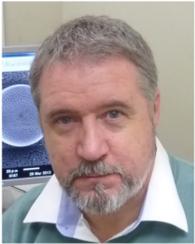
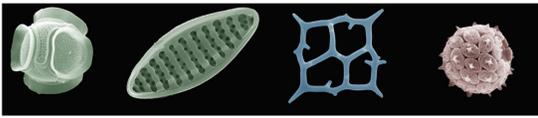


A lifetime studying marine biodiversity and phytoplankton evolution

Richard Jordan (Faculty of Science)



I have spent over 40 years studying marine phytoplankton, particularly from polar and tropical environments. During that time I have described many new taxa of living and fossil haptophytes, pamales, diatoms and silicoflagellates. Most of these organisms are very small (<10 μm), so the scanning electron microscope (SEM) has been an essential tool in my laboratory's research. These new taxa are often extremely rare, and so may appear insignificant, yet they provide valuable information on specialised habitats and evolutionary trends.



Why is biodiversity important?

It is essential that every niche is occupied by living organisms and that they contribute to the physical and chemical processes that support life on the planet.

What do we know about our planet's biodiversity?

The world's governments spend huge amounts of money on searching for extraterrestrial life, and yet we still know very little about what is on our own planet. In fact, a survey by UNESCO found that only 1% of the Earth's surface has been mapped.

How many living species are there on the Earth?

A recent article estimated that there are at least 8.75 million living species (80% of which are hypothetical), but the real number could range from 2 million-3 trillion (Wiens, 2023). Of those species, 1-10 million are protists (Adl *et al.*, 2007).

Where should we look for hidden biodiversity?

For marine phytoplankton, the obvious places to look are extreme environments and remote areas (lower photic zone, marine lakes, coral reefs, polar regions), while for microfossils, almost everywhere is poorly investigated. In terms of geological time, the Oligocene, Paleocene and Early Cretaceous diatom assemblages, in particular, are not well documented.



Adl SM, Leander BS, Simpson AGB *et al.* (2007). Diversity, nomenclature, and taxonomy of protists. *Syst. Biol.* 56: 684-689. Wiens J (2023). How many species are there on Earth? *Progress and problems. PLoS Biol.* 21: e3002388.

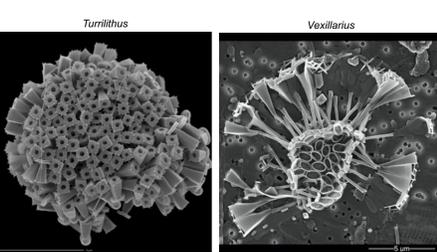
HAPTOPHYTES

My career began when I did a one-year internship at the Institute of Oceanographic Sciences in Wormley, UK (1982-1983). I was asked to investigate phytoplankton assemblages on membrane filters using a SEM. This was at a time when using filters and the SEM were unusual in marine plankton research. Later, this project was expanded to become my PhD, when I also conducted research in the temperate and subtropical regions of the North Atlantic Ocean during two scientific cruises of the RRS *Discovery*.



The 'shade flora' of the Lower Photic Zone

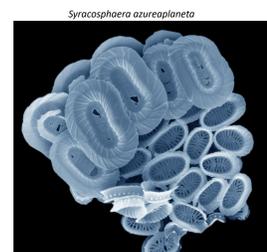
Most scientists collected subtropical-tropical phytoplankton samples from the top 100m of the ocean, however, during my PhD (and thereafter), I sampled down to 300m. As a result, I encountered a lot of new and rare taxa of calcareous haptophytes (e.g., Jordan *et al.*, 1991; Andruleit & Jordan, 2017). Subsequent work off Puerto Rico showed that the deep chlorophyll maximum was often below 100m water depth (Jordan & Winter, 2000).



Andruleit H & Jordan RW (2017). Two new species of Vexillarius (Prymnesiozoa) from the eastern Indian Ocean. *Phycologia* 56: 510-516. Jordan RW, Knappertbusch M, Simpson WR & Chamberlain AH (1991). *Turillithus kretzschmayeri* gen. et sp. nov., a new coccolithophorid from the deep photic zone. *Br. phycol. J.* 26: 175-183. Jordan RW & Winter A (2000). Assemblages of coccolithophorids and other living microplankton off the coast of Puerto Rico during January-May 1995. *Marine Microplanktonology* 39: 113-130.

Wikipedia species

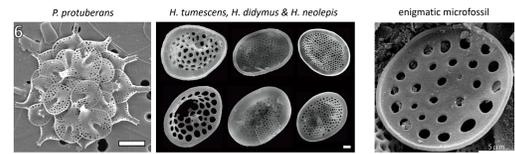
One new species has its own Wikipedia page, because it is the only species named after a TV programme ('The Blue Planet') (Young *et al.*, 2018).



Young JR, Brown PR, Cross L, Hagino K & Jordan RW (2018). *Syracosphaera azureplaneta* sp. nov. and revision of *Syracosphaera carolla* Leal, 1966. *J. Natn. Res.* 38: online, open access.

Siliceous haptophytes

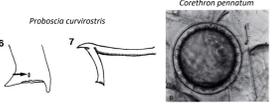
A global review of living haptophytes with siliceous scales revealed a new species of *Petasaria* (Jordan *et al.*, 2016). In addition, two species of *Hyalolithus* were discovered in the fossil record (Abe *et al.*, 2016; 2022). This line of research could initiate a new branch of haptophyte science, which has traditionally been focused on calcite scales. We are now concentrating on other enigmatic siliceous microfossils which may be potential haptophytes.



Abe K, Pellegrino L, Lozar F, Tsutsumi H & Jordan RW (2022). *Hyalolithus didymus* sp. nov. (Haptophyta): a late Miocene siliceous microfossil from Sicily, Italy. *Phycologia* 61: 504-513. Abe K, Tsutsumi H & Jordan RW (2016). *Hyalolithus tumescens* sp. nov., a siliceous scale-bearing haptophyte from the middle Eocene. *Journal of Microplanktonology* 35: 143-149. Jordan RW, Abe K *et al.* (2016). Observations on the morphological diversity and distribution of two siliceous nanoplankton genera, *Hyalolithus* and *Petasaria*. *Microplanktonology* 61: 439-455.

DIATOMS

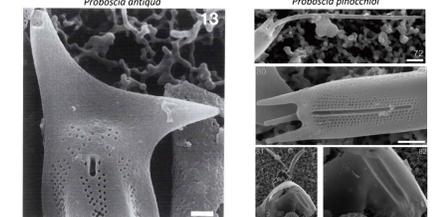
My undergraduate thesis (1984) was on polysaccharides and freshwater diatoms, but my studies on marine diatom taxonomy didn't start until I worked for the British Antarctic Survey in Cambridge, UK (1988-1991). This connection to polar research still continues today, although in Yamagata my studies have branched out into tropical regions, and older fossil records. Here I introduce my studies of two old lineages, *Proboscia* and *Corethron*, which I began working on 35 years ago (Jordan & Priddle, 1991; Jordan *et al.*, 1991).



Jordan RW & Priddle J (1991). Fossil members of the diatom genus *Proboscia*. *Diatom Research* 6: 55-61. Jordan RW, Priddle J, Pusley CJ, Barker PF & Whitehouse MJ (1991). Unusual diatom layers in Upper Pleistocene sediments from the northern Weddell Sea. *Deep-Sea Research* 38: 829-843.

35 years of Proboscia research

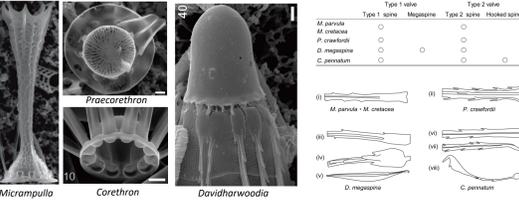
Initially, my studies focused on transferring some of the living *Rhizosolenia* species to *Proboscia* (Jordan *et al.*, 1991) and describing some new ones. However, I soon began to describe new fossil taxa; from the late Miocene (Japan), Late Cretaceous (Southern Ocean; Jordan & Ito, 2002), and more recently, the early Eocene (Jutland; Abe & Jordan, 2023).



Abe K & Jordan RW (2023). On the enigmatic diatom *Rhizosolenia dubia*, its relationship to *Pseudopyxilla* and *Proboscia*, and description of a new species, *Proboscia pinocchio* sp. nov. *Diatom Research* 38: 1-12. Jordan RW & Ito R (2002). Observations on *Proboscia* species from Late Cretaceous sediments, and their possible evolution from *Kregeria*. In: *15th IOS, Koeltz Scientific Publishers*: 313-329. Jordan RW, Ligowski R, Nohth E-M & Priddle J (1991). The diatom genus *Proboscia* in Antarctic waters. *Diatom Research* 6: 63-78.

The enigmatic genus, Corethron

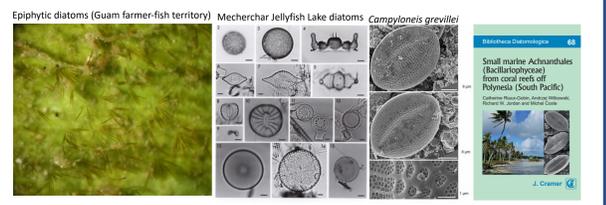
Among living diatoms, *Corethron* has unique features – articulated spines in sockets, and hooked spines. But where did it come from? Until recently, there were no known ancestors. Our research has now revealed three older genera; *Praecorethron* and *Micrampulla* from the Late Cretaceous (Abe *et al.*, 2021; 2022), and *Davidharwoodia* from the early Eocene (Abe & Jordan, 2023).



Abe K, Harwood DM & Jordan RW (2022). Observations on Late Cretaceous *Micrampulla* (*Corethrales*, Bacillariophyceae) from the Campbell Plateau (Zealandia), southwest Pacific Ocean. *Diatom Research* 38: 1-12. Abe K & Jordan RW (2023). *Davidharwoodia megaspina* gen. et sp. nov. (*Corethrales*), a new fossil marine diatom genus from Mors, Jutland (early Eocene). *Diatom Research* 38: 13-20. Abe K, Lam DW, Ashworth MP, Harwood DM & Jordan RW (2023). Observations on *Praecorethron crawfordii* gen. et sp. nov. (*Corethrales*, Bacillariophyceae) from the Upper Cretaceous marine sediments, southwest Pacific. *Nova Hedwigia, Beihft* 151: 273-314.

Coral reefs and farmer-fish territories

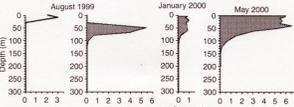
Tropical environments are poorly investigated, because they are in remote areas or located in countries which lack good research facilities. Over the last 20 years we have sampled various habitats, describing new taxa from farmer-fish territories in Guam (Lobban *et al.*, 2011), marine lakes in Palau (Konno & Jordan, 2008), and atolls in the South Pacific and Indian Ocean (e.g., Riaux-Gobin *et al.*, 2015).



Konno S & Jordan RW (2008). *Parola longispina* sp. nov., an extant species from Palau and Haha-jima, western North Pacific. *Proceedings of the Nineteenth International Diatom Symposium 2006* Listvyanka, Russia. Biopress Ltd. 55-69. Lobban CS, Ashworth MP, Aral H & Jordan RW (2011). Marine medusae-chain Fragilariaceae (Bacillariophyceae) from Guam, including descriptions of *Koereriella* and *Peyssonnetia* genera nova. *Phycological Research* 59: 175-193. Riaux-Gobin C, Compère P & Jordan RW (2015). Coccoid Erenberg assemblage (Bacillariophyceae) from Napuka Atoll (Tuamotu Archipelago, South Pacific) with description of two new taxa. *Diatom Research* 30: 175-196.

PARMALES

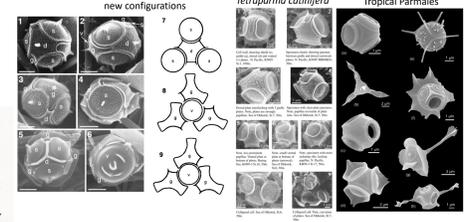
During Dec. 1996-Feb. 1997 and summer 1999, I participated in two R/V *Hakuho-maru* cruises. On these cruises I collected underway surface seawater samples, as well as vertical water samples (0-300m) at designated stations, and core sediments. The water samples were filtered through membrane filters and investigated for phytoplankton assemblages using a SEM. The data from the vertical samples at Station KNOT, in western North Pacific, gave us the first picture of Parmales seasonality (dark shade in figure below) and their abundance revealed their importance to primary production (Komuro *et al.*, 2005).



Komuro K, Narita H, Imai K, Nojiri Y & Jordan RW (2005). Microplankton assemblages at Station KNOT, subtropical western Pacific, in 1999-2000. *Deep-Sea Research* 52: 2206-2217.

New taxa and plate configurations

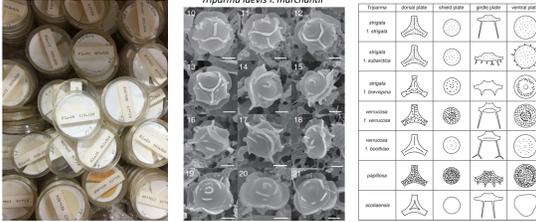
After studying the polar taxa it was realised that the published plate configurations of the Parmales genera were wrong, so we revised them (Konno & Jordan, 2007). The filters from the two R/V *Hakuho-maru* cruises allowed us to describe many new taxa and to further understand their ecology (Konno *et al.*, 2007; Fujita & Jordan, 2017).



Fujita R & Jordan RW (2017). Tropical Parmales (Bolidophyceae) assemblages from the Sulu Sea and South China Sea, including the description of five new taxa. *Phycologia* 56: 499-509. Konno S & Jordan RW (2007). An amended terminology for the Parmales (Chrysophyceae). *Phycologia* 46: 612-616. Konno S, Ohira R, Komuro K, Harada N & Jordan RW (2007). Six new taxa of subtropical Parmales (Chrysophyceae). *J. Natn. Res.* 29: 108-128.

The 'Big Mac Project'

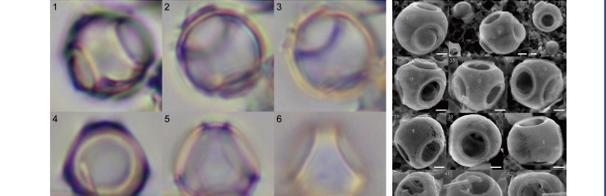
Marine phytoplankton samples on membrane filters were collected from all over the world by US scientists (notably A. McIntyre) from the 1960s. This huge filter collection therefore represents a great resource for studying phytoplankton before the current rise in CO₂ levels. We used the filters to look at Parmales distribution, and described numerous new taxa (Hoshina *et al.*, 2021a-c).



Hoshina K, Narita H, Harada N & Jordan RW (2021b). *Triparma laevis* f. *marchantii* f. nov. (Bolidophyceae) from the Southern Ocean, and comparison with other intraspecific taxa of *T. laevis*. *Phycologia* 60: 180-187. Hoshina K, Narita H, Harada N & Jordan RW (2021a). Diversity within the *Triparma striata*-*Triparma verrucosa* group (Bolidophyceae) including five new taxa from polar-subpolar regions. *Phycologia* 60: 215-224. Hoshina K, Uezato Y & Jordan RW (2021c). Parmales (Bolidophyceae) assemblages in the subtropical Pacific Ocean during the mid-1960s. *Phycologia* 60: 35-47.

The oldest fossil Parmales

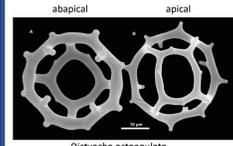
The diatoms are thought to have evolved from a siliceous scaly ancestor. However, until recently, there were only a few studies on fossil Parmales, and these were from either surface sediments or the Quaternary. The general feeling was that the Parmales plates were too fragile to survive deep-time preservation. However, during our study of Late Cretaceous diatoms we noticed well-preserved Parmales with fused plates, apart from the shield plates (Abe & Jordan, 2022). Now the search is on for more fossil species.



Abe K & Jordan RW (2022). Re-examination of *Archaeomonas mirabilis* from the Late Cretaceous reveals its true identity as the oldest known fossil Parmales (Bolidophyceae). *Phycologia* 60: 362-367.

SILICOFAGELLATES

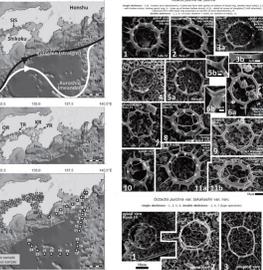
Although I'd published images of silicoflagellates before, everything changed when I met Kevin McCartney in 2013. He gave a talk on the rarity of silicoflagellate double skeletons and asked if anyone had seen one. I knew my students had seen over 30. Kevin initially doubted my claim, but the rest is history. What came next is a series of papers on the taxonomy and evolution of silicoflagellates ... and lots of double skeletons (McCartney *et al.*, 2022).



McCartney K, Witkowski J, Jordan RW, Abe K *et al.* (2022). Silicoflagellate evolution through the Cenozoic. *Marine Microplanktonology* 71: 102-108.

Ecological varieties

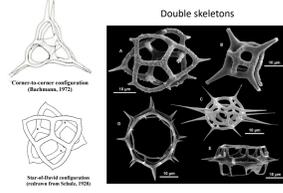
A new and thinner variety of *Octactis pulchra* was found in the oligotrophic Kuroshio, while the thicker variety lived in the eutrophic Seto Inland Sea (Abe *et al.*, 2015).



Abe K, McCartney K, Fukunaga Y, Narita H & Jordan RW (2015). Silicoflagellates and ctenidians from the Seto Inland Sea and Kuroshio, including the description of *Octactis pulchra* var. *takahashi* var. nov. *J. Natn. Res.* 35: 111-128.

Double skeletons

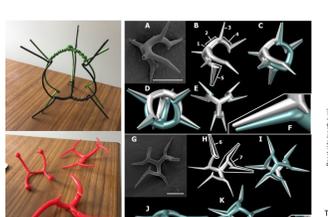
Double skeletons are formed when cells divide, so do not remain attached for very long. Hence, they are rare. Modern species only make corner-to-corner configurations, whereas some fossil species can make Star-of-David configurations (McCartney *et al.*, 2014; 2015).



McCartney K, Witkowski J, Jordan RW *et al.* (2014). Fine structure of silicoflagellate double skeletons. *Marine Microplanktonology* 13: 10-15. McCartney K, Abe K, Harrison MA *et al.* (2015). Silicoflagellate double skeletons in the geologic record. *Marine Microplanktonology* 117: 65-79.

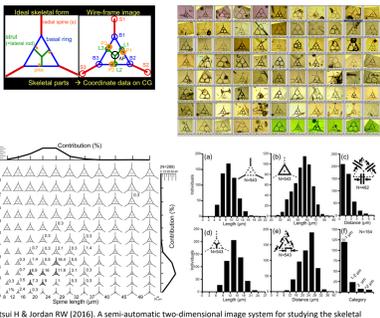
Double skeleton models

Usually, silicoflagellates are observed as single skeletons. So, how can we determine what kind of double skeletons they can make? In one paper, we produced physical models (wire models, 3D-printer plastic models) and 3D rotating computer models (McCartney *et al.*, 2015).



Skeletal variation

We also developed computer programmes to help process hundreds of photos for morphometric data (Tsutsumi & Jordan, 2016; Tsutsumi *et al.*, 2018).



Tsutsumi H & Jordan RW (2016). A semi-automatic two-dimensional image system for studying the skeletal design of the silicoflagellate genus *Corbisema* (Dictyocheales, Dictyocheaceae). *J. Natn. Res.* 36: 139-147. Tsutsumi H, Jordan RW, Nishiwaki N & Nishida S (2018). Morphometric analysis of early Eocene *Corbisema* skeletons (Silicoflagellata) in Mors, Denmark. *J. micropal.* 37: 283-293.

Silicoflagellate evolution

After a decade of collaborative research, we now have a much better idea of silicoflagellate evolution and of the timing of key events (McCartney *et al.*, 2022). However, we still need to understand how pike-bearing and pike-less forms and double skeleton configurations fit into the evolution.

