REPORT

Problematic Cambrian acritarchs and the evolution of the phytoplankton – a summary

Modern phytoplankton consists primarily of coccolithophores, diatoms and dinoflagellates, which first appeared in the Mesozoic. This means the phytoplankton of the Palaeozoic is mostly unknown and unique (Grant 1992; Falkowski et al. 2004; Knoll et al. 2007). The phytoplankton is one of the most influential bio-systems on the planet, so the investigation of this system at a major time such as the Cambrian is vital for our understanding of evolution and ecosystems (Falkowski et al. 2004). The fossil evidence of Cambrian phytoplankton consists primarily of acritarchs, which by the group's nature have an unknown taxonomic affinity, presenting a major problem when investigating the makeup of the early phytoplankton (Martin & Servais 2020).

Methodology

In this study a new approach to the investigation of acritarch affinity is adopted. In this the frequency, form and size of internal structures in species of *Skiagia*, candidate colonial green algae with possible encysting green algal affinity from the late early Cambrian Forteau Formation of Newfoundland, Canada (Moczydłowska 2010; Harvey 2023) were documented. One pre-prepared palynology slide from each of four localities within the Forteau Formation were analysed using a Zeiss AxioImager. Two hundred acritarchs were documented on each slide and any *Skiagia* specimens with a medial split structure (a lineal split along the radius of the vesicle) or an internal structure (internal inclusions with a visible colour difference) were recorded and photographed to test its encysting green algal affinity. The internal structures of *Skiagia* together with colonial acritarchs (Harvey 2023) were then measured using ImageJ software and compared to those of modern and fossil proxies to test competing hypotheses of their origin.

Results

Specimens from each of the localities in this study exhibited medial splits, implying that this plays a key role in the life cycle of *Skiagia*. The internal structures within *Skiagia* appear as small biconvex concentrated bodies and are consistent in size and shape across all localities (Fig. 1). The colonial acritarchs measured also exhibit internal structures with consistent proportions to the concentrated bodies within *Skiagia* (Figs 1 and 2). Concentrated bodies in both *Skiagia* and the colonial acritarchs are similarly well constrained and show a consistent cell to structure ratio to that of the nucleus of modern green algae (Fig. 3). The colonial acritarchs also exhibit a diffuse internal structure with a granular texture (a granular mass) which is either present within a vesicle on its own or with a concentrated body (Fig. 2). When compared to the organelles of modern proxies the granular mass does not directly match the proportions of any organelle (Fig. 3). Some granular mass structures also contain hoop-like structures which are morphologically similar to the decayed organelle pyrenoid (Fig. 2).

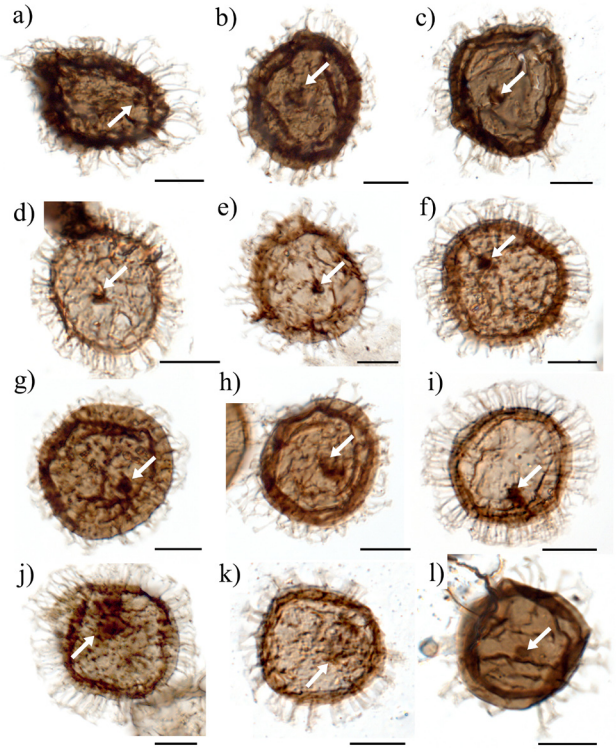

Figure 1. *Figure showing internal structures present in* Skiagia *spp. from the Cambrian Forteau Formation: a–c show specimens from locality BER, d–j from locality LALQ, and k–l from locality WRAA. Arrows point to the internal structures; a–j show small concentrated structures whereas k and l are more diffuse. Scale bar is 10µm for all. All photos are light microscope images. Note: details of localities are not included in the present abstract.*

Discussion

The presence of medial splits within *Skiagia* adds support to the proposed encysting lifestyle (Moczydłowska 2010). However, unlike previous studies, endocysts were not found within and instead internal structures were concentrated bodies with a morphology that suggests an exceptionally preserved fossilised nuclei interpretation. Further research is needed to understand why the nuclei have preserved but other organelles have not and the exact diagenetic conditions within the Forteau Formation that allowed for this exceptional result. While questions still remain, these findings suggest a eukaryote interpretation for these enigmatic acritarchs and deepens our understanding into the influential ecosystems of the early Cambrian.

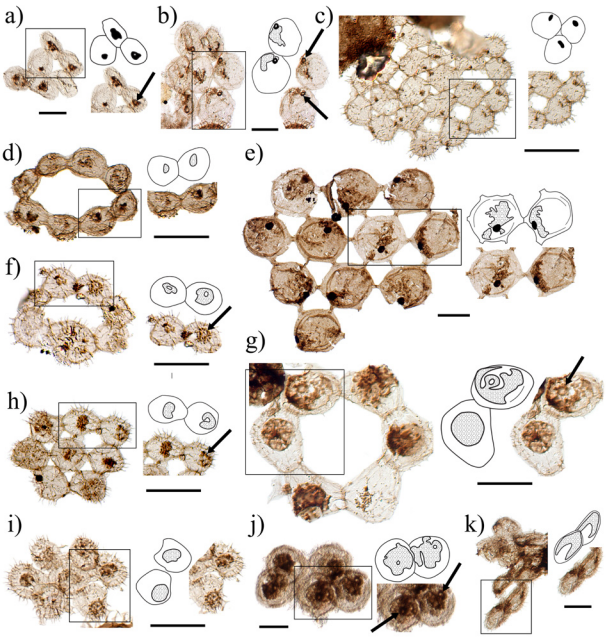

Figure 2 *(left). Figure outlines of the internal structures present in the colonial acritarchs from the Cambrian Forteau Formation (modified from Harvey 2023, fig. 1). There are two categories of internal structures present: concentrated bodies and granular mass. Concentrated bodies are present in a, b, c, and e and are filled in with black in the diagrams. Granular masses are present in b, and d–k and are filled in using dots in the diagrams. Arrows represent hoop-shaped structures preserved within the granular mass or concentrated bodies. Scale is 20µm for all. All photos are light microscope photographs.*

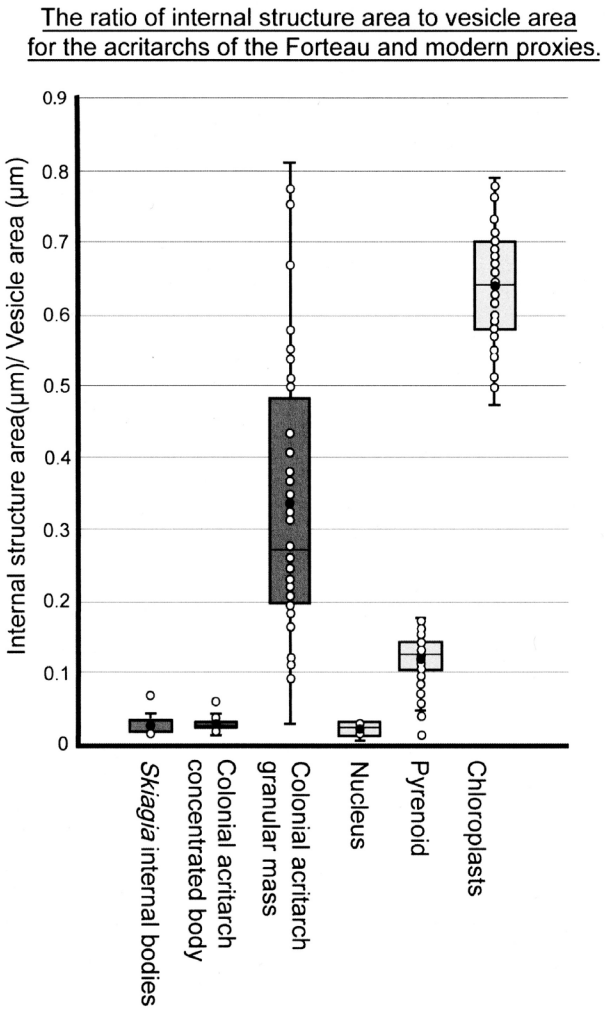

Figure 3 *(below left). Box and whisker plot comparing the ratios of internal structures to vesicle/cell for the acritarch internal bodies and the organelles of modern proxies. The dark coloured boxes represent acritarchs while the light-coloured boxes represent the proxies. Chloroplasts have been measured from* Gonium*,* Pediastrum*,* Chlorella*, and* Pandorina*. Pyrenoids have been measured from* Gonium*,* Pediastrum*,* Chlorella*, and* Pandorina*. Nuclei have been measured from* Chlorella *and an exceptionally preserved Jurassic fern. The range bars show the lower and upper bounds of the upper and lower quartiles. The boxes represent the interquartile range. The white dots represent measured datapoints. The black dot is the median and the black line in the box is the mean. Datapoints outside the range bars represent statistical outliers.*

References

Falkowski, P. G., Katz, M. E., Knoll, A. H., Quigg, A., Raven, J. A., Schofield, O., & Taylor, F. J. R. 2004. The evolution of modern eukaryotic phytoplankton. *Science*, **305**, 354–360 (doi: 10.1126/science.1095964)

Grant, S. W. F. 1992. Carbon isotopic vital effect and organic diagenesis, Lower Cambrian Forteau Formation, northwest Newfoundland: implications for δ13C chemostratigraphy. *Geology*, **20**, 243–246.

Harvey, T. H. P. 2023. Colonial green algae in the Cambrian plankton. *Proceedings of the Royal Society B*, **290** (doi: https://doi.org/10.1098/rspb.2023.1882)

Knoll, A. H., Summons, R. E., Waldbaur, J. R. & Zumberge, J. E. 2007. The geological succession of primary producers in the oceans. In: *Evolution of primary producers in the sea* / edited by P. G. Falkowski & A. H. Knoll. Academic Press, pp 133–163.

Martin, R. E. & Servais, T. 2020. Did the evolution of the phytoplankton fuel the diversification of the marine biosphere? *Lethaia*, **53**, 5–31.

Moczydłowska, M. 2010. Life cycle of early Cambrian microalgae from the Skiagia-plexus acritarchs. *Journal of Paleontology*, **84**, 216–230 (doi:10.1666/09-117R.1)

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