1955) Eisenack 1972
 2213 *Veryhachium* spp.

2214
 2215

2216 **APPENDIX 4: QUANTITATIVE RANGE CHARTS**

2217

2218 The quantitative palynomorph distribution data for this project is given in
 2219 Appendix 4. Tables 1-3 are the dinoflagellate cyst range charts and Tables 4-6 include
 2220 the data for the other palynomorph groups.

2221

2222 Table 1. Quantitative dinoflagellate cyst data for the 14 samples studied from the
 2223 Perseus-3A well. The numbers refer to counted specimens. Material observed outside
 2224 the counts is indicated by an 'X'. Three dots (...) indicate that the form is absent.

2225

2226 Table 2. Quantitative dinoflagellate cyst data for the 29 samples studied from the
 2227 Sunrise-2 well. The numbers refer to counted specimens. Material observed outside
 2228 the counts is indicated by an 'X'. Three dots (...) indicate that the form is absent.

2229

2230 Table 3. Quantitative dinoflagellate cyst data for the 21 samples studied from the
 2231 Sunset West-1 well. The numbers refer to counted specimens. Material observed

2232 outside the counts is indicated by an ‘X’. Three dots (...) indicate that the form is
2233 absent.

2234

2235 Table 4. Quantitative data on pollen, spores and miscellaneous palynomorphs for the
2236 14 samples studied from the Perseus-3A well. The numbers refer to counted
2237 specimens. Material observed outside the counts is indicated by an ‘X’. Three dots
2238 (...) indicate that the form is absent. The seven right hand columns depict the total
2239 numbers of dinoflagellate cysts, pollen and spores and percentages.

2240

2241 Table 5. Quantitative data on pollen, spores and miscellaneous palynomorphs for the
2242 29 samples studied from the Sunrise-2 well. The numbers refer to counted specimens.
2243 Material observed outside the counts is indicated by an ‘X’. Three dots (...) indicate
2244 that the form is absent. The seven right hand columns depict the total numbers of
2245 dinoflagellate cysts, pollen and spores and percentages.

2246

2247 Table 6. Quantitative data on pollen, spores and miscellaneous palynomorphs for the
2248 21 samples studied from the Sunset West-1 well. The numbers refer to counted
2249 specimens. Material observed outside the counts is indicated by an ‘X’. Three dots
2250 (...) indicate that the form is absent. The seven right hand columns depict the total
2251 numbers of dinoflagellate cysts, pollen and spores and percentages.

2252

2253

2254 **APPENDIX 5: REGISTER OF FIGURED SPECIMENS**

2255

2256 All dinoflagellate cyst specimens figured herein are listed with essential
2257 details. These specimens are curated in the Commonwealth Palaeontological
2258 Collection (CPC) of Geoscience Australia, Canberra, ACT, Australia. The
2259 dinoflagellate cyst genera and species are listed alphabetically. The locations of the
2260 specimens on the slides are provided as ‘England-Finder’ (EF) co-ordinates.

2261

2262 **[Appendix 5 is attached as an excel spreadsheet]**

2263

2264 **FIGURE CAPTIONS**

2265

2266 Fig. 1. The North West Shelf of Australia illustrating the locations and extents of the
2267 Northern Carnarvon, Roebuck, Offshore Canning, Browse and Bonaparte basins
2268 (collectively the Westralian Superbasin), and the locations of the Perseus-3A, Sunrise-
2269 2 and Sunset West-1 wells.

2270

2271 Fig. 2. A comparison of the chronostratigraphical position of the *Wanaea verrucosa*
2272 dinoflagellate cyst zone and equivalent zones in successive zonation schemes. The
2273 shaded areas represent the *Wanaea verrucosa* Zone and subzones, or the equivalent
2274 portion of the *Caddasphaera halosa* Zone. The diagonal hatched area indicates a gap
2275 in the dinoflagellate cyst zonation.

2276

2277 Fig. 3. Lithological and gamma ray logs of the successions studied herein from the
2278 Perseus-3A, Sunset West-1 and Sunrise-2 wells (from west to east). The dinoflagellate
2279 cyst zones follow Helby et al. (2004) and Partridge (2006), and the subzones are as
2280 described herein.

2281

2282 Fig. 4. The stratigraphical distribution of selected dinoflagellate cysts throughout the
2283 *Wanaea verrucosa* Zone from the two Bonaparte Basin wells (Sunrise-2 and Sunset
2284 West-1) studied herein, depicted from the data compiled from Tables 2-3 of
2285 Appendix 4. The dashed, thin and thick lines indicate that the taxa are rare (i.e. only
2286 present outside the count), consistently present or abundant respectively.

2287 *Valvaeodinium spinosum*, *Endoscrinium kempiae* and *Wanaea verrucosa* are in bold
2288 font because they are the principal index taxa for the *Wanaea verrucosa* Zone and its
2289 constituent subzones.

2290

2291

2292 Plate I. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2293 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μm .

2294

2295 1-16. *Meiourogonyaulax straussii* sp. nov. 1-2, paratype, dorsoventral view, high and
2296 median foci, respectively. 3-4, oblique view, median and high foci, respectively. 5-6,
2297 holotype, dorsoventral view, low and high foci, respectively. 7-8, dorsoventral view,
2298 low and high foci, respectively. 9-10, paratype, dorsoventral view, high and low foci,
2299 respectively. 11-12, ventral view, high and median foci, respectively. 13-14, paratype,

2300 ventral view, high and low foci, respectively. 15-16, dorsoventral view, high and low
2301 foci, respectively.

2302

2303

2304 Plate II. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2305 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μ m.

2306

2307 1-2. *Meiourogonyaulax* sp. A. 1, dorsoventral view, high focus. 2, dorsoventral view,
2308 high focus.

2309 3. *Escharisphaeridia* sp. A, dorsoventral view, high focus.

2310 4. *Escharisphaeridia* sp. B, dorsoventral view, high focus.

2311 5-8. *Meiourogonyaulax* sp. B. 5, dorsoventral view, high focus. 6. dorsoventral view,
2312 median focus. 7. dorsoventral view, high focus. 8. dorsoventral view, high and median
2313 foci combined.

2314 9-12. *Meiourogonyaulax* sp. C. 9, dorsoventral view, high focus. 10, dorsoventral
2315 view, high focus. 11, dorsoventral view, high focus. 12, dorsoventral view, high
2316 focus.

2317 13-16. *Kallosphaeridium hypornatum* Prauss 1989. 13, ventral view, high focus. 14.
2318 dorsoventral view, low and median foci combined. 15, dorsoventral view, high focus.
2319 16, dorsoventral view, high and median foci combined.

2320

2321

2322 Plate III. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2323 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μ m.

2324

2325 1-2, 4-5, 7-8. *Wanaea verrucosa* Riding & Helby 2001. 1, high/median focus. 2, high
2326 focus. 4, high and median foci combined. 5, median focus. 7, high focus. 8, high
2327 focus.

2328 3. *Wanaea enoda* Riding & Helby 2001, high focus.

2329 6, 9. *Wanaea lacuna* Riding & Helby 2001. 6, median focus. 9, median focus.

2330

2331

2332 Plate IV. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2333 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μ m.

2334

2335 1-12. ?*Bradleyella adela* (Fenton et al. 1980) Woollam 1983. 1, dorsoventral view,
2336 median focus. 2, dorsal view, high focus. 3, dorsal view, high focus. 4, ventral view,
2337 high focus. 5, lateral view, high focus. 6, dorsal view, high focus. 7, dorsoventral
2338 view, median focus. 8, dorsoventral view, median focus. 9, dorsal view, high focus.
2339 10, dorsal view, median focus. 11, lateral view, median focus. 12, dorsoventral view,
2340 median focus.

2341 13-15. *Ctenidodinium* sp. A. 1, dorsoventral view, low focus. 2, dorsoventral view,
2342 high focus. 3, oblique view, high focus.

2343

2344

2345 Plate V. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2346 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 µm.

2347

2348 1-3, 5-6. *Ctenidodinium* sp. B. 1-2, hypocyst, lateral view, median and low foci,
2349 respectively. 3, lateral view, high and median foci combined. 5, dorsal view, high
2350 focus. 6 lateral view, median focus.

2351 4. *Ctenidodinium* sp., hypocyst, dorsal view, high focus.

2352 7-9. *Ctenidodinium* sp. C. 7, ventral view, median focus. 8, lateral view, median
2353 focus. 9, lateral view, median focus.

2354

2355

2356 Plate VI. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2357 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 µm.

2358

2359 1-2, 4-6. *Dissiliodinium* sp. A. 1, dorsal view, median focus. 2, ventral view, high
2360 focus. 4, lateral view, high focus. 5, dorsal view, high focus. 6, ventral view, high and
2361 median foci combined.

2362 3. *Dissiliodinium* sp., dorsal view, median focus.

2363 7-10. *Durotrigia* spp. 7, dorsal view, median focus. 8-9, ventral view, high and low
2364 foci respectively. 10, dorsal view, high focus.

2365 11-12. ?*Durotrigia* sp., ventral view, low and high foci, respectively.

2366

2367

2368 Plate VII. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2369 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μm .
2370
2371 1-2. ?*Rhynchodiniopsis* spp. 1, polar view, median focus. 2. polar view, high and
2372 median foci combined.
2373 3. *Leptodinium?* *ancoralium* Mantle 2005, lateral view, high and median foci
2374 combined.
2375 4-5. *Rhynchodiniopsis* spp. 4, lateral view, median focus. 5, dorsoventral view, high
2376 and median foci combined.
2377 6. *Leptodinium* sp., ventral view, high focus.
2378 7, 9. *Endoscrinium luridum* (Deflandre 1938) Gocht 1970. 7, ventral view, high focus.
2379 9, dorsal view, high focus.
2380 8. *Endoscrinium* sp. cf. *E. luridum* (Deflandre 1938) Gocht 1970, lateral view, high
2381 focus.
2382 10. *Endoscrinium kempiae* (Stover & Helby 1987) Lentin & Williams 1989, ventral
2383 view, high, median, and low foci combined.
2384 11. *Aldorfia* sp., ventral view, high focus.
2385 12. *Acanthaulax crista* (Wetzel 1967) Woollam & Riding 1983, ventral view, high
2386 and median foci combined.
2387
2388
2389 Plate VIII. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2390 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μm .
2391
2392 1. *Fostericysta scarffei* (Tykoezinski et al. 2001) comb. nov., ventral view, high focus.
2393 2-5. *Jansonia* spp. 2, dorsal view, high focus. 3, ventral view, high focus. 4, dorsal
2394 view, high focus. 5, ventral view, high focus.
2395 6-12. *Valvaeodinium spinosum* (Fenton et al. 1980) Below 1987. 6, dorsal view, high
2396 focus. 7, dorsal view, median focus. 8, lateral view, high and median foci combined.
2397 9, dorsal/lateral, median focus. 10, lateral view, median focus. 11-12, lateral view,
2398 median and high foci respectively.
2399 13-15. *Valvaeodinium vermicylindratum* Below 1987. 13-14, ventral view, high and
2400 median foci, respectively. 15, dorsal view, high and median foci combined.

2401 16-25. *Valvaeodinium cookii* sp. nov. 16, lateral view, high and median foci
2402 combined. 17. dorsal-lateral view, high focus. 18, paratype, dorsal view, high focus.
2403 19, lateral view, high and median foci combined. 20, dorsal view, high focus. 21,
2404 ventral view, low focus. 22, dorsal view, high and median foci combined. 23,
2405 paratype, dorsal view, median focus. 24, dorsal view, high and median foci combined.
2406 25. holotype, ventral view, median focus.

2407

2408

2409 Plate IX. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2410 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μ m.

2411

2412 1-3. ?*Egmontodinium* sp. A. 1, median focus. 2, median focus. 3, median focus.
2413 4. *Ternia balmei* Helby & Stover 1987, anteroventral view, median focus.
2414 5-7, 9, 13. *Pareodinia* spp. 5, dorsal view, high focus. 6, dorsal view, median focus. 7,
2415 dorsolateral view, median focus. 9, lateral view, median focus. 13, ventral view, high
2416 focus.
2417 8. *Pareodinia halosa* (Filatoff 1975) Prauss 1989 emend. Prauss 1989, median focus.
2418 10-12. *Evansia* sp. A. 10, dorsoventral view, high and low foci combined. 11, dorsal
2419 view, high focus. 12, lateral view, median focus.
2420 14-16. *Pareodinia* sp. A. 14, dorsoventral view, median focus. 15, lateral view,
2421 median focus. 16, dorsoventral view, high and low foci combined.

2422

2423

2424 Plate X. Selected dinoflagellate cyst taxa from the *Wanaea verrucosa* Zone of the
2425 Perseus-3A, Sunrise-2 and Sunset West-1 wells. The scale bars represent 10 μ m.

2426

2427 1-4, 6-10. *Phallocysta granosa* Riding & Helby 2001. 1-2, low and high foci,
2428 respectively. 3, median focus. 4, median focus. 6, high focus. 7, dorsal view, median
2429 focus. 8, median focus. 9, median focus. 10, ventral view, low focus.
2430 5. *Phallocysta* sp., high focus.
2431 11-15. *Mancodinium semitabulatum* subsp. *semitabulatum* (Morgenroth 1970)
2432 Fensome et al. 1993. 11-12, ventral view, high and low foci, respectively. 13, ventral
2433 view, high focus. 14-15, ventral view, low and high foci, respectively.

2434 16-18. *Nannoceratopsis deflandrei* Evitt 1961 subsp. *deflandrei* (autonym). 16, right
2435 lateral view, high focus. 17, right lateral view, median focus. 18, right lateral view,
2436 median view.
2437 19. *Nannoceratopsis* spp., right lateral view, median focus.
2438 20. *Nannoceratopsis spiculata* Stover 1966, right lateral view, median focus.
2439 21-23. *Nannoceratopsis deflandrei* Evitt 1961 subsp. *senex* (van Helden 1977) Ilyina
2440 in Ilyina et al. 1994. 21, left lateral view, high focus. 22, right lateral view, high focus.
2441 23, right lateral view, high focus.