What is ‘marine snow’? Marine snow is made up of macroaggregates containing a wide range of species and sizes of living and dead microscopic plants (phytoplankton) and animals (zooplankton) and their faecal pellets. It was given its name by divers because the aggregates, which are usually greater than 0.5 mm across, really do look like snow flakes when seen in the water. They are held together by a sticky matrix of mucopolysaccharides produced by dying, nutrient-depleted phytoplankton cells or mucus feeding webs of zooplankton. These sinking particles also contain an enriched and active population of bacteria, relative to free-living bacteria, which are grazed by bacterivorous flagellates. Marine snow is the major component of the flux of organic material to the deep sea and is generally produced in the productive upper 100 m of the water column. Its production in the ocean cycles also exhibits strong seasonal variation with peaks shortly after the spring and autumn phytoplankton blooms in temperate waters such as those in the North Atlantic.

Long-term removal of carbon
The deep sea is an important sink in the global carbon budget. About 40% of global primary production is carried out by marine micro-organisms <10 µm in size. While 10–40% of primary production may sink out of the upper 100 m of the north east Atlantic, most gets remineralized during its descent so that only a small proportion arrives on the deep-sea bed. Much of the carbon fixed by the microscopic photosynthetic cells in the upper ocean is recycled to the atmosphere within weeks through a dynamic food web. These single cells are just too small and light to sink from the surface of the ocean and have a significant effect on long-term carbon removal. However, some of the cells aggregated into the larger sinking particles, known as marine snow, remove the carbon for centuries by transporting it to mid- and deep waters, or even for millions of years when it is laid down in sediments.

Supply of food to the deep-sea bed
The arrival of marine snow on the sea bed is the major determinant of abundance and activity of large and small deep-sea animals, many of which are deposit feeders. Many taxa respond to this seasonal influx of material. For example, populations of opportunistic species may increase and its arrival may regulate the reproduction and growth cycles of some animals.

Perhaps the greatest opportunists are bacteria that respond rapidly by increased enzyme production, DNA and protein synthesis and respiration; on occasions an increase in sediment bacterial biomass can be seen after this seasonal arrival of organic matter. Bacteria produce hydrolytic enzymes which cleave particulate organic matter into smaller molecules to support their metabolism. There is evidence that deep-sea-adapted bacteria are more effective at degrading the less labile organic matter present in marine snow.
Life on marine snow

Not surprisingly, bacteria and flagellates find the marine snow to be rich in organic and inorganic nutrients, which produce active populations in an otherwise nutrient-replete environment. Bacteria that colonize the marine snow clearly play an important role in the remineralization and solubilization of particulate organic carbon, so that many aggregates will not only be formed in the sunlit waters of the upper ocean, but will also be recycled there. However, many — most likely the larger, stronger aggregates — do escape to the twilight zone of the midwaters and the dark abyss of the deep sea where decomposition rates by the colonizing bacteria originating from surface waters may be reduced by the cooler temperatures and higher pressures. Protein and DNA synthesis in bacteria attached to the aggregates in the surface waters may be drastically influenced by the high pressures (100 atm every 1,000 m) as well as the low temperatures experienced during the sinking of large particles. The reduced microbial activity on such particles may contribute to the delivery of relatively underaged aggregates to the deep-sea bed.

Sustenance of free-living bacteria in the twilight zone and deep-sea

The waters of the twilight zone and deep sea are probably the most under-studied oceanic environments, but make up the largest volumes of the oceans. Studies have centred on the interfaces, such as the productive upper ocean, the sediment and coastal environments. Although the upper 100 m of the oceanic water column contains higher concentrations of bacteria, the greatest reservoirs lie below this — about 60% of the total water column bacteria. We know that these areas are truly nutrient-replete, so how are these bacteria surviving?

There is evidence that bacteria attached to marine snow may play an important role in releasing dissolved organic carbon to the surrounding water and the free-living bacteria that live there through extracellular enzymic hydrolysis of the particulate organic carbon it contains. Presumably, this will be patchy and sporadic, and in the form of microzones around the descending aggregates. But is that sufficient to sustain them? Some scientists have proposed that these bacteria also tap the substantial reservoir of old, refractory dissolved organic carbon found in the deep sea. Others have proposed that there is a downward flux of the more labile dissolved organic carbon occurring in the upper oceans. Not surprisingly, these sinking particles are also the main food resource for the animals that live in these watery depths and they have evolved adaptations to scavenge the particles during their descent. However, the enormous reservoir of carbon within the free-living bacteria is also a great potential food resource — if it can be captured. Little work has been done on the food web in deep waters, but there are animals that can filter large volumes of water or capture microscopic cells using their mucus webs and have the potential to extract the bacteria.

Mechanism for genetic exchange between isolated populations?

The deep ocean covers 60% of the earth’s surface and previously scientists thought that bacteria surviving at these enormous pressures and depths, in total darkness, were very isolated from most other bacteria occurring in the surface of the oceans. However, as many as $1 \times 10^{12}$ bacterial cells per m$^2$ per year, which is equivalent to around $3 \times 10^{13}$ plasmid encoded phenotypic genes per m$^2$ per year, can be transferred from the surface of the ocean to the deep-sea bed, a distance of about 4–5 km, through sinking of marine snow. The big question then is does the formation and sinking of marine snow also act as a method of genetic exchange between populations previously assumed to be genetically isolated from the enormous population of bacteria found in deep-sea sediments?
Conclusions

The formation and sinking of marine snow in the sunlit upper water column and its microbial degradation during and after its descent is of key importance to the global carbon cycle as well as to the delivery of food to organisms within the inner space of the deep-sea water column and on the deep-sea bed. The deep oceans are the largest and perhaps the oldest biosphere on Earth and hold an enormous reservoir of bacteria that is a potential resource of diverse and unique micro-organisms that may have evolved around 3.5 billion years ago. Marine snow plays a role in the sustenance of these micro-organisms and in combination with the wide range of pressures and temperatures found in the deep sea may contribute to the creation of a high metabolic and phylogenetic diversity. Obviously, there are still many unresolved questions and it is this and the fascination of the unknown that drives researchers in this ‘extreme’, at least to us, environment.

Further reading


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