

# Sea, cells, genes, smells, on the seashore

One molecule, dimethyl sulfide, affects cloud formation, bird behaviour and the smell of the seaside. Scientists are just beginning to unravel the many ways, the many genes and the many microbes that make the gas. **Andy Johnston** investigates.



David Clapp/OSF/Photolibrary.com

**S**ulfur is essential to life. Yet the most abundant biological molecule containing this element – dimethylsulfoniopropionate, or DMSP for short – is one most people have never heard of. This is not only because of its eleven syllables (though that is reason enough) but because DMSP is an offshore molecule, made by little-known organisms that live in the oceans, far from human gaze.

DMSP is produced in large amounts by myriad single-celled plants in the sea. In some of these plants it reaches concentrations equivalent to around ten

## It is astonishing that we still do not know of a single gene for DMSP synthesis.

teaspoons of sugar in a cup of tea. Although tiny, these marine plants, or phytoplankton, are so abundant that the total global annual production of DMSP approaches one billion tonnes. As well as plankton, many seaweeds and a few land plants make DMSP. In short: there's a lot of it about.

So, it is surprising that we are uncertain

of its exact function(s). People have suggested it is used as defence against predators, or it may protect organisms from the sun's ultraviolet light, too much oxygen, or the saltiness of the sea. Another idea is that it is simply a compound for storing sulfur.

Not only is DMSP important in its own right, but hundreds of millions of tonnes are used as food by marine microbes, and some of its breakdown products are themselves globally influential. In particular, the gas dimethyl sulfide (DMS) has several claims to fame. When released into the atmosphere from the oceans, it oxidises to sulfates.

These act as cloud condensation nuclei – they induce cloud formation over the oceans. And, in a very different

context, DMS is a chemical attractant for animals as diverse as tiny crustaceans, harbour seals and seabirds, from penguins to shearwaters. This makes sense of course: DMS is a signpost for planktonic food supplies. It even appeals to us – DMS is a component of that tangy, evocative smell of the seaside.

We set out three years ago to use genetics to understand how different bacteria break down DMSP, emitting the by-product DMS. The approach was fairly straightforward. We isolated bacteria that grow on DMSP and use the molecule as their sole carbon source. We chopped up their genomes into little bits of DNA and inserted these into *E. coli*, a bacterium which over the last decades has become the workhorse of the molecular biologist. We wanted to see if any of our engineered strains made DMS. No fancy instruments were required for this – our incubator smelled like a beach, when, to our delight, we succeeded.

We got our first bacterium, *Marinomonas*, from the roots of a saltmarsh grass called *Spartina* – one of the rare land plants known to make DMSP. By sequencing the gene (called *dddD*) responsible for making DMS production, we quickly gained useful information. Our team deduced the type of enzyme the *dddD* gene encoded (Class III Acyl CoA transferase, actually). But, some marine bacteria known to make DMS did not contain the *dddD* gene; they must employ other, completely different mechanisms. This was unexpected.

Using the clone-by-phone approach – grabbing genome data from online databases – we got hold of two of these bacteria and repeated the exercise. Sure enough, two wholly new genes popped up – one called *dddP* in a strain of *Roseovarius* and one called *dddL* in *Sulfitobacter*. By looking at these genes and the sequences of the proteins that these genes produced, we saw they were indeed wholly different from each other – and from the original *dddD*. Although all three enzymes, ‘D’, ‘L’ and ‘P’, drive the reaction that releases DMS from DMSP, the way they do it is not the same. It is like taking Route 66 from Chicago to Los Angeles by Cadillac or wagon train – both make the same trip, but the methods used are poles apart.

One of the many great powers of molecular genetics is that once a gene of interest is sequenced, one can ask if it, or something very similar, occurs in other organisms. Although we could see that the three *ddd* genes existed in some bacteria that were already known to make DMS, this form of genome-peeping also threw up some real surprises.

We saw *dddD* in some terrestrial bacteria that formed symbioses with plants such as beans and clovers. No one had suspected these bacteria of making DMS before. Even more remarkably, *dddP* occurs in some fungi that cause disease in crop plants. Although fungi are microbes, they are far more closely related to plants and animals than they are to bacteria.

The explanation for this remarkable distribution of the *ddd* genes is that they have been moved around by clandestine coupling between organisms that are totally

Filtering a water sample during Craig Venter’s Global Ocean Sampling expedition.



J. Craig Venter Institute

## It is like taking Route 66 from Chicago to Los Angeles by Cadillac or wagon train – both make the same trip, but the methods used are poles apart.



Surveying Stiffkey Marsh, North Norfolk, for *Spartina anglica*, one of the few land plants that makes DMSP.

unrelated or, in the jargon, by ‘horizontal gene transfer’. This is increasingly recognised as a driving force for microbial evolution, but simply does not occur in the rather less adventurous sex lives of plants and animals.

And, we can see this even in organisms that have never been cultured, whose presence is known by looking directly at their genes. Most notable of these efforts are Craig Venter’s Global Ocean Sampling expeditions, in which millions of genes were sequenced, directly, from such uncultured marine bacteria.

By screening these so-called metagenomic sequences, we could, from the comfort of our own laptops, say with some confidence how abundant *dddL*, *dddD* and *dddP* are in the Gulf of Mexico, the Galapagos or off the coast of Maine. (Might have been more fun being there, though.)

Given the importance of DMS production, from bird behaviour to global climate, it is surprising that scientists have only just begun to use genetics to investigate it. So, this is just the start – we need to know more about the basic properties of the enzymes that make DMS and how the genes that encode them are regulated. And, beyond that, two big questions come to mind.

The first refers to the remarkable diversity of DMS production, the types of organisms that do it and how they do it. What are the particular *Ddd* enzymes and the species that are most important in breaking down DMSP in the oceans, not to mention other hotspots where DMS production is particularly high, such as corals? The numbers of the various *ddd* and

*dmdA* genes indicate their abundance, but our census only provides a baseline – the different enzymes may be more or less stable, more or less efficient, for example. And, since similar genes occur in very different organisms, these genetic headcounts do not necessarily tell us which microbe is doing the business. And, to complicate things, what of those bacteria with multiple different ways of degrading DMSP? How do they decide which particular pathway to use under a given set of circumstances?

And the second big challenge? Well, if it was surprising that genes for DMSP breakdown were only discovered in 2006, it is astonishing that we still do not know of a single gene, or purified enzyme for its synthesis, in any organism. If we make mutants that no longer make DMSP, this will let us nail its main functions and may reveal if, like the genes for its breakdown, there is unexpected and rampant biodiversity in the ways in which it is made. ❖

### MORE INFORMATION

Andy Johnston is professor of biology at the University of East Anglia.  
Email: a.johnston@uea.ac.uk

The work on DMSP catabolism at the University of East Anglia School of Biological Sciences was funded by NERC and the Biotechnology and Biological Sciences Research Council, who respectively supported the post-doctoral work of Jonathan Todd and Andy Curson in Andy Johnston’s laboratory.