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Comment on ‘*Wetzeliiella* and its allies – the ‘hole’ story: a taxonomic revision of the Paleogene dinoflagellate subfamily Wetzeliielloideae’ by Williams et al. (2015)

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ABSTRACT

The taxonomic revision of the dinoflagellate cyst subfamily Wetzeliielloideae by Williams et al. (2015) places primary emphasis on the type of archaeopyle, and secondarily on wall ornamentation. Williams et al. (2015) argues that this provides more clarity for taxonomic differentiation within the subfamily of Wetzeliielloideae, and adds to the stratigraphical significance of species within. We find, however, that their proposed revision (1) introduces taxonomic criteria that divert drastically from these in other dinoflagellate cyst subfamilies, (2) unnecessarily erects and emends many new genera and species, and (3) poses serious practical limitations, which together (4) lead to profound reduction of the stratigraphical applicability of many marker species. In this contribution, we substantiate our concerns regarding the approach and criteria used by Williams et al. (2015). We propose to retain the generic definitions of Wetzeliielloideae that existed prior to the revisions by Williams et al. (2015), until a revision supported by the community is available.

KEYWORDS

Comment; taxonomic revision; dinoflagellate cyst; Wetzeliielloideae; stratigraphy

1. Introduction

Williams et al. (2015) have proposed a taxonomic revision of the dinoflagellate cyst subfamily Wetzeliielloideae. In their view the ‘generic definitions within the subfamily of Wetzeliielloideae have been blurred, and too much focused on wall ornament and horn development’ (Williams et al. 2015, p. 290). These authors further argue that the blurred generic definitions have ‘limited the utility of Wetzeliielloideae as biostratigraphic marker’. As an example the authors refer to *Wetzeliiella articulata*, a species that has a remarkably long stratigraphical range of 32 million years, from the Paleocene to the Oligocene. In fact, they assume that the criteria used in this species concept are not satisfactorily distinctive to cover (apparent) morphological variability. Therefore, they have introduced novel concepts for the taxonomy at the generic level for the Wetzeliielloideae, placing primary emphasis on the type of archaeopyle, and secondarily on wall ornamentation. Williams et al. (2015) argued that the emphasis placed on the archaeopyle type provides much more clarity for taxonomic differentiation within the subfamily Wetzeliielloideae.

Williams et al. (2015) defined five different types of the 2a intercalary archaeopyle (equipepeliiform, hyperepeliiform, latiepepeliiform, soleiform and hypersoleiform). Further, these authors defined five different types of wall ornamentation, which they applied as a secondary criterion at the generic level. The

authors reviewed all species in the subfamily in terms of archaeopyle type and wall ornamentation, resulting in a matrix. Their review requires the formal description of no less than 13 new genera, emendation of the diagnosis of three existing genera, and the formal description of three new species. They concluded that the soleiform archaeopyle is a consistent feature in the younger stratigraphical range (i.e. Bartonian and younger) of the Wetzeliielloideae, while the epeliiform archaeopyles in this subfamily occur in the older stratigraphical record (Selandian–Bartonian).

We agree with Williams et al. (2015) that a thorough review of the taxonomic concepts and definitions for Wetzeliielloideae would benefit the scientific community, and we greatly appreciate the efforts made in this direction. In theory, the approach taken by Williams et al. (2015) could result in a solid, consistent taxonomic framework, since it is based on clear generic criteria. We also agree that some variability in archaeopyle type and level of detachment exists within the subfamily of Wetzeliielloideae. After careful consideration, however, we find that their proposed revision (1) introduces taxonomic criteria that divert drastically from well-established conventions, (2) unnecessarily erects and emends many new genera and species, and (3) poses serious analytical and practical limitations, which together (4) lead to a profound reduction of the stratigraphical applicability of marker species, while not introducing any new stratigraphical markers in replacement. In this contribution, we

substantiate our concerns regarding the approach and criteria used by Williams et al. (2015) and, based on these concerns, propose to retain the original generic definitions of Wetzelielloideae.

2. Problems resulting from the new classification

Although in theory the taxonomic revision proposed by Williams et al. (2015) provides a clear and consistent set of definitions, we have identified several critical issues in its application that can essentially be narrowed down to four main issues.

2.1. Pragmatism versus hypothesised evolutionary lineages

Extinct dinoflagellate cyst species cannot be directly linked to the affiliated biological species – even extant motile/cyst relationships are not established fully (e.g. Head 1996). Therefore, any taxonomic framework for extinct dinoflagellate cysts must rely on clearly visible, distinguishable morphological characteristics. For this reason, dinoflagellate cyst families are typically separated based on plate tabulation patterns following the system of Fensome et al. (1993). Taxonomic definitions at the generic level are made predominantly based on specific morphological and geometric features (such as cyst outline, cavation, number of wall layers, process outline and distribution, plate and/or sutural ornamentation, etc.), with the archaeopyle type being a consequence of geometry. Williams et al. (2015) broke with this convention because they specifically consider archaeopyle type to be an indicator of phylogeny. Specifically, Williams et al. (2015) applied the basic assumption that the archaeopyle type directly reflects the shape of the plate(s) involved in archaeopyle formation, which is not necessarily the case for all dinoflagellate cyst species (e.g. Harland 1982). Because sutures are not always discernible for Wetzelielloideae, this cannot be proven for many Wetzelielloideae specimens. Therefore, we are sceptical about the validity of this fundamental assumption underlying the taxonomic revisions of Wetzelielloideae. We have concerns that the drastic revisions of the primary criteria for taxonomic classification as proposed by Williams et al. (2015) do not reflect phylogenetic significance. Regardless of our concerns, the revision of taxonomic concepts to accommodate just one subfamily seems an illogical step if the taxonomic concepts applied towards the other dinoflagellate cyst groups remain the same.

2.2. Morphological differences between species should be more prominent than morphological variability within species

The validity of the proposed taxonomic definitions in the subdivision of Wetzelielloideae does not allow for plasticity in archaeopyle type within otherwise morphologically similar dinoflagellate cysts. This leads to taxonomic separation of – apart from the type of archaeopyle – morphologically indistinguishable species (Plate 1). However, many other dinoflagellate cyst taxa are characterised by variability in archaeopyle type, and the level of detachment of the operculum is permitted

within a genus, and even within species definitions. For instance, *Dissilodinium* and *Durotrigia* (Bailey 1987; Feist-Burkhardt et al. 2001) have a variable archaeopyle consisting of one to five precingular plates; *Lingulodinium machaerophorum* (Wall 1967) and *Diphyes* (Goodman & Witmer 1985) have either a 3' precingular or a tA apical archaeopyle; *Florentinia* (e.g. Sluijs & Brinkhuis 2009) varies its archaeopyle involving from tA to tA3P; *Schematophora* (Bijl et al. 2013b) has various levels of detachment of the apical series; species of *Spinidinium* and *Vozzhennikovia* (Sluijs et al. 2009) involve either one (2A) or all three anterior intercalary plates in the archaeopyle; and *Phthanoperidinium* (Islam 1982) varies its archaeopyle by occasionally including the 4'' plate to the otherwise 2A archaeopyle. Notably, many *Protoperidinium* species (e.g. Harland 1982) vary in outline and type of the 2A archaeopyle. For these genera, taxonomic concepts at genus and species levels are not primarily set on archaeopyle type but, rather, on wall morphology, ornamentation and process distribution. We indeed observe variability in the type of archaeopyle in many Wetzelielloideae, even within the same samples, for example in specimens of *Apectodinium* in the original description (see examples in Plate 1). Scanning electron microscope images of a specimen of *Apectodinium hyperacanthum* (Bijl et al., 2013b, plate VII, figure n) show a clear angular, rectangular archaeopyle but with an adnate anterior end. These two characteristics together are not compatible with the proposed taxonomic concept of Williams et al. (2015) for *Apectodinium hyperacanthum*, which should have a detached operculum. If we followed the taxonomic concepts proposed, we should erect a new genus and new species for the specimen illustrated by Bijl et al. (2013). However, based on wall ornament, this specimen is clearly a species of *Apectodinium* in its original taxonomic concept. The proposed taxonomic revision of Williams et al. (2015) would place the specimens exhibiting adnate soleiform archaeopyles within *Wetzeliella*, while based on all the other morphological features, they have close affinities to *Apectodinium*, which it restricts to equiepiliform archaeopyles. In our view, the adnate soleiform versus free epiliform archaeopyles both occur within a complex of Wetzelielloideae that are similar in many more morphological characteristics than they differ, which is why in the original concept all of these were grouped into *Apectodinium*.

The original taxonomic concept of Wetzelielloideae is very practical for most of the species. Applying the new taxonomic concept to the latter leads to many discussions, confusion, and unnecessary and unwanted taxonomic splitting. Taxonomic uncertainty in the original concepts of Wetzelielloideae occurs predominantly at the species level and only very rarely at the generic level. For instance, in many cases (sub-optimal preservation, overload of amorphous organic matter, clumping, over-oxidation), the – in our view – subtle differences in outline and ornament between *Charlesdowniea columna* and *Charlesdowniea coleothrypta* make it difficult to separate them from one another in the original taxonomic framework. However, Williams et al. (2015) considered these two species to be within two different genera, as they have noted slight differences in archaeopyle type. This proposed taxonomic revision does not at all alleviate the difficulty in deciding to which of the two species a specimen belongs. In fact it complicates the situation

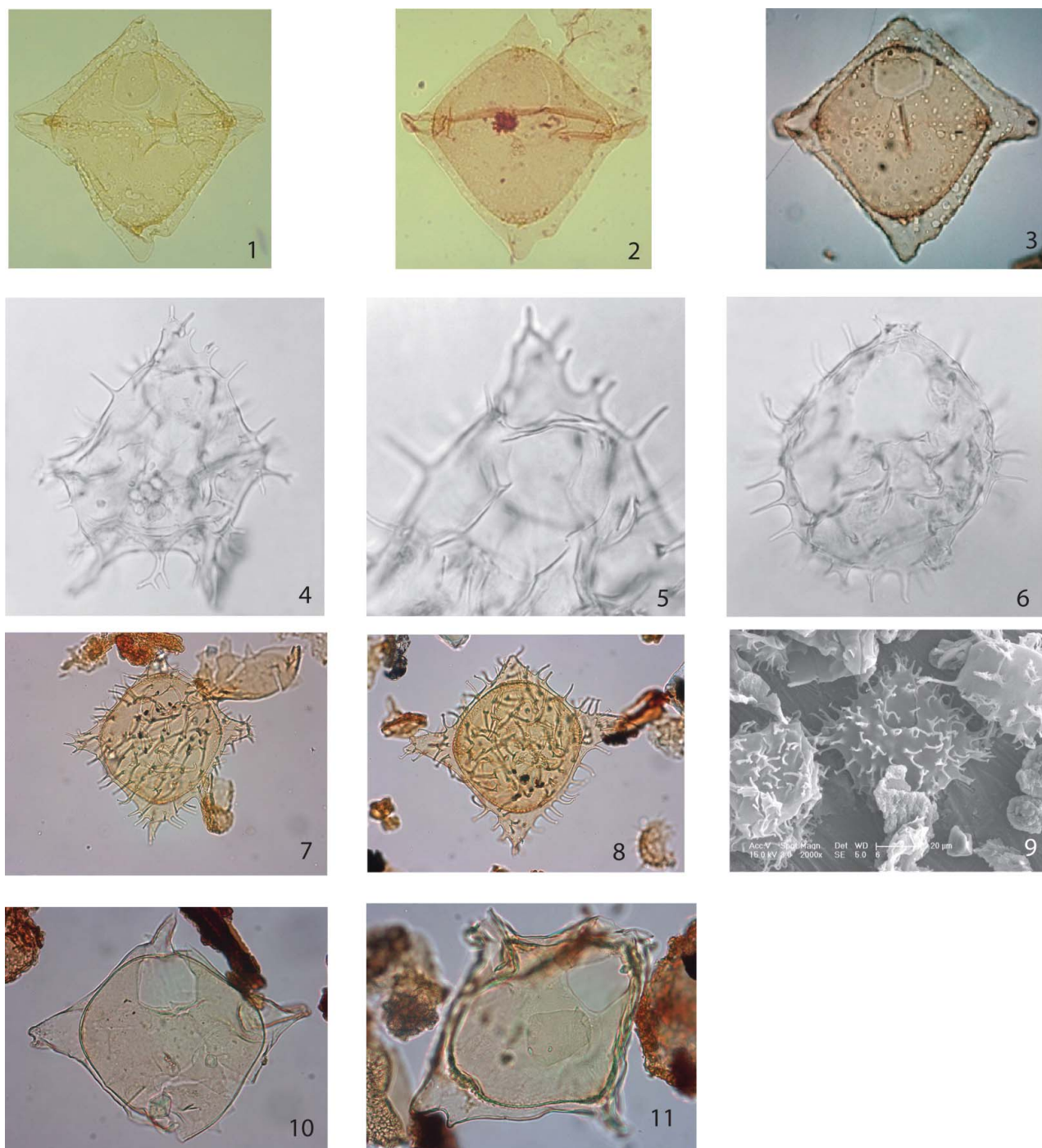


Plate 1. Examples of Wetzelielloideae specimens that show similar morphology but slight variability in archaeopyle type. Specimens herein are classified based on the taxonomic concepts prior to the contribution by Williams et al. (2015). 1–3. *Rhombodinium porosum* specimens published previously in Williams et al. (2004) showing variability in archaeopyle type from hypersoleiform to ?epeliform. In our view, the strikingly similar morphological features of these specimens indicate these species should be placed within one genus. According to the taxonomic concepts of Williams et al. (2015), the specimens should be placed in at least two different genera. 4–6. *Apectodinium* specimens showing an archaeopyle, which involves also the 4' precingular plate (previously published in Crouch et al. 2003). If involvement of the 4' plate in the archaeopyle formation is not allowed within *Apectodinium*, a new genus must be erected for these specimens. 7, 8. *Wetzeliella symmetrica* specimens from the Oligocene of the North Sea showing a soleiform archaeopyle (7) and a (slightly?) hypersoleiform archaeopyle (8). To us, the morphological features indicate these species should be placed in one species, and not in different genera which would be the case if the taxonomic concepts of Williams et al. (2015) were to be followed strictly. 9. Scanning electron microscope image of a specimen of *Apectodinium* with an angular archaeopyle with clear posterior attached archaeopyle. The specimen is from Paleocene–Eocene boundary sediments from Ocean Drilling Program Site 1172, and has previously been illustrated in Bijl et al. (2013). 10, 11. *Rhombodinium draco* from the mid-Oligocene of the North Sea Basin. 10. At first sight this specimen has a hyperrepeliform archaeopyle; hence, it should be considered a (new?) species of *Rhadinodinium* according to Williams et al. (2015). However, the anterior margin of the archaeopyle shows clear signs of rupture of the (likely) once-soleiform archaeopyle. When it becomes questionable whether an operculum is secondarily ruptured or primarily attached/detached, identification at the genus level becomes impossible if too much emphasis is given to the archaeopyle type for classification. However, this specimen clearly belongs to *Rhombodinium draco* if we allow for some plasticity in archaeopyle type.

because, in the new taxonomic concept, the generic classification is compromised if the archaeopyle type is not clearly discernible. We argue that because the two species share so many morphological features, it is most practical to at least retain these species in the same genus. Williams et al. (2015) broke with this basic principle of hierarchy in morphological variation for the Wetzelielloideae, which is a profound concern for the field of dinoflagellate cyst palaeontology.

2.3. Applicability of archaeopyle type as a primary generic criterion

Central to the taxonomic definitions proposed by Williams et al. (2015) is the type of archaeopyle. In practice, however, this particular morphological feature is not easily assessed using transmitted light microscopy, particularly in Wetzelielloideae. This is because the archaeopyle can be poorly visible in many specimens for numerous factors including poor contrast between the archaeopyle and the translucent wall; specimens are often sub-ideally oriented on the microscope slide, lack parasutural/penitabular ornamentation, and in some instances bear numerous processes that may obscure the visibility of the archaeopyle (e.g. Sluijs & Brinkhuis 2009 plate 1, figures I, J; Bijl et al. 2013, plate I, figures e, j). Finally, some specimens (may) have partially adnate opercula (see examples in Plate 2), to say nothing of specimens that have not hatched.

The orientation of the cyst relative to the plane of view poses a serious limitation on the practicality of the proposed taxonomic criteria underlying the revision. In the paper by Williams et al. (2015), this problem was illustrated in figures 15 and 16 of plate 1, and figures 15 and 16 of plate 2. Two seemingly similar specimens with identical cyst outline and wall ornament were illustrated. However, Williams et al. (2015) placed these two specimens into two different genera because they deduced a difference in archaeopyle type. According to Williams et al. (2015) the specimen illustrated in plate 1 has an equiepiliform archaeopyle, and, according to their scheme, is to be placed in *Sophismatia*, while the specimen illustrated in plate 2 exhibits a hyperepiliform archaeopyle and is therefore to be assigned to another genus, i.e. *Sagenodinium*. However, the specimen in plate 1 is oriented in oblique polar view, while the specimen in plate 2 is photographed in equatorial view. The oblique polar view results in an underestimation of the height of the archaeopyle relative to its width, giving the impression of an equiepiliform archaeopyle. This example also supports the inference that two cysts that are as similar as these two specimens should be assigned to the same species, or at least the same genus, based on outline and ornamentation, even if the archaeopyles differ slightly (see Section 2.2).

The practical application of taxonomic concepts should be reconsidered when generic assignment is easily influenced by analytical issues, such as the angle of view. Even more crucially, taxa with identical cyst outline and wall ornamentation, such as the above examples, cannot be classified to the genus level if the archaeopyle type cannot be determined, which is often the case in Wetzelielloideae. Our example given here clearly points to the ambiguity induced by the taxonomic concepts proposed.

We therefore find that the proposed revision leads to unnecessary speciation of dinoflagellate cyst taxa that are highly similar (if not identical) in cyst outline and wall ornamentation, but only vary slightly, if at all (see examples above), in archaeopyle type. We now observe very chaotic, inconsistent genus and species concepts, in which cysts with the same wall features are placed in different genera just because of a slight, often non-diagnostic difference in archaeopyle type.

2.4. Applicability of the proposed taxonomic framework to existing stratigraphically important species

Williams et al. (2015) argued that some species within *Wetzeliella* (notably *W. articulata*) have a generic species definition and as such have a long stratigraphical range. The proposed revision aims to add more stratigraphical importance to such long-ranging species. Interestingly, even after the proposed taxonomic revision, *Wetzeliella articulata* remains a species with a rather broad taxonomic description and a long stratigraphical range. There are, however, numerous examples where species within the Wetzelielloideae, well defined within the original taxonomic framework, represent clear, unambiguous stratigraphical markers, such as; *Apectodinium augustum* at the Paleocene–Eocene Thermal Maximum (e.g. Sluijs et al. 2007); *Charlesdownia edwardsii*, *Dracodinium waipawaense* and *Wetzeliella samlandica* in the early Eocene (Hollis et al. 2009; Hollis et al. 2012; Bijl et al. 2013a, b; Dallanave et al. 2016); *Dracodinium rhomboidum*, *Dracodinium pachydermum* and *Charlesdownia columna* in the middle Eocene (Eldrett et al. 2004; Eldrett & Harding 2009; Firth et al. 2013); and *Wetzeliella gochtii* and *Rhombodinium perforatum* in the Oligocene (e.g. Pross 2001; Fensome et al. 2008; Pross et al. 2010; Sliwinska et al. 2012; Egger et al. in press). Williams et al. (2004) published a cornerstone stratigraphical article in which many wetzelielloid dinoflagellate cyst species are listed as good biostratigraphical markers including *Charlesdownia columna*, *C. crassiramosa*, *C. edwardsii*, *Dracodinium condylos*, *D. politum*, *D. varielongitudum*, *D. waipawaense*, *Rhombodinium draco*, *R. perforatum*, *R. porosum*, *Wetzeliella gochtii*, *W. meckelfeldensis* and *Wilsonidium echinosuturatum*. If we accept the proposed taxonomic revisions, the stratigraphical ranges of many of these species may need to be seriously reconsidered and, in the worst case, may become practically useless if we do not allow for some plasticity in archaeopyle type. The stratigraphical ranges of species with a stable archaeopyle type and morphology will in theory remain unaffected by the taxonomic revision. However, we cannot be certain that these species really have stable archaeopyle types, as this has never been the primary criterion to distinguish genera or species. Therefore, it would require a thorough revisiting of the stratigraphical records where species were initially stratigraphically calibrated to verify whether, according to the taxonomic concepts of Williams et al. (2015), the stratigraphical calibration of the species is still correct, or whether the species which were initially grouped together now need to be separated based on a different archaeopyle type. Contrary to Williams et al. (2015), we thus see no improvement in the stratigraphical applicability of Wetzelielloideae in the revised taxonomic concepts.

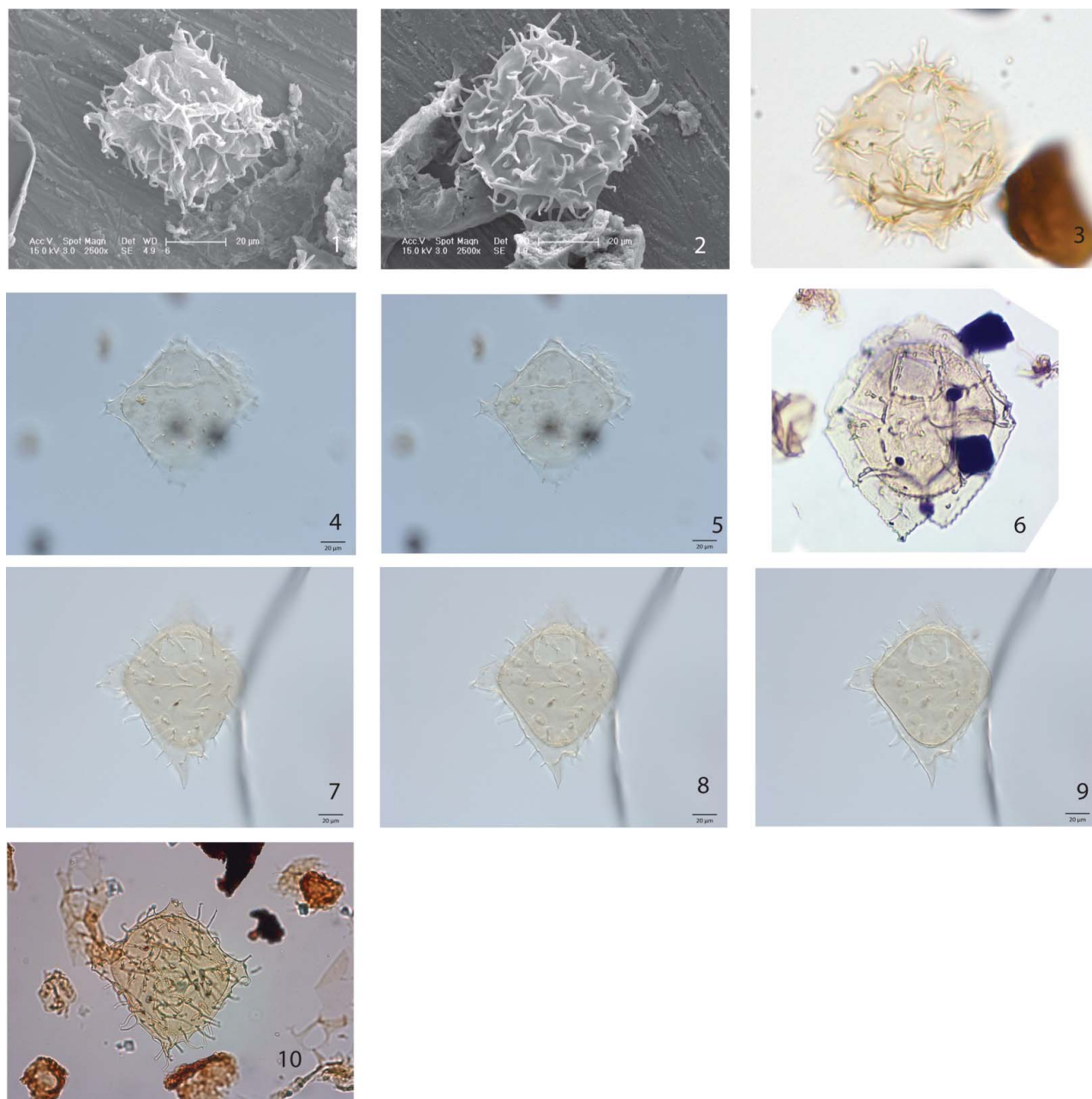


Plate 2. Examples of specimens that do not clearly show an archaeopyle type, and, therefore, are impossible to classify at the genus level using the proposed taxonomic concepts of Williams et al. (2015). The dominance of such specimens that are folded or in which the archaeopyle is otherwise poorly visible over those with a clear archaeopyle outline illustrates the problems of practicality of the proposed taxonomic division. 1, 2. Scanning electron microscope images of specimens of *Apectodinium* from the Palaeocene–Eocene boundary sediments from Ocean Drilling Program Site 1172, which were previously published in Bijl et al. (2013). Ambiguity about archaeopyle outline and whether the operculum is posteriorly attached makes it impossible to classify these specimens at the genus level. With light microscopy such subtle archaeopyle outlines are even more difficult to discern. Based on morphological features of the wall and pericoels, these specimens are easily recognised as *Apectodinium homomorphum*, but with the primary focus on archaeopyle type, they can only be classified on a subfamily level. 3. Specimen of *Apectodinium homomorphum* from the Palaeocene–Eocene boundary sediments from Ocean Drilling Program Site 1172, which was previously published in Bijl et al. (2013). This specimen seems to show a hyperrepeliform archaeopyle, but it might also be the result of folding. 4, 5. *Wetzelella symmetrica* specimen from the Oligocene of the western North Atlantic [Integrated Ocean Discovery Program (IODP) Leg 342, Site U1411]. The operculum is still in place, yet it is difficult to discern whether it is still posteriorly attached. 6. *Wilsonidium echinosuturatum* with an operculum in place, which seems to be attached at the posterior left corner. This specimen illustrates the possibility that any archaeopyle type can be attached to some degree. 7–9. *Wetzelella symmetrica* specimen from the Oligocene of the western North Atlantic (IODP Leg 342, Site U1411). Operculum seems to be in place, but it is difficult to discern whether the operculum is still attached or not. The Williams et al. (2015) concepts would impose a serious limitation on classifying this specimen at the genus level, while using previous classifications this specimen clearly belongs to *Wetzelella symmetrica*. Also note the apparent variability in archaeopyle outline between this specimen and that shown in figures 4 and 5. 10. *Wetzelella symmetrica* from the North Sea Basin. The archaeopyle is difficult to discern, making classification at the genus level impossible according to the classifications of Williams et al. (2015).

3. Concluding remarks

We recognise that dinoflagellate cyst taxonomy is imperfect for all groups, including the Wetzelielloideae, and that there is a constant need for improvement. Williams and colleagues are profound experts in this field and their countless high-quality contributions are invaluable. However, based on the material we have observed, we find the variability and plasticity of cyst-wall and archaeopyle morphology within the Wetzelielloideae equally large, but render the cyst-wall morphology in practice a much more practical criterion for taxonomic differentiation than archaeopyle type, and more in line with that within other families. The above considerations on the taxonomic revisions proposed by Williams et al. (2015) lead us to propose to retain the taxonomic concepts within Wetzelielloideae that existed prior to their contribution.

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References

- Bailey DA. 1987. *Durotrigia daveyi* gen. et sp. nov., an Early Bajocian dinocyst with a variable precingular archaeopyle. *Journal of Micropalaeontology* 6:89–96.
- Bijl PK, Bendle APJ, Bohaty SM, Pross J, Schouten S, Tauxe L, Stickley CE, McKay RM, Röhl U, Olney M, et al. 2013a. Eocene cooling linked to early flow across the Tasmanian Gateway. *Proceedings of the National Academy of Sciences of the United States of America* 110, 9645–9650.
- Bijl PK, Sluijs A, Brinkhuis H. 2013b. A magneto-chemo-stratigraphically calibrated dinoflagellate cyst zonation of the early Paleogene South Pacific Ocean. *Earth-Science Reviews* 124:1–31.
- Crouch EM, Brinkhuis H, Visscher H, Adatte T, Bolle M. 2003. Late Paleocene-early Eocene dinoflagellate cyst records from the Tethys: Further observations on the global distribution of *Apectodinium*. *Special Paper of the Geological Society of America* 369:113–131.

- Dallanave E, Bachtadse V, Crouch EM, Tauxe L, Shepherd CL, Morgans HEG, Hollis CJ, Hines BR, Sugisaki S. 2016. Constraining early to middle Eocene climate evolution of the southwest Pacific and Southern Ocean. *Earth and Planetary Science Letters* 433:380–392.
- Egger LM, Śliwińska KK, van Peer TE, Liebrand D, Lippert PC, Friedrich O, Wilson PAW, Norris RD, Pross J. *in press*. Magnetostratigraphically calibrated dinoflagellate cyst bioevents for the uppermost Eocene to lowermost Miocene of the western North Atlantic (IODP Expedition 342, Paleogene Newfoundland sediment drifts). *Review of Palaeobotany and Palynology*. doi: 10.1016/j.revpalbo.2016.08.002
- Eldrett JS, Harding IC. 2009. Palynological analyses of Eocene to Oligocene sediments from DSDP Site 338, Outer Vøring Plateau. *Marine Micropaleontology* 73:226–240.
- Eldrett JS, Harding IC, Firth JV, Roberts AP. 2004. Magnetostratigraphic calibration of Eocene-Oligocene dinoflagellate cyst biostratigraphy from the Norwegian-Greenland Sea. *Marine Geology* 204:91–127.
- Feist-Burkhardt S, Monteil E. 2001. Gonyaulacacean dinoflagellate cysts with multi-plate precingular archaeopyle. *Neues Jahrbuch für Geologie und Paläontologie. Abhandlungen* 219:33–81.
- Fensome RA, Crux JA, Gard G, MacRae RA, Williams GL, Thomas FC, Fiorini F, Wach G. 2008. The last 100 million years on the Scotian Margin, offshore eastern Canada: an event-stratigraphic scheme emphasizing biostratigraphic data. *Atlantic Geology* 44:93–126.
- Fensome RA, Taylor FJR, Norris G, Sarjeant WAS, Wharton DI, Williams GL. 1993. A classification of modern and fossil dinoflagellates. *Micropalaeontology, Special Paper*, New York.
- Firth JV, Eldrett JS, Harding IC, Coxall HK, Wade BS. 2013. Integrated biomagnetostratigraphy for the Palaeogene of ODP Hole 647A: Implications for correlating palaeoceanographic events from high to low latitudes. *Geological Society Special Publication* 373:29–78.
- Goodman DK, Witmer RJ. 1985. Archeopyle variation and paratabulation in the dinoflagellate *Diphyes colligerum* (Deflandre and Cookson, 1955) Cookson, 1965. *Palynology* 9:61–83.
- Harland R. 1982. A review of Recent and Quaternary organic-walled dinoflagellate cysts of the genus *Protoperidinium*. *Palaeontology* 25:369–397.
- Head MJ. 1996. Modern dinoflagellate cysts and their biological affinities. In: Jansonius J, McGregor DC, editors. *Palynology: principles and applications*. Dallas; p. 1197–1248. Salt Lake City, USA.
- Hollis CJ, Crouch EM, Morgans HEG, Handley L, Baker JA, Creech J, Collins KS, Gibbs SJ, Huber M, Schouten S, et al. 2009. Tropical sea temperatures in the high latitude South Pacific during the Eocene. *Geology* 37:99–102.
- Hollis CJ, Taylor KWR, Handley L, Pancost RD, Huber M, Creech JB, Hines BR, Crouch EM, Morgans HEG, Crampton JS, et al. 2012. Early Paleogene temperature history of the Southwest Pacific Ocean: Reconciling proxies and models. *Earth and Planetary Science Letters* 349–350:53–66.
- Islam MA. 1982. Archeopyle structure in the fossil dinoflagellate *Phthanoperidinium*. *Review of Palaeobotany and Palynology* 36:305–316.
- Pross J. 2001. Dinoflagellate cyst biogeography and biostratigraphy as a tool for palaeoceanographic reconstructions: An example from the Oligocene of western and northwestern Europe. *Neues Jahrbuch für Geologie und Paläontologie. Abhandlungen* 219:207–219.
- Pross J, Houben AJP, Simaëys Sv, Williams GL, Kotthoff U, Coccioni R, Wilpshaar M, Brinkhuis H. 2010. Umbria-Marche revisited: A refined magnetostratigraphic calibration of dinoflagellate cyst events for the Oligocene of the Western Tethys. *Review of Palaeobotany and Palynology* 158:213–235.
- Śliwińska KK, Abrahamsen N, Beyer C, Brünings-Hansen T, Thomsen E, Ulleberg K, Heilmann-Clausen C. 2012. Bio- and magnetostratigraphy of Rupelian–mid Chattian deposits from the Danish land area. *Review of Palaeobotany and Palynology* 172:48–69.
- Sluijs A, Bowen GJ, Brinkhuis H, Lourens LJ, Thomas E. 2007. The Palaeocene-Eocene thermal maximum super greenhouse: biotic and geochemical signatures, age models and mechanisms of global change. In: Williams M, Haywood AM, Gregory FJ, Schmidt DN, editors. *Deep time perspectives on Climate Change: Marrying the Signal from Computer Models and Biological Proxies*. The Micropalaeontological Society, Special Publications. London: The Geological Society; p. 323–347.
- Sluijs A, Brinkhuis H. 2009. A dynamic climate and ecosystem state during the Paleocene-Eocene Thermal Maximum: inferences from dinoflagellate cyst assemblages on the New Jersey Shelf. *Biogeosciences* 6:1755–1781.
- Sluijs A, Brinkhuis H, Williams GL, Fensome RA. 2009. Taxonomical revision of the *Spinidinium-Vozzhennikovia* group of organic walled, peridinioid dinoflagellate cysts. *Review of Palaeobotany and Palynology* 154:34–53.
- Wall D. 1967. Fossil microplankton in deep-sea cores from the Caribbean Sea. *Palaeontology* 10:95–123.
- Williams GL, Brinkhuis H, Pearce MA, Fensome RA, Weegink JW. 2004. Southern Ocean and global dinoflagellate cyst events compared: Index events for the late Cretaceous - Neogene. In: Exon NF, Kennett JP, Malone MJ, editors. *Proceedings of the Ocean Drilling Program, Scientific Results*, volume 189, pp. 1–98. College Station, TX, USA.
- Williams GL, Damassa SP, Fensome RA, Guerin GR. 2015. *Wetzeliella* and its allies - the 'hole' story: a taxonomic revision of the Paleogene dinoflagellate subfamily Wetzelielloideae. *Palynology* 39:289–344.