

1 **The Late Cretaceous dinoflagellate cyst genus *Manumiella* – taxonomy,**
2 **biostratigraphy and palaeoecological signals in Antarctica**

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10 **Abstract**

11 New work on the Maastrichtian (latest Cretaceous, 71-65 Ma) species of
12 *Manumiella* Bujak and Davies 1983 in the James Ross Basin, Antarctic Peninsula has
13 highlighted the biostratigraphical and palaeoecological significance of this peridinioid
14 dinoflagellate cyst genus, in particular with reference to oceanic changes associated
15 with the Cretaceous/Tertiary (KT) boundary. New palynological analyses throughout
16 the upper part of the late Maastrichtian López de Bertodano Formation on Seymour
17 Island has resulted in the emendation of *Manumiella* to include the presence of a
18 mesophragm, and the formal description of *Manumiella bertodano* sp. nov. A
19 morphological continuum exists between *Manumiella* taxa, but the apparent

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1 biostratigraphic significance of end-member morphologies emphasises the need for
2 consistent and distinct species concepts. Consequently, a new taxonomic key has
3 been devised based on morphological features of *Manumiella bertodano* sp. nov.,
4 *Manumiella conorata* (Stover 1973) Bujak and Davies 1983, *Manumiella druggii*
5 (Stover 1973) Bujak and Davies 1983, *Manumiella seelandica* (Lange 1969) Bujak
6 and Davies *emend.* Firth 1987 and *Manumiella seymourensis* Askin 1999.
7 *Manumiella druggii* and *Manumiella seelandica* are retained as separate species. The
8 key has been successfully tested on the well-preserved dinoflagellate cyst
9 assemblages from the López de Bertodano Formation on Seymour Island, resulting in
10 a clear biozonation based on the preliminary scheme of Askin (1988a). Abundance
11 spikes of *Manumiella* immediately prior to the KT boundary in this succession have
12 also been recognised globally, and may be related to short-term regressions and/or
13 ocean cooling before the KT catastrophe.

14

15 *Keywords:* Late Cretaceous; Maastrichtian; dinoflagellate cysts; *Manumiella*;
16 Seymour Island; Antarctic Peninsula

17

18 **1. Introduction**

19 *Manumiella* Bujak and Davies 1983 is an important peridinioid dinoflagellate cyst
20 genus in the Southern Hemisphere. It is also of stratigraphical significance in the
21 Maastrichtian worldwide (e.g., Wilson, 1978; Helby et al., 1987; Yepes, 2001; Habib
22 and Saaedi, 2007). It is distinguished from other genera by its well-developed
23 circumcavate cyst organisation and an intercalary lati- or iso-deltaform hexa 2a

1 archaeopyle style. This generic distinction can often be difficult to determine from
2 damaged or folded specimens, particularly with closely related genera, for example
3 the otherwise similar but bicavate *Isabelidinium* Lentin and Williams 1977 *emend.*
4 Marshall 1988.

5 This paper involves five species of *Manumiella* from the uppermost 280 m of the
6 López de Bertodano Formation on Seymour Island, northern Antarctic Peninsula
7 (Figure 1). This sedimentary sequence, including the Cretaceous/Tertiary (KT)
8 boundary, is a key high-latitude reference section for the Maastrichtian Stage, and the
9 distribution of *Manumiella* within it is important for stratigraphic correlation. This
10 paper reviews previously-described *Manumiella* species in light of a complex
11 morphological continuum within this genus. A taxonomic key is presented that
12 resolves five distinct morphotypes observed in the Seymour Island succession, which
13 would previously have been interpreted as either separate species or end-members of
14 a large suite of forms. Their stratigraphical distribution in the Seymour Island
15 sequence and general palaeoecological significance are also considered. One of these
16 morphotypes, “*Manumiella*” n. sp. 2 of Askin (1988a), is formally described as
17 *Manumiella bertodano* sp. nov.

18

19 **2. Material studied**

20 The López de Bertodano Formation is one of four subdivisions of the Coniacian-
21 Danian Marambio Group and is confined to the James Ross Basin, Antarctic
22 Peninsula region (Figures 1 and 2; Pirrie et al., 1997; Crame et al., 2004). It is
23 predominantly exposed on Seymour Island, where it attains a thickness of
24 approximately 1150 m, and is Maastrichtian to earliest Palaeocene in age based on
25 macroinvertebrate and strontium isotope stratigraphy (Macellari, 1988; Crame et al.,

1 2004, Fig. 3). The authors of this paper logged, measured and collected material from
2 the López de Bertodano Formation on Seymour Island during the 2006 field season
3 (Thorn et al., 2007). Only samples from the upper part of the formation are discussed
4 here (section lines D5.219, D5.220, D5.222 and D5.229, presented as a composite
5 section in Figure 2). The sequence dips $\sim 9^\circ$ to the southeast and consists of
6 unconsolidated clayey silts and silty clays, commonly bioturbated. The sediments
7 contain both authigenic and detrital glauconite and are interpreted to represent a mid-
8 to inner-shelf depositional setting. The terrestrial and marine palynology of this
9 sequence is diverse and well-preserved, having undergone minimal burial diagenesis
10 since deposition (Askin, 1988a,b, 1990, 1994).

11 Samples that contribute to this paper are listed (Table 1) and shown against a
12 summary lithological log of the upper 280 m of the López de Bertodano Formation
13 with abundance data for marine taxa (as palynomorphs per gram of sediment, Figure
14 3). The palynology of the lowermost 700m on Seymour Island is an ongoing project.
15 All material in this study (i.e. rock/sediment sample, fossils, microscope slides and
16 prepared residues) are curated in the collections of the British Antarctic Survey,
17 Cambridge, United Kingdom. The unique collection numbers are in the format
18 D5.***.1 for bulk sediment samples, with the suffix A (e.g. D5.1247.1A) referring to
19 microscope slide A prepared from the organic residue.

20

21 **3. Methodology**

22 Sediment was processed for quantitative biostratigraphic palynology using
23 standard laboratory techniques. Sediment was sieved at $180\mu\text{m}$, treated with
24 hydrochloric and hydrofluoric acids, and then oxidised for one or two minutes with
25 nitric acid. Organic particles were separated from the remaining inorganics using zinc

1 chloride heavy liquid and a swirling technique with a final sieve through a 10µm
2 mesh. Notably, it was found that 10µm mesh cloths from different manufacturers
3 retained different size fractions, depending on the method of mesh manufacture.
4 Consistent retention of fine palynomorphs (specifically the smallest bryophyte spores,
5 for example *Stereisporites antiquasporites* (Wilson and Webster 1946) Dettmann
6 1963) was only achieved with a heated and rolled mesh. This appeared to maintain
7 the stated mesh hole diameter when stretched over a mesh cloth holder in the
8 laboratory. A similar issue using mesh cloths of different materials and sizes during
9 palynological processing was discussed by Lignum et al. (2008) and is a serious
10 problem that all palynologists should be aware of.

11 A known volume (0.5 g) of the extracted organic residue was permanently
12 mounted with PVA onto glass slides, allowing a calculation of palynomorphs per
13 gram of sediment. Palynomorphs were counted along traverses across each cover slip
14 to a total of at least 300 grains (excluding *Micrhystridium* spp.) using a Leitz Ortholux
15 transmitted light microscope. Photographs were taken on an Olympus transmitted
16 light microscope with a Leica digital camera.

17

18 **4. Taxonomy**

19 Dimensions and a summary of key characteristics of all *Manumiella* species
20 observed in the López de Bertodano Formation are presented in Tables 2 and 3 to aid
21 comparison. To clarify the identification of *Manumiella* species a morphological key
22 has been constructed as a tool for consistent taxonomic identification during counts.
23 The premise of the key is that any specimens that are transitional between the
24 published characteristics (or are too poorly preserved to designate further) should
25 simply be assigned “*Manumiella* sp.” status and not forced into a particular species

1 (e.g., Figure 4 d, e), thus increasing confidence in stratigraphic range interpretations.

2 It is acknowledged that there are similarities between the morphologies of

3 *Manumiella* and *Isabelidium* genera, however, the important feature is the

4 circumcavate nature of the former and bicavate nature of the latter.

5

6 Morphological Key for species of *Manumiella*:

7

8 (1) Peridinioid cyst, circumcavate_____ (2)

9 Peridinioid cyst, bicavate_____ *Isabelidium*

10 (2) Endocyst barely visible_____ *Manumiella seymourensis*

11 Endocyst prominent_____ (3)

12 (3) Evenly rounded or dimpled apex (antapex: concavity separating poorly
13 developed antapical horns) _____ *Manumiella druggii*

14 Apical horn_____ (4)

15 (4) Prominent apical horn*; elongate, sub-pentagonal periphragm outline
16 (antapex: asymmetrical well-developed antapical horns, longest often pointed)
17 _____ *Manumiella bertodano* sp. nov.

18 Short, truncated apex or poorly developed apical horn_____ (5)

19 (5) Apical knob; antapical horns rounded, fairly well-developed, asymmetrical,
20 rounded and lozenge-shaped outline _____ *Manumiella conorata*

21 Reduced antapical horn_____ *Manumiella seelandica*

1

2 * Refer to the dimensions of *M. bertodano* sp. nov. in the following text.

3

4 **5. Systematic Palaeontology**

5

6 Division DINOFLAGELLATA (Bütschli 1885) Fensome et al. 1993

7 Subdivision DINOKARYOTA Fensome et al. 1993

8 Class DINOPHYCEAE Pascher 1914

9 Subclass PERIDINIPHYCIDAE Fensome et al. 1993

10 Order PERIDINIALES Haeckel 1894

11 Suborder PERIDINIINEAE (autonym)

12 Family PERIDINIACEAE Ehrenberg 1831

13 Subfamily DEFLANDREOIDEAE Bujak and Davies 1983

14

15 *Manumiella* Bujak and Davies 1983 *emend. nov.*

16 ***Type species:*** *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983 *emend.*

17 Firth 1987

18 ***Emended diagnosis:*** The original generic diagnosis of Bujak and Davies (1983, p.

19 160) is emended here to include forms with a single layer of mesophragm.

1 **Remarks:** Representatives of *Manumiella bertodano* sp. nov., *M. conorata* (Stover
2 1973) Bujak and Davies 1983, *M. druggii* (Stover 1973) Bujak and Davies 1983, *M.*
3 *seelandica* (Lange 1969) Bujak and Davies 1983 *emend.* Firth 1987, and transitional
4 forms from Seymour Island exhibit a thin layer of mesophragm, hence the generic
5 diagnosis needs emending to incorporate this feature (Figure 4 a-c, e-h and Figure 5
6 a,c). Mesophragm is a relatively rare morphological element that refers to any
7 intermediate cyst layers between the endophragm and periphragm. In the samples
8 examined, the least folded, and therefore easiest specimens to observe and
9 photograph, commonly exhibited a mesophragm, which presumably increased the
10 robustness of the cyst and retained its original outline. A mesophragm was not
11 observed in any *M. seymourensis* Askin 1999 specimens in these samples. Habib and
12 Saeedi (2007, pl. I, fig. 1) also noted a three-layered wall in *M. seelandica* from a KT
13 section in New Jersey (illustrated within a *M. druggii* morphotype specimen).
14 Similarly, Soncini and Rauscher (1990, plate 1, fig.12) observed three wall layers in
15 Lower Palaeocene *M. cf. seelandica* specimens from Morocco.

16

17 *Manumiella bertodano* new species

18 Figure 4 a-c

19 **Full synonymy:**

20 “*Manumiella*” n. sp. 2 Askin 1988a, fig. 9.4 (not 9.5).

21 “*Manumiella*” n. sp. 2 of Askin 1988a. Pirrie et al., 1991, figs. 7f, 7j.

22 “*Manumiella*” n. sp. 2 of Askin 1988a. Riding et al., 1992, pl. 2, fig. 10.

1 *Manumiella* n. sp. 2 of Askin 1988a. Roncaglia et al., 1999, fig. 16.9.

2 **Description:**

3 Deflandreoid dinoflagellate cyst with an elongate, sub-pentagonal outline in
4 dorso-ventral view. Periphragm relatively thin, smooth, microscabrate to finely
5 granular in surface texture. Circumcavate cyst organisation. Epicyst and hypocyst
6 approximately equal in size. Smooth, relatively thin mesophragm present in some
7 specimens, occupying varying amounts of the pericoel and closely following the
8 internal surface of the periphragm (commonly adjacent to it) for most of its outline.
9 The mesophragm does not normally reach into the extremities of the horns.
10 Equatorial folding in the periphragm often suggests slight paracingulum development.
11 However, there are no unequivocal traces of paratabulation other than the archeopyle.
12 Intercalary monoplacoid periarcheopyle (Type I/-/-). Bilaterally symmetrical, iso- to
13 lati-deltaform hexa 2a, sub-rounded. Free operculum. Prominent, sharply tapering
14 apical horn with a pointed or rounded tip. Two antapical horns are present, separated
15 by an intervening concavity. The antapical horns are asymmetrical, the left antapical
16 horn is more prominent, and is commonly distally pointed. The left antapical horn is
17 shorter than the apical horn, but is significantly longer than the right antapical horn,
18 which is typically reduced. Endocyst smooth, relatively thick and prominent, ovoid in
19 outline, infrequently folded.

20 **Dimensions:** Pericyst length 97(136)172 μm , standard deviation (sd) 19.4; pericyst
21 width 68(91)112 μm , sd 11.3; pericyst length to width ratio 1:0.65 to 1:0.70.
22 Endocyst length 37(68)88, sd 10.8 μm ; endocyst width 32(76)95 μm , sd 13.4. The
23 range of apical horn length is not stated due to the difficulty of consistent
24 measurement between specimens with no sharp break in slope at the 'base' of the
25 horn.

1 Thirty specimens measured.

2 **Etymology:** From the López de Bertodano Formation, Seymour Island, from which
3 this species was first illustrated by Askin (1988a).

4 **Holotype:** Specimen illustrated in Figure 4 c from slide D5.1237.1A, England Finder
5 co-ordinates L40-4. Pericyst length 163 μm ; pericyst width 88 μm (length to width
6 ratio 1: 1.85). Endocyst length 68 μm ; endocyst width 80 μm . Mesophragm present.
7 It is curated (under collection number D5.1237.1A; L40-4) in the collections of the
8 British Antarctic Survey, Cambridge, United Kingdom.

9 **Type locality and biostratigraphy:** Stratigraphic level 959 m in López de Bertodano
10 Formation composite section (equivalent to 10 m level in sub-section D5.222),
11 Marambio Group, Seymour Island, Antarctic Peninsula, late Maastrichtian.
12 *Isabelidinium* Superzone (Helby et al., 1987), *Isabelidinium korojonense* Range Zone
13 to *Manumiella druggii* Interval Zone (Helby et al., 1987).

14 **Remarks and comparisons:**

15 *Manumiella bertodano* sp. nov. is distinguished by the combination of a
16 prominent endocyst, a tendency to an elongate, sub-pentagonal outline, a consistently
17 prominent apical horn, a large, distally-pointed left antapical horn and a reduced
18 typically rounded right antapical horn. Specimens of *Manumiella bertodano* sp. nov.
19 occur within the uppermost López de Bertodano Formation on Seymour Island from
20 834 - 969 m (except rare, probably reworked specimens up to 995 m) in the section
21 (Figure 3).

22 Askin (1998a, fig. 9.4) first illustrated *M. bertodano* sp. nov. as “*Manumiella*” n.
23 sp. 2. However, Askin (1988a) did not describe this taxon. *Manumiella bertodano*

1 sp. nov. was also illustrated by Pirrie et al. (1991), Riding et al. (1992) and Roncaglia
2 et al. (1999) from the late Maastrichtian of Vega Island, Antarctica and New Zealand.

3 The specimen of *Manumiella* sp. 2 of Askin 1988a in Mohr and Mao (1997, pl. 1,
4 fig. 7) from the Maastrichtian of the Maud Rise off the coast of East Antarctica is
5 bicavate, and hence is not considered to be *M. bertodano* sp. nov. The specimen of
6 Mohr and Mao (1997, pl. 1, fig. 7) also has a short endocyst and a narrow antapical
7 area, lacks a particularly prominent apical horn, and is relatively small.

8 Transitional forms possessing most, but not all, of the characteristic features were
9 observed by Askin (1988a, figs. 9.3, 9.5) and also during the current study (referred to
10 *Manumiella* sp., Figure 4 d, e). Marensi et al. (2004, fig. 6F) figured a specimen that
11 appears to be transitional between *M. bertodano* sp. nov. and *M. seelandica*. This is
12 within the “*Manumiella* complex” from the Calafate Formation of southern Patagonia,
13 Argentina. This specimen would here be designated *Manumiella* sp. because it does
14 not directly satisfy the criteria for either of these two species.

15

16 *Manumiella conorata* (Stover 1973) Bujak and Davies 1983

17 Figure 4 f-i

18 ***Selected synonymy:***

19 *Deflandrea conorata* Stover 1973, p. 171-172, fig. 3C, pl. 1, figs. 8a,b.

20 *Manumiella conorata* (Stover 1973) Bujak and Davies 1983, p. 160.

21 *Manumiella* n. sp. 1, Askin, 1988a, figs. 9.2 (not 9.1).

22

1 **Remarks:**

2 *Manumiella conorata* was described as “lozenge-shaped” with slightly convex
3 and rounded lateral margins of relatively large size (Stover, 1973, p.171).

4 Characteristic features include a short, usually blunt, weakly to moderately developed
5 apical horn and rounded, asymmetrical, “fairly well differentiated” antapical horns.

6 The larger left antapical horn may be more pointed than the smaller right horn. The
7 endocyst occupies the majority of the pericoel, and is circumcavate. Within the
8 uppermost López de Bertodano Formation of Seymour Island, unequivocal *M.*

9 *conorata* was observed in relatively high numbers, at only at 959 m in the composite
10 section. This is 70m stratigraphically below the KT boundary (Table 1, Figure 3).

11 The specimens of *M. conorata* from Seymour Island are smaller than the type material
12 of Stover (1973) (Table 2).

13 One of the two specimens of *Manumiella* n. sp. 1 from the López de Bertodano
14 Formation of Seymour Island illustrated by Askin (1988a, fig. 9.2) is conspecific with
15 *M. conorata*. This is corroborated here using the new taxonomic key. The other
16 specimen of *Manumiella* n. sp. 1 illustrated by Askin (1988a, fig. 9.1) is attributed
17 here to *Manumiella* sp. because it exhibits transitional features between *M. bertodano*
18 sp. nov. and *M. conorata*. Marensi et al. (2004) recorded a ‘*Manumiella* complex’ in
19 the Maastrichtian Calafate Formation of southern Patagonia, Argentina. Some
20 specimens of this plexus compare well with *Manumiella* n. sp. 1 of Askin (1988a).

21 These specimens were not illustrated.

22

23 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983

24 Figure 4 j,k

1 ***Selected synonymy:***

2 *Deflandrea cretacea* Cookson 1956. Lange, 1969, pl. I, figs. 1-5.

3 *Deflandrea cretacea* Cookson 1956. Drugg, 1967, pl. 2, fig. 17 (only).

4 *Deflandrea cretacea* Cookson 1956. Wilson, 1971, pl. 1, fig. 5.

5 *Deflandrea druggii* Stover 1973, p. 171, fig. 3B, pl. 1, figs. 3a, 3b, 4.

6 *Deflandrea cretacea* Cookson 1956. Haskell and Wilson, 1975, pl. 1, fig. 3.

7 *Isabelia druggii* (Stover 1973) Lentin and Williams 1976, p. 58, fig. 121.

8 *Isabelidium druggii* (Stover 1973) Lentin and Williams 1977, p. 167.

9 *Isabelia druggii* (Stover 1973) Lentin and Williams 1976. Wilson, 1978, p. 76-78,
10 figs. 2-5, 13.

11 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983, p. 161, pl. 7, fig. 12.

12 *Isabelidium tingitanense* Rauscher and Doubinger 1982, p. 103-104, pl. 1, figs. 1, 2
13 only, pl. 2, fig. 17.

14 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983. Helby et al., 1987, fig.
15 43A.

16 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983. Firth, 1987, pl. 2, fig. 1
17 (only).

18 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983. Wilson, 1987, pl. 1, fig. 1.

19 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983. Askin, 1988a, fig. 9(7).

1 *Manumiella* sp. cf. *M. druggii* (Stover 1973) Bujak and Davies 1983. Wilson, 1987,
2 pl. 1, fig. 1.

3 *Manumiella* sp. Eshet et al., 1992, pl. II, fig. 4.

4 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983. Roncaglia et al., 1999, fig.
5 16.8.

6 *Manumiella* sp. Marensi et al., 2004, figs. 6a,b.

7 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983. Marensi et al., 2004, figs.
8 6c,d.

9 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983. Habib and Saeedi,
10 2007, pl. 1, figs. 1-3 (only), pl. 2, fig. 3 (only).

11 **Remarks:**

12 Stover (1973) originally described *M. druggii* as broadly elliptical in outline,
13 rarely elongate, with poorly developed antapical horns separated by a shallow
14 concavity. The periphragm may be smooth to finely granulate in texture and exhibits
15 a relatively small archeopyle with an antapically-hinged operculum. The endocyst
16 occupies a major part of the pericoel, is circumcavate, commonly folded and generally
17 circular in outline. The apex may be rounded or bear a short and blunt apical horn. In
18 the López de Bertodano Formation on Seymour Island, *M. druggii* was observed in
19 the 40 m below the KT boundary (Figure 3).

20 Lange (1969, pl. I, figs. 1-5) illustrated five peridinioid specimens that, although
21 described as *Deflandrea cretacea* Cookson 1956 (now *Manumiella? cretacea*
22 (Cookson 1956) Bujak and Davies 1983), are considered to be conspecific with
23 *Manumiella druggii*. Furthermore, the size of the material of Lange (1969) (mean

1 length and width 104 and 74 μm respectively) is consistent with the type material of
2 *M. druggii*. This is 104-122 μm long and 92-103 μm wide (Stover, 1973). Stover
3 (1973) stated that *M. druggii* is distinguished from *D. cretacea* by being circumcavate
4 and twice the size (Wilson, 1978). The overall length and width of *D. cretacea* is 45-
5 65 μm and 43-56 μm respectively (Cookson, 1956). Stover (1973) noted that a
6 specimen of Drugg (1967, pl. 2, fig. 17), identified as *D. cretacea*, is probably
7 conspecific with *M. druggii*. Wilson (1978) discussed the differentiation of
8 *Deflandrea (Manumiella?) cretacea* from *Isabelia (Manumiella) druggii* in detail.
9 The distinction between these two taxa is important because the stratigraphic range of
10 the former is significantly older (mid Santonian to early Maastrichtian) than the latter
11 (Helby et al., 1987).

12 Wilson (1978) also discussed variation in the apical region of *Isabelia*
13 (*Manumiella) druggii*, and separated those with an apical horn ('small tuberculate or
14 conical protuberance to a relatively long, tapered, pointed horn, often capped by a
15 solid papilla') into *Isabelia* (now *Manumiella) seelandica*. This restricted *M. druggii*
16 to specimens with rounded or sub-rounded apices. Wilson (1978) conceded that the
17 two species are 'very closely related' due to their 'virtually identical' dimensions and
18 similar overall shape and morphology apart from the apex. An illustration of
19 *Manumiella* sp. cf. *M. druggii* in Askin (1988a) was compared to the species due to its
20 truncated apex, but this seems an unduly cautious assignment and appears to fit well
21 within the range of variation of this species concept. Eshet et al. (1992, pl. II, fig. 4)
22 illustrated a specimen of *Manumiella* sp. from a KT section at Hor Hahar, Israel,
23 which compares well with the holotype.

24 Marensi et al. (2004, figs. 6c,d) retained *M. druggii* as a separate species to *M.*
25 *seelandica*, and illustrated two relatively granulate specimens from the Maastrichtian

1 Calafate Formation of southern Patagonia. They also illustrated two specimens of
2 *Manumiella* sp. (Marensi et al., 2004, figs. 6a,b); these are assigned to *M. druggii*
3 based on the new taxonomic key above. Marensi et al. (2004, fig. 6a) has a dimpled
4 apex with poorly developed antapical horns. The other specimen (Marensi et al.,
5 2004, fig. 6b) closely resembles *M. druggii*, despite being relatively elongate in
6 outline, with an incipient antapical horn in the form of a slight protrusion. Stover
7 (1973) noted rare elongation in outline in his original description, which may be a
8 result of lateral compression. The *Manumiella* sp. in Marensi et al. (2004, fig. 6b) is
9 slightly folded.

10

11 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983 *emend.* Firth 1987

12 Figure 5, a-c

13

14 ***Selected synonymy:***

15 *Deflandrea cretacea* Cookson 1956. Cookson, 1956, pl. 1, fig. 5.

16 *Broomea seelandica* Lange 1969, p. 113, 114, pl. II, fig. 10, pl. III, fig. 3.

17 *Isabelia seelandica* (Lange 1969) Lentin and Williams 1976, p. 58, fig. 306.

18 *Deflandrea cretacea* Cookson 1956. Koch and Olsson, 1977, text-figs. 3(2,3).

19 *Isabelia seelandica* (Lange 1969) Lentin and Williams 1976. Wilson, 1978, p. 78-80,
20 figs 6-12.

21 *Isabelidinium seelandicum* (Lange 1969) Lentin and Williams 1977, p. 168.

- 1 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983, p. 162.
- 2 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983. Firth, 1987, p. 213-
3 214, pl. 2, figs.2-6 (only).
- 4 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983. Wilson, 1987, pl. 1,
5 fig. 3.
- 6 *Manumiella druggii* (Stover 1973) Bujak and Davies 1983. Eshet et al., 1992, pl. III,
7 fig. 3.
- 8 *Manumiella cf. seelandica* (Lange 1969) Bujak and Davies 1983. Strong et al., 1995,
9 fig. 13(1).
- 10 *Manumiella seelandica* (Lange 1969) Bujak and Davies 1983. Habib and Saeedi,
11 2007, pl. 1, fig. 4 (only), pl. 2, figs. 1,2,4 (only).

12 **Remarks:**

13 Lange (1969) established this species as *Broomea seelandica* and described it as
14 having an oval to rhombic outline, a finely granulate periphragm, and a square to
15 rectangular archaeopyle. The epicyst has a truncated or pointed apical horn and the
16 larger hypocyst a smaller antapical horn. Habib and Saeedi (2007) noted a
17 characteristically ovoid endocyst with a flattened, rounded triangular apex, wider than
18 it is high. In this study *Manumiella seelandica* occurs only in the uppermost López de
19 Bertodano Formation (949-1025 m in the composite section), immediately underlying
20 the KT boundary (Figure 3).

21 Stover (1973) suggested that the specimen with a poorly-developed apical horn
22 and a reduced antapical horn illustrated by Cookson (1956, pl. 1, fig. 5) as *Deflandrea*
23 *cretacea* is *Manumiella druggii*. However, this specimen corresponds more closely

1 with *Manumiella seelandica* using the taxonomic key herein. Furthermore, specimens
2 referred to *Deflandrea cretacea* from the Late Cretaceous of the New Jersey coastal
3 plain (Koch and Olsson, 1977, text-figs. 3[2,3]) are closer to *Manumiella seelandica*
4 (*sensu* Lange) using the key. Similarly, Eshet et al. (1992, pl. III, fig. 3) illustrated a
5 specimen with a distinct, short, distally-pointed antapical horn as *Manumiella druggii*.
6 This specimen appears to be *Manumiella seelandica*. In a study of the Cretaceous-
7 Palaeogene transition of Mead Stream, Marlborough, New Zealand, Strong et al.
8 (1995, fig. 13(1)) recorded both *Manumiella druggii* and *Manumiella seelandica*.
9 These authors illustrated one specimen as *Manumiella cf. seelandica*, which appears
10 to be conspecific with the type material.

11 Due to morphological continuities in the complex of forms between the
12 *Manumiella seelandica* and *Manumiella druggii* species concepts, individual
13 specimens in previous studies have either been identified as one or other of the
14 separate species. An example of this is Wilson (1978) who uses both *Isabelia*
15 *seelandica* and *Isabelia druggii*; others are specimens identified as *Manumiella*
16 *seelandica* that encompassing forms ranging between the two end members of
17 *seelandica*- and *druggii*-types (e.g. Stover, 1973; Fensome and Williams, 2004).

18 Bujak and Davies (1983) retained both *Manumiella seelandica* and *Manumiella*
19 *druggii* within their new genus *Manumiella*, nominating *Manumiella seelandica* as the
20 type species. Askin (1988a, figs. 9.7, 9.9) recognised both species. In the present
21 study, recognition of key morphological distinctions aided by the new taxonomic key
22 are considered sufficient and consistent enough to retain the two separate species.

23 Firth (1987), however, studied the Maastrichtian and Danian of Georgia, U.S.A.
24 and considered the range of variability within *Manumiella seelandica* (*sensu* Wilson,
25 1978) to be greater than that between *Manumiella seelandica* and *Manumiella druggii*

1 and hence considered the former to be a senior synonym of the latter. Firth (1987, pl.
2 2, fig. 1) illustrated a specimen that would be classified herein as *Manumiella druggii*.
3 The other specimens (Firth, 1987, pl. 2, figs. 2-6) are referable to *Manumiella*
4 *seelandica*. Soncini and Rauscher (1990), Fensome and Williams (2004) and Habib
5 and Saeedi (2007) also considered *Manumiella seelandica* to be a taxonomic senior
6 synonym of *Manumiella druggii*. The “*Manumiella seelandica* morphotype” of Habib
7 and Saeedi (2007, pl. I, fig. 4; pl. II, figs. 1,2,4) was considered to be variation within
8 the concept of *Manumiella seelandica* by these authors.

9

10 *Manumiella seymourensis* Askin 1999

11 Figure 5 d-j

12

13 **Full synonymy:**

14 Gen. et sp. indet. 1 Palamarczuk et al., 1984, pl 1, fig. 2.

15 *Manumiella* n. sp. 3 Askin, 1988a, figs. 8.4-8.6.

16 *Manumiella* n. sp. 3 of Askin, 1988a. Pirrie et al., 1991, figs. 7c-e.

17 *Manumiella* n. sp. 3 of Askin, 1988a. Riding et al., 1992, pl. 2, fig. 9.

18 *Manumiella* n. sp. 3 of Askin, 1988a. Smith, 1992, fig.7k.

19 *Manumiella* n. sp. 3 of Askin, 1988a. Barnes and Riding, 1994, figs 4C, 4F.

20 *Manumiella* cf. *druggii* (Stover 1973) Bujak and Davies 1983. Pirrie et al., 1997, figs.

21 10c,d,f.

1 *Manumiella seymourensis* Askin 1999, p. 373-377, figs. 2.1-2.9, 3.1-3.9.

2 *Manumiella* n. sp. 3 of Askin, 1988a. Roncaglia et al., 1999, fig. 13.8.

3 *Manumiella seymourensis* Askin 1999. Roncaglia, 2000, fig. 5I.

4 **Remarks:**

5 The characteristic feature of *M. seymourensis* is the thin, virtually invisible
6 endocyst. It has a relatively large intercalary periarcheopyle, commonly with the
7 operculum still attached, and is typically ovoid in outline. The pericyst wall is smooth
8 and relatively thick. On Seymour Island *M. seymourensis* is present in the lower part
9 of the uppermost López de Bertodano Formation and the range top is above 870 m in
10 the composite section (approximately 200 m below the KT boundary, Figure 3). Rare
11 and somewhat torn specimens, which are probably reworked, occur up to 931 m.

12 The apical and antapical areas of *M. seymourensis* typically lack horns. These
13 morphotypes are either truncated or rounded, often with dimples; for example, Smith
14 (1992, fig. 7k) and Roncaglia (2000, fig. 5I, p. 141). Other forms exhibit single,
15 prominent polar horns (Askin, 1988a, figs. 8.5, 8.6; 1999, figs. 3.1-3.4). In this study,
16 horned specimens are rare compared to hornless forms, with no apparent stratigraphic
17 pattern within the López de Bertodano Formation in the occurrence of these
18 morphotypes. The relative rarity of the horned end-members, the overall similarity of
19 the remainder of the pericyst, and the lack of any apparent stratigraphic significance
20 to horn development suggest that all these variations should not given subspecific
21 status, and hence are all retained within the specific diagnosis.

22

23 **6. Discussion**

1

2 *Biostratigraphical significance*

3 The species of *Manumiella* from Seymour Island are useful biostratigraphic
4 markers due to their abundance and diversity within the late Maastrichtian López de
5 Bertodano Formation. Using the preliminary biozonation scheme of Askin (1988a),
6 the interval of approximately 280m up to the KT boundary can be divided into Zones
7 2 to 4, passing into Zone 5 in the earliest Palaeocene sediments (Figure 3).

8 *Manumiella seymourensis* is present in the lower part of the composite section up
9 to around 870 m, with occasional reworked specimens present up to approximately
10 930 m. Zone 2 of Askin (1988a) is characterised by abundant *Manumiella*
11 *seymourensis*, with occasional reworked specimens appearing in Zone 3. This places
12 the Zone 2/Zone 3 boundary in the current section at 870 m (Figure 3). *Manumiella*
13 *bertodano* sp. nov. is present from 834 m in the composite section, defining the lower
14 boundary of the upper subzone of Zone 2. The upper limit of *M. bertodano* sp. nov. at
15 969 m, in addition to the first appearance of *M. druggii* at 989 m, defines the Zone
16 3/Zone 4 boundary at approximately 979 m. Askin (1988a) however, attributed a
17 longer range to *M. bertodano* sp. nov. to the top of her Zone 4 (i.e. the KT boundary)
18 than was observed in this study. Askin (1988a, b) considered *M. druggii* to be an
19 important marker species of her Zone 4 from Seymour Island, and noted its
20 occurrence in other latest Maastrichtian sequences (e.g. Drugg, 1967; Hultberg, 1986).
21 *Manumiella conorata* and *M. seelandica* occur above 959 m, coincident with
22 abundance peaks of *M. bertodano* sp. nov., *M. spp.* and the closely-related
23 *Isabelidinium* spp. This acme is probably related to environmental change.

24 The species of *Manumiella* discussed herein are regarded as reliable
25 biostratigraphic markers for the late Maastrichtian of the Southern Hemisphere (e.g.

1 Yepes, 2001; Olivero et al., 2002). The “*Isabelidinium*” *druggii* Zone of latest
2 Haumurian-earliest Teurian age (late Maastrichtian-early Danian) is defined in New
3 Zealand by the ranges of *M. druggii* and *M. seelandica* (Wilson, 1978, 1984). Helby
4 et al. (1987) used the ranges of *M. conorata*, *M. druggii* and *M. seelandica* to define a
5 late Maastrichtian to earliest Danian *Manumiella druggii* Interval Zone in Australia.
6 Furthermore, Askin (1988b) noted that the *M. druggii*-*M. seelandica* complex are
7 present approximately 10 m into the Palaeocene in her Seymour Island section,
8 although they disappear at the KT boundary in this study.

9 Mao and Mohr (1992) and Mohr and Mao (1997) extend the range of *Manumiella*
10 taxa into the early and mid Maastrichtian. Mohr and Mao (1997) recorded
11 *M. bertodano* sp. nov. (as *Manumiella* sp. 2 of Askin, 1988a) from the early
12 Maastrichtian at ODP Site 690, Maud Rise in the Weddell Sea area off the east
13 Antarctic coast, and from ODP Site 748 on the Kerguelen Plateau. Mohr and Mao
14 (1997, fig. 7) suggested the range for this taxon is from latest Campanian to the KT
15 boundary (Text-fig. 7), and then inconsistently state in the text (p. 52) that the last
16 appearance datum of *M. sp. 2* may be located near the Campanian/Maastrichtian
17 boundary. The specimen of *M. bertodano* sp. nov. illustrated by these authors is a
18 mis-identification (see above). *Manumiella* sp. 2 (Askin, 1988a) of Mohr and Mao
19 (1997, pl. 1, fig. 7) is clearly a specimen of *Isabelidinium*.

20

21 ***Palaeoecology***

22 The peridinioid genus *Manumiella* spp. and related forms are considered to be
23 typical of relatively near-shore, inner-shelf marine environments (e.g. Askin, 1988a;
24 Askin and Jacobson, 1996; Habib and Saeedi, 2007). Morphological development
25 within *Manumiella* may reflect cyst evolution in response to varying water depths.

1 For example, Askin (1988a) related an increase in horn development in *M.*
2 *seymourensis* to palaeoenvironmental change such as a basinal deepening then
3 shallowing during the latest Maastrichtian on Seymour Island, in conjunction with the
4 simultaneous appearance of *M. bertodano* sp. nov. Furthermore, within the López de
5 Bertodano Formation on Seymour Island, Askin (1999) noted that *M. seymourensis*
6 occurs with a great abundance of the small, acanthomorph acritarch genus
7 *Micrhystridium* spp., which has been interpreted as representing near-shore
8 environments, perhaps inner neritic, but still open water, transgressive facies (Wall,
9 1965; Downie et al., 1971; Firth, 1987).

10 In this study, the ranges of *M. seymourensis* and *Micrhystridium* spp. do not
11 coincide. This suggests slightly different environmental preferences and a potentially
12 significant change in the depositional environment of the basin at 831 m where
13 *Micrhystridium* spp. abundance decreases markedly (Figure 3). Significantly, there is
14 an abrupt peak of *Manumiella* and *Isabelidinium* spp. at 959 m in the composite
15 section, ~70m below the KT boundary, and a similar one at 1015 m, around 15m
16 below the KT. The reason for acmes at these horizons is unclear (there are no
17 significant features in the sedimentology) but it is likely that an abrupt marine
18 palaeoecological change, perhaps indicating short-term sea-level change prior to the
19 KT, favoured the habitat preferences of this particular group and reflect a change in
20 nutrient availability, water temperature or chemistry.

21 Others have noted the phenomenon of *Manumiella* ‘spikes’ immediately prior to
22 the KT. For example, Habib and Saedi (2007) reported a *Manumiella seelandica*
23 spike, interpreted as representing a mild cooling and regression in the New Jersey
24 section immediately prior to the KT catastrophe. A *Manumiella* spp. spike (mostly
25 *Manumiella seelandica*) has also been recognised elsewhere, both in the Northern and

1 Southern Hemispheres (e.g. Drugg, 1967; Firth, 1987; Eshet et al., 1992; Moshkovitz
2 and Habib, 1993; Nøhr-Hansen and Dam, 1997; Oboh-Ikuenobe et al., 1998;
3 Palamarczuk, 2004; Przemyslaw, 2004). Askin (1988b) and Elliot et al. (1994) also
4 reported similar acmes as part of KT boundary studies on Seymour Island. This spike
5 of abundance suggests that conditions in the latest Cretaceous shelf seas were already
6 changing significantly prior to the KT environment change.

7 Evidence is accumulating for significant global eustatic sea level changes during
8 the latest Cretaceous based on multi-proxy analyses of both outcrop and drill-core
9 sequences. Barrera and Savin (1999) noted an episode of high positive benthic
10 foraminiferal $\delta^{18}\text{O}$ values between 67.5 and 65.4 Ma from southern high-latitude
11 Ocean Drilling Program Sites 689-690 (South Atlantic), which correlated with a
12 significant regression in the Haq et al. (1987) eustatic sea-level curve. Further, Li et
13 al. (2000) reported several sea-level fluctuations in a Campanian to Palaeocene
14 sequence in Tunisia, four of which are recognised globally, suggesting a eustatic
15 signature, (including a short-term regression during the latest Maastrichtian, 65.45-
16 65.3 Ma). Significant and rapid sea level changes during the Late Cretaceous have
17 also been reconstructed from the Russian platform and New Jersey passive margin
18 using backstripping techniques on sedimentary sequences (Sahagian et al., 1996;
19 Miller et al., 2005). The New Jersey record contains large (>25m) and rapid (<1 myr)
20 eustatic sea-level drops, paced by Milankovitch orbital cyclicities (Miller et al., 2003,
21 2005; Kominz et al., 2003; Van Sickle et al., 2004). Miller et al. (2005) infer a
22 glacioeustatic origin for these sea-level changes because of their global occurrence
23 and the rapidity and magnitude of change, which is interesting due to their occurrence
24 during the Cretaceous global 'greenhouse' climate. The *Manumiella* and

1 *Isabelidinium* spikes of abundance from Seymour Island may correlate with these
2 periods of global regression but requires further work and precise dating.

3

4 **7. Conclusions**

5 New work on the late Maastrichtian species of *Manumiella* from the James Ross
6 Basin has highlighted the biostratigraphical and palaeoecological significance of this
7 group, both in this basin and worldwide, in particular with reference to changes
8 associated with the KT boundary. Observations on hundreds of specimens throughout
9 a thick section of the latest Maastrichtian López de Bertodano Formation on Seymour
10 Island have allowed clearer definitions of five taxa to allow consistency in analytical
11 recording. As a result, *Manumiella* has been emended to include the presence of a
12 mesophragm, and *M. bertodano* sp. nov. has been formally described. A new
13 taxonomic key has been erected to aid identification of five *Manumiella* taxa (*M.*
14 *bertodano* sp. nov., *M. conorata*, *M. druggii*, *M. seelandica* and *M. seymourensis*).
15 The success of the key has been illustrated by a quantitative palynological study from
16 the sediments of the López de Bertodano Formation, indicating how *Manumiella* is
17 key to subdividing the sequence into biozones based on the scheme of Askin (1988a).

18 The peridinioid genus *Manumiella* spp. may be typical of relatively near-shore,
19 inner-shelf marine environments with morphological evolution of the cyst responding
20 to changing water depths. Peaks in abundance of *Manumiella* (and closely related
21 *Isabelidinium*) noted from Seymour Island may indicate short-term regressions and/or
22 ocean cooling prior to the KT. Similar ‘spikes’ in abundance of *Manumiella*
23 associated with the KT boundary elsewhere in the world have also been related to
24 mild cooling and regression. This work contributes to increasing evidence of

1 significant sea level change during the Maastrichtian, possibly related to glacioeustasy
2 during cooling climates after the mid-Cretaceous greenhouse.

3

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1 **Figure captions**

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3 Figure 1 Locality maps of the area studied and measured sections. a, location of
4 Seymour Island, James Ross Basin, Antarctic Peninsula. b, photograph of the López
5 de Bertodano Formation exposed on Seymour Island, looking south-eastwards
6 towards the Weddell Sea. c, enlarged map of the southern end of Seymour Island to
7 show the geology (including the Cretaceous/Tertiary boundary) and the location of
8 measured sections.

9 Figure 2 Lithostratigraphy and summary sedimentary log of the measured
10 sections (D5.2**) for the López de Bertodano Formation on Seymour Island. Grain
11 size abbreviations: cl, clay; si, silt; fs, fine sand; ms, medium sand. KT,
12 Cretaceous/Tertiary boundary. Stratigraphic height relates to the entire composite
13 section referred to in the text. Sample levels are marked alongside the log and listed
14 in detail in Table 1.

15 Figure 3 Abundance of *Manumiella*, *Isabelidium* and *Micrhystridium* per gram
16 of sediment throughout the López de Bertodano Formation on Seymour Island.
17 Legend and comments for the sedimentary log are the same as for Figure 2. KT,
18 Cretaceous/Tertiary boundary. The biozonation is interpreted from the scheme of
19 Askin (1988a). The graph includes the stratigraphic levels of horned *Manumiella*
20 *seymourensis* specimens (the remainder being hornless), and the holotype of
21 *Manumiella bertodano* sp. nov.

22 Figure 4 Dinoflagellate cysts from the López de Bertodano Formation on
23 Seymour Island. *Manumiella bertodano* sp. nov.: a, D5.1160.1A, G47-3; b,

1 D5.1184.1A, D40-2; c, D5.1237.1A, L40-4 (holotype); d, transitional form with
2 *Manumiella conorata* (Stover 1973) Bujak and Davies 1983 D5.1237.1A, F67-3; e,
3 transitional form with *Manumiella seelandica* (Lange 1969) Bujak and Davies *emend.*
4 Firth 1987 D5.1225.1A, Q44-2. *Manumiella conorata* (Stover 1973) Bujak and
5 Davies 1983: f, D5.1237.1A (slide number), D42-4 (England Finder co-ordinates); g,
6 D5.1237.1A, F58-3; h, D5.1237.1A, F56-2; i, D5.1237.1A, F49-1. *Manumiella*
7 *druggii* (Stover 1973) Bujak and Davies 1983: j, D5.1253.1A, F43-2; k, D5.1253.1A,
8 T42-2. HF, high focus; LF, low focus. Arrows indicate mesophragm. The unique
9 British Antarctic Survey collection numbers are in the format D5.***.1 for bulk
10 sediment samples, with the suffix A (e.g. D5.1247.1A) referring to microscope slide
11 A prepared from the organic residue.

12 Figure 5 Dinoflagellate cysts from the López de Bertodano Formation on
13 Seymour Island. *Manumiella seelandica* (Lange 1969) Bujak and Davies *emend.* Firth
14 1987: a, D5.1237.1A, T41-4; b, D5.1242.1A, N53-3; c, D5.1237.1A, F48-0.
15 *Manumiella seymourensis* Askin 1999: d, D5.1155.1A, H72-2; e, D5.1168.1A, M62-
16 4; f, D5.1142.1A, K54-3; g, D5.1121.1A, O63-1; h, D5.1142.1A, L70-3; i,
17 D5.1142.1A, K67-4; j, D5.1220.1A, V63-4. HF, high focus; MF, mid focus; LF, low
18 focus. Arrow indicates mesophragm. The unique British Antarctic Survey collection
19 numbers are in the format D5.***.1 for bulk sediment samples, with the suffix A (e.g.
20 D5.1247.1A) referring to microscope slide A prepared from the organic residue.

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1 **Table captions**

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3 Table 1 *Manumiella*, *Isabelidinium* and *Micrhystridium* per gram of sediment
4 from the López de Bertodano Formation, Seymour Island, Antarctica.

5 Table 2 Specimen dimensions of five *Manumiella* species measured during this
6 study. Measurements of specimens from the original published descriptions or
7 illustrations of each species are included in square brackets. Presented as: minimum
8 (average) maximum, sd = standard deviation. ^a Stover (1973); ^b Lange (1969); ^c
9 Askin (1999); ^d Askin (1988a), measured directly from illustrated specimen in Fig.
10 9(4).

11 Table 3 Characteristics of five *Manumiella* species from the original published
12 descriptions, with additional comments from other authors (^{e, f, g}). ^a Stover (1973); ^b
13 Lange (1969); ^c Askin (1999); ^d this paper; ^e Habib and Saeedi (2007); ^f Soncini and
14 Rauscher, 1990. The outline and endocyst are described from the dorso-ventral view.
15 All are circumcavate with an intercalary archeopyle.

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