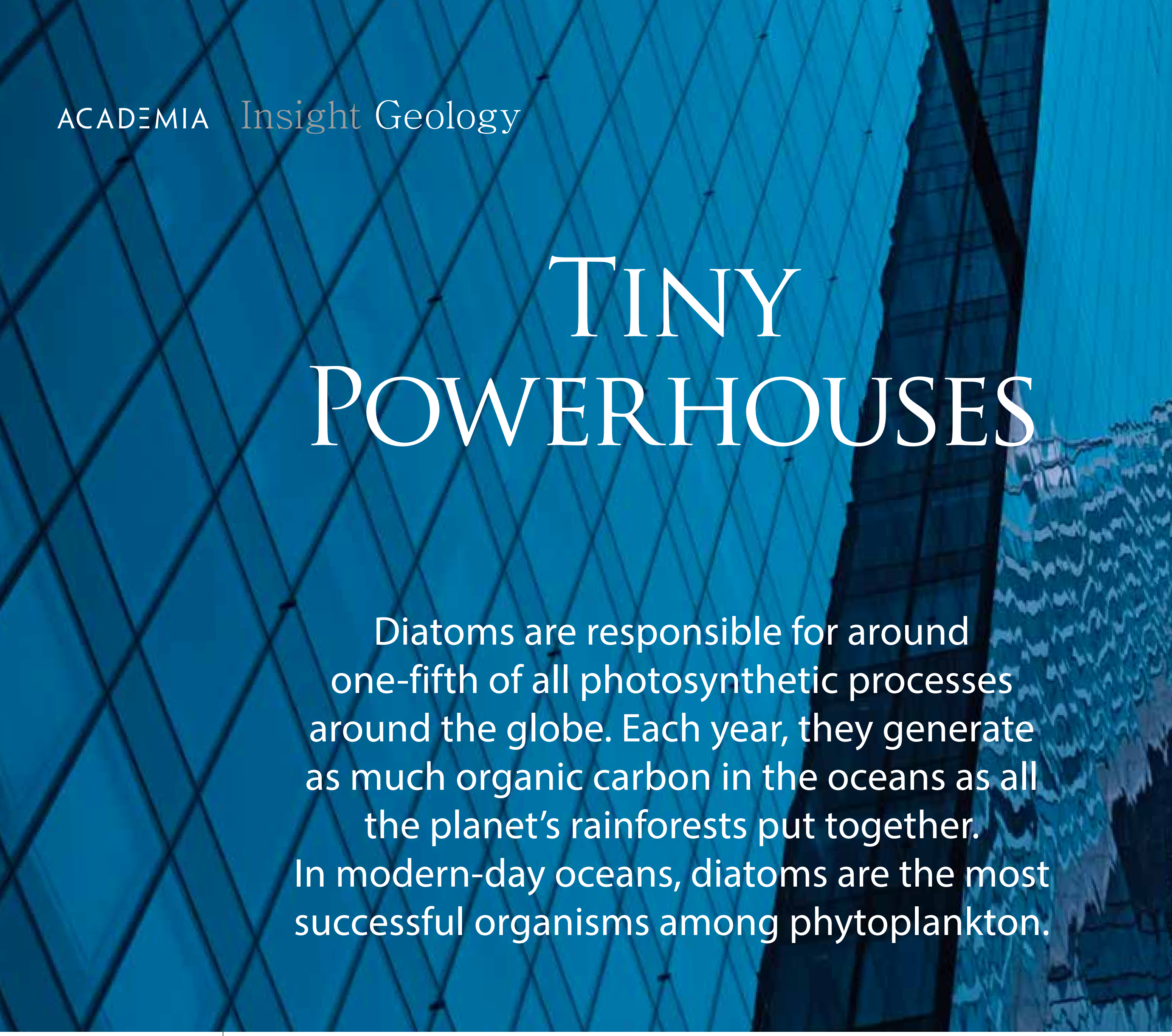

Tiny Powerhouses

Diatoms are responsible for around one-fifth of all photosynthetic processes around the globe. Each year, they generate as much organic carbon in the oceans as all the planet's rainforests put together. In modern-day oceans, diatoms are the most successful organisms among phytoplankton.

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Diatoms are unicellular organisms generally ranging in size from 2 to 200μm. They inhabit all aquatic environments including fresh water, open oceans, coastal seas, upwelling zones, oligotrophic environments, sea ice, saltwater, alkali and acidic lakes and incessantly moist environments such as soil. They can live as a solitary cell or in colonies, as a part of plankton, at the bottoms of lakes and seas or attached to plants, animals or ice. Although they are not members of the plant kingdom, they are mainly photosynthetic. In contrast to plants, however, their chloroplasts are brownish-yellow and contain different pigments: chlorophylls a and c, beta-carotene, fucoxanthin, diatoxanthin and diadinoxanthin. This wide range of pigments enables them to make the most of a wide range of light intensities and wavelengths, allowing them to survive in environments where plant life is not supported, for example in low-light conditions under thick ice.

But the most distinctive feature of diatoms is the cell's encapsulation in a silica "box" known as a frustule. The frustule comprises two valves, with one fitting inside the edge of the other. Both parts are often richly ornamented with pores, processes, spines and ribbing separated by smooth surfaces of varying sizes and shapes. The valves themselves also come in a myriad shapes, from round via elliptical, triangular and square to spindle-shaped.

Why did diatoms "decide" to close themselves up in their silica homes, given that these shells may hin-

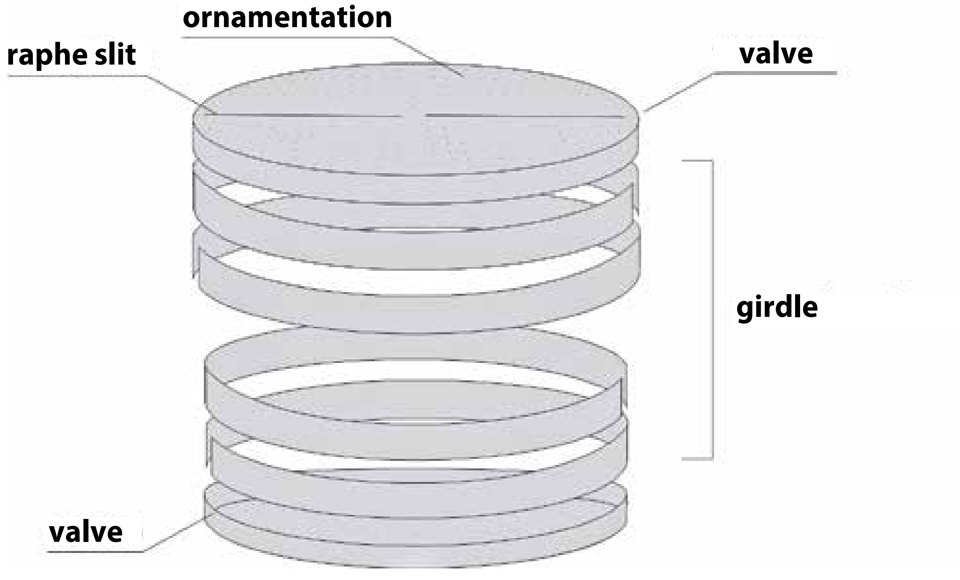
der life functions such as growth and reproduction? Unfortunately we still do not really have an answer. Silicon dioxide (silica) plays many important roles in living organisms, such as delaying cell ageing, reducing the impact of toxic metals and protecting against fungal infections, but its excess can be harmful. Perhaps one of the reasons for frustule formation is the desire to eject excess material from the cells. Some researchers believe that diatoms have inherited their ability to synthesize silica shells from their ancestors, improving and perfecting it. This theory is tied to another which indicates that many organisms related to diatoms use silica to protect their endospores, so it is possible that diatoms have adopted a similar technique for their vegetative cells. An important advantage of the silica skeleton is that its secretion bears a relatively low energy cost in comparison with similar skeletons formed of calcium carbonate.

While the cells are alive, the frustules protect them against mechanical damage and ingestion by other organisms, since the rigid, uneven carapaces are difficult to swallow. They are also sufficiently hard to put off many grazers and send them in search of an easier meal. On the other hand, since diatoms constitute tasty morsels in waters poor in nutrients, many marine animals such as krill have evolved to crush the hard silica casings. It's also worth noting that pathogens (including viruses and parasites) are very rarely found within diatom cells. Additionally, the numerous protrusions help diatoms stay afloat for longer before sinking to the bottom.

Diatoms change the world

Although diatoms might seem like simple, primitive organisms – we can almost think of them as starting points for more advanced creatures – they are in fact a relatively young group. The molecular clock estimates their origins as the early Triassic, around 250 million years ago, not long after the largest Phanero-

Schematic depiction of the silica skeleton of a diatom



zoic mass extinction, although the earliest confirmed fossils date back to the Jurassic, around 190 million years. What's the reason for this discrepancy? Perhaps early diatom fossils are so rare they simply haven't been found yet; perhaps the chemistry of ancient oceans was different and the frustules dissolved more quickly. Or perhaps, as some researchers believe, early diatoms didn't have silica shells in the first place. While we currently don't have an answer, we know that they became common fossils from the Cretaceous and during the Cenozoic.

Studying the environmental requirements of today's organisms allows us to reconstruct past environmental conditions quite accurately.

Using paleontological findings and geochemical data obtained from rocks, researchers frequently divide the last two billion years of the existence of photosynthesizing marine organisms into three eras. Until the mid-Mesozoic, the main component of phytoplankton was cyanobacteria; they were then replaced by green algae. The emergence of diatoms (alongside coccolithophores and dinoflagellates) on a large scale started the third era. The result was a change in the global carbon cycle and a drop in carbon dioxide levels in the atmosphere, with the corresponding significant increase in oxygen levels. Diatoms also started to dominate the silica cycle in the oceans, in turn influencing the further evolution of other silica-secreting organisms such as radiolarians and certain sponges. Since diatoms are far more efficient at extracting silica from water and incorporating it in their skeletons, other organisms suffered a shortage of the material, decreasing their size as a result. According to estimates, diatoms control the substance to the extent that each silicon dioxide molecule is bound into diatom shells around 39 times before it eventually settles on the ocean bed.

Today, diatoms are found at all latitudes and in all environments, providing there is sufficient light and nutrients. These small organisms are responsible for over 40% of aquatic primary production, and they play an important role in the carbon cycle. However, in contrast with carbon produced by trees – for example in rainforests – the organic carbon generated by diatoms is immediately captured and consumed by other organisms. This is because diatoms are at the base of the food chain in marine trophic networks and in polar regions where glaciers and permafrost limit photosynthesis on the continent, entire land and marine ecosystems depend on them.

In coastal zones, diatoms give rise to the best fishing areas. In open ocean waters, relatively high volumes of organic matter originating from diatoms fall to the bottom and become food for bottom feeders. Low volumes of diatoms – between 1% and 10% – avoid being destroyed, eaten or dissolved and reach the seabed, where under certain conditions they become one of the sources of crude oil.

Diatoms in ancient environments and climates

Unlike almost any other scientific activity, research into present-day climate change is relevant to all social groups. The topic is prominent at all stages of education and record-breaking temperatures are being reported in the media. The subject of climate changes which occurred in the past is incomparably less often mentioned in the popular press; however, it is perhaps the most important area of interest to climate scientists, because only by following long-term trends are we able to learn more about what is driving the changes we observe today. A range of tools and methods are used in past climate research, with the study of microorganisms – and among them diatoms – playing a leading role. Their usefulness stems from their wide distribution and from the fact that frustules are well preserved in the fossil record.

Diatom fossils were originally mainly used in biostratigraphic research – dating and comparing rocks on the basis of the fossils they contain. Since diatoms developed rapidly throughout the Cenozoic, researchers have been able to create a detailed biostratigraphy of various regions, for example the North Atlantic. In the 1980s, it became possible to extrapolate contemporary links between the environment and past diatom populations to reconstruct ancient environments and climates.

Diatoms are especially significant in the study of the Holocene – the most recent 11,000 years – since many species from that era found in the fossil record still exist today. This means that studying the environmental requirements of today's organisms allows us to reconstruct past environmental conditions with a high degree of precision. The Southern Ocean is described in most detail, since diatoms occur on a vast scale and create blooms in spring and summer; additionally, silica skeletons are preserved better in these cold waters than carbon shells. Researchers have reconstructed many environmental parameters such as sea surface temperature, presence and range of sea ice, currents and confluence of fresh water.

Previously the reconstructions were based on factors such as variability of one or a few selected species with known environmental requirements, as well as relationships between these species. However, it has become clear in recent years that only statistical methods based on large data sets will make it possible to fully understand assemblage composition variability and changes of past environments and climates. These methods have been used for example in studies into poorly understood diatoms from very young marine sediments collected along the western coast of the Antarctic Peninsula, mainly from fjords and bays with a wide range of depths, morphologies and hydrologies. By using factor analysis, researchers have studied the relationships between almost 50 diatom species from over 30 samples collected from various locations, and discovered similarities and differences that were not seen previously. These similarities and our understanding of the environmental requirements of the most important species living today were used to create three models of diatom assemblages typical for environments with different durations of sea ice cover: regions where ice does not occur at all or lasts less than three months, regions covered with ice for about six months, and regions which are permanently or almost permanently frozen. The duration of sea ice depends on many factors, mainly atmospheric and water temperature – or, in a word, on the climate.

Generating climate change models is all the more important given that just a tiny proportion of diatom skeletons reaches the seabed and is preserved in the fossil record. The majority are crushed, dissolved, eaten by grazers or transported by currents far beyond the area of their origin. This means that the remains found in the fossil record, such as in Holocene sediments, never fully reflect a living assemblage that lived near the water's surface. The most likely to disappear are tiny species or these that have fragile frustules, even if they are most abundant during their lifetime. This is why models based on young, assemblages, no older than a few decades, may turn out to be more useful than comparisons with living complexes: their composition more closely reflects fossil assemblages, yet they are sufficiently young to record conditions very similar to those occurring today.

Marlena Świło

Holocene diatoms from the western Antarctic

Further reading:

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