Plastic Age: How it's reshaping rocks, oceans and life

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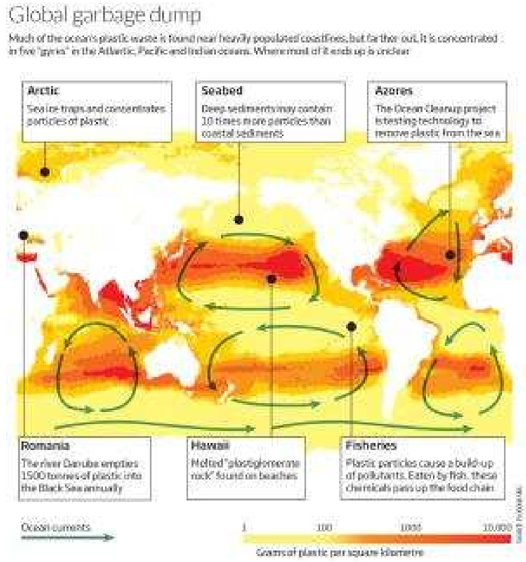

Dawn of the Plasticene Age *(Image: Bigshot Toyworks)*

The ultimate fate of waste plastic is hazy – but we know future geologists will find traces of a fleeting era written in the stones. Welcome to the Plasticene

ONE million years from now, geologists exploring our planet's concrete-coated crust will uncover strange signs of civilisations past. "Look at this," one will exclaim, cracking open a rock to reveal a thin black disc covered in tiny ridges. "It's a fossil from the Plasticene age."

Our addiction to plastics, combined with a reticence to recycle, means the stuff is already leaving its mark on our planet's geology. Of the 300 million tonnes of plastics produced annually, about a third is chucked away soon after use. Much is buried in landfill where it will probably remain, but a huge amount ends up in the oceans. "All the plastics that have ever been made are already enough to wrap the whole world in plastic film," palaeobiologist Jan Zalasiewicz of the University of Leicester, UK, recently told a conference in Berlin, Germany. It sounds enough to asphyxiate the planet.

What will become of this debris? Landfill will stay buried until future generations rediscover it, but it's a different story for plastic that reaches the ocean. Some is washed up on beaches or eaten by wildlife. Most remains in the sea where it breaks down into small fragments. However, our knowledge of its ultimate fate is hazy. We don't really know how much plastic pollution is choking the seas. Nor do we understand its potential impact on the health of sea creatures and those who eat them. Nor do we have any idea where the stuff will end up in the distant future – will plastic debris break down entirely or will it leave a permanent mark?

The scale of our plastic problem became clear in 1997 when US oceanographer Charles Moore came across a huge area of floating trash – now dubbed the "Great Pacific Garbage Patch" – as he sailed across the Pacific Ocean from Hawaii to California. It was soon found that other oceans contained similar concentrations of rubbish.

These patches are created by surface currents, or gyres, which meander from coast to coast in circular loops on either side of the equator – clockwise in the northern hemisphere and anticlockwise in the southern hemisphere. And just as noodles gather in the centre of a bowl of stirred soup, anything caught in these currents is likely to drift into the middle. The five biggest concentrations of marine debris are in the Indian Ocean, the North and South Pacific and North and South Atlantic (see Map). This year Moore reported finding one spot in the Pacific gyre where there was so much accumulated rubbish you could walk on it.

Most of the debris is plastic. "On a global basis, about 70 per cent of all the litter in the sea is plastic," says marine biologist Richard Thompson of Plymouth University, UK.

How much is that? To find out, an international team headed by Marcus Eriksen at the Five Gyres Institute in Santa Monica, California, gathered data on the amount of plastic caught in nets towed behind research ships on 24 expeditions over a period of six years. This was added to records from spotters who stood on the decks of these ships and counted every piece of plastic they observed. The team estimate that 5.25 trillion pieces of plastic, weighing more than 260,000 tonnes, are currently floating at sea. Most is big stuff like buckets, bottles, bags, disposable packaging and polystyrene foam. The highest concentrations found were on the order of 10 kilograms of plastic – equivalent to about 800 water bottles – per square kilometre. Given the huge size of the oceans, this represents an incredible amount of trash.

What is most surprising, however, is that Eriksen and his team didn't find more plastic. According to PlasticsEurope, a plastics industry trade association, production has increased from 1.5 million tonnes annually in the 1950s to 299 million tonnes in 2013. Given that it's often cheaper for manufacturers to produce virgin material than to buy and use recycled plastic, much of this material is thrown away after use. For example, in 2012, only 9 per cent of the 32 million tonnes of plastic waste generated in the US was recycled.

Eriksen's study found less than 0.1 per cent of the plastic produced each year. This is close to the result of a 1975 survey by the US National Academy of Sciences, which estimated that 0.1 per cent of global plastic production makes its way into the ocean annually – equivalent to about 300,000 tonnes this year.

More surprisingly, the amount of plastic in the gyres doesn't seem to be changing. A team led by oceanographer Kara Lavender Law of the Sea Education Association in Woods Hole, Massachusetts, combed through decades of data recording plastic collected during research voyages in the North Atlantic and the Caribbean Sea, and found that the amount was fairly constant (*Science*, vol 329, p 1185). "Despite a strong increase in discarded plastic, no trend was observed in plastic marine debris in the 22-year data set," they reported. "Where is all the plastic?" asks Law.

The answer could be that plastic breaks down more quickly than we thought, as the action of sunlight and waves degrades it into small fragments. The missing plastic may exist as a soup of tiny pieces suspended in the water column.

In July 2014, Andrés Cózar of the University of Cadiz in Spain, working with a team of international marine scientists, calculated the total amount of plastic fragments floating in the seas at between 7000 and 35,000 tonnes (*PNAS*, vol 111, p 10239). Eriksen's team reckons there are 35,500 tonnes of plastic particles measuring less than 5 millimetres across (*PLoS One*, e111913). But both figures seem low – a million tonnes of these tiny pieces should have been found in the water.

Through the net

There are a few possible explanations. Plastic particles less than a third of a millimetre across will slip through the trawl nets because the mesh size is too large, so a huge amount of plastic could have been overlooked.

Thompson believes that some plastic might also be locked up in ice. In June 2014, his team reported finding up to 234 particles of plastic per cubic metre of Arctic sea ice – several orders of magnitude higher than in the heavily contaminated waters of the gyres. He suggests that as seawater turns to freshwater ice, it traps and concentrates small particles. Given that there are about 6 million square kilometres of sea ice, this could represent a huge reservoir of plastic. If the ice melts, this material will be released back into the sea.

More recently, Thompson's team has discovered another place where plastic is accumulating. In December, the group published data showing that tiny pieces of plastic and other polymers, mostly in the form of fibres, are up to 10,000 times more abundant in deep-sea sediments in the Atlantic Ocean, the Mediterranean Sea and Indian Ocean than in surface waters. Samples contained up to 800,000 particles per cubic metre. The small number of samples – just 12 sediment cores taken from seven expeditions, and four coral samples – was small, but they found plastic debris everywhere they looked.

Could deep-sea sediments hold the key to the missing plastic? It seems likely, given that there are about 300 million square kilometres of seabed.

Some plastic particles are heavier than water and will sink, while others will become colonised by creatures such as phytoplankton, or clump together with other particles and drift downwards towards the seabed like falling snow. This process could be aided by ocean currents, Thompson says.

Confirming this model won't be easy. We don't know the density of minute particles of plastic in the sea, says Law, because we don't have a good way to measure anything there that is smaller than about 0.5 millimetres. But marine geochemist Tracy Mincer of the Woods Hole Oceanographic Institution has a solution. His group is using a special laser scanning microscope to investigate seawater. "We have just begun this work and are seeing plastics in the 2-20 micrometre range," he says.

There are similar gaps in our knowledge when it comes to understanding what impact this stuff is having on marine creatures. We know larger creatures like birds, turtles, fish and whales confuse plastic trash with food, and then choke to death or die of starvation as their stomachs become clogged. But the effect on smaller sea dwellers is far more complex.

For some microbes, plastic is the equivalent of a hotel buffet table. Any hard surface in the ocean becomes a collection plate for nutrients, says Mincer. This is why structures like oil rigs or sunken ships become oases of life.

Other species, too, are taking advantage of the floating debris. Across the Great Pacific Garbage Patch, the insect species *Halobates sericeus*, a type of water strider, deposits its eggs on the floating plastic. As plastic debris has increased in the Pacific, so too has these insects' reliance on it.

H. sericeus isn't alone. Erik Zettler of the Sea Education Association, working with Mincer and Linda Amaral-Zettler of the Marine Biological Laboratory in Woods Hole, discovered that the plastics are even providing an entirely new ecosystem – one Amaral-Zettler dubs the "plastisphere". Like the rhizosphere of microbes colonising roots, there is an entire "cast of characters that colonise plastic", says Mincer. The ones that are attracting most of his attention are bacterial strains called *Vibrio*. "These are very good at colonising surfaces and can be pathogenic as well," he says. There have been cases of people getting a hook caught in the hand while fishing at sea and coming down with

Vibrio infections that are difficult to treat, he says.

Pathogenic *Vibrio* colonise the intestines of fish, empty the tissues of nutrients and salts, and break down blood cells to collect iron. Once excreted, they can attach themselves to a piece of plastic, regroup and wait to attack the next fish that mistakes their home for plankton.

Viruses might also find plastic useful. "We can't say confidently 'that is a virus' but we do see viral signals in the metagenomic data sets from plastic," says Mincer. It's not surprising, he says: there are far higher concentrations of viruses in the water column than there are microbial cells. "The more I look at genomic sequences, the more I tell my team to wash their hands and be careful," he says.

There are other reasons to worry about plastics. There is evidence that plastic microparticles are entering the food chain. *Vibrio*, for example, are bioluminescent, and can create a spectacular blue-green glow in the water. "During midnight tows in the summer, you frequently see the plastic glowing in the dark," says Mincer. The fact that plastic particles loaded with harmful bacteria mimic food using bioluminescence "is diabolical in its own way", he says.

Microplastics aren't good news for fish. The particles can reduce the efficiency of food absorption, and as they break down, release additives such as phthalates and bisphenol A, which can mimic hormones, as well as toxic flame retardants. Plastics also act like sponges for chemicals in seawater, absorbing organic pollutants such as polychlorinated biphenyls, and pesticides such as DDT. Studies suggest that pollutants stuck to plastics can poison fish.

We might feel these effects too. According to environmental toxicologist Lisbeth Van Cauwenberghe of Ghent University in Belgium, eating shellfish can expose you to 11,000 pieces of microplastic each year. Her tests show that commercially grown mussels contained an average of 0.36 microplastic particles per gram of tissue. Oysters contained slightly more. You would have to eat a lot of this seafood, says Van Cauwenberghe, "but marine microplastics could pose a threat to food safety".

So what will happen to all our discarded plastic in the long term? Rocks on Kamilo beach, a remote spot in Hawaii, may hold one answer. Here hikers often burn plastic in campfires and the sand is now strewn with "plastiglomerates", a mix of sand and artificial materials, all glued together with melted plastic that has cooled and hardened. Although these have so far only been found in relatively small amounts, it is conceivable that similar "plasticene" deposits might form on beaches where lava flows run, or where forest fires and extreme temperatures occur, says geologist Patricia Corcoran at the University of Western Ontario in Canada. Corcoran and her colleagues have collected hundreds of fragments of this new "rock" and suggest it could eventually become embedded in the geological record.

Zalasiewicz agrees. "We are creating novel materials, which are very widespread in the environment. How do we know these will preserve?" Zalasiewicz works on fossilised plankton that leave a very small and delicate shell of organic polymers. "We know how they change when they enter the rock strata," he says: they lose hydrogen, nitrogen and oxygen, leaving carbon films, or become coated with iron sulphides or carbonates which leave fossil impressions in the strata. Similarly, as temperatures rise over time, pieces of buried plastic will begin to darken as the polymers break down, eventually releasing tiny amounts of oil and gas, and leaving a residue of brittle carbon. "On that basis, I see no problem in plastic drink bottles or CDs being preserved as fossils in the future – not exactly as they are, but as recognisable remnants," he says.

"What I would really like to see would be the preservation of vinyl long-playing records – good enough to preserve details of the grooves," says Zalasiewicz. And why not? Fossil worms preserved in 500 million-year-old Burgess Shale rocks show signs of fine grooves that would have created colours by refraction. These grooves are separated by less than a micrometre. Given that the grooves on LPs are around 20 times wider, there is a chance they, too, could survive, given the right conditions. "That would mean fossilisation of the patterns of sounds," says Zalasiewicz – music locked up in the geological record. So plastic could leave more than one type of rock for future generations to discover.

Correction, 29 January 2015: *When this article was first published, it misstated the abundance of tiny pieces of plastic that Richard Thompson's team found in deep-sea sediments.*

This article appeared in print under the headline "Dawn of the plasticene age"

Stemming the flow

Huge amounts of plastic enter the oceans via rivers. Major components of this waste are fibres from synthetic clothes released during washing. It also contains microbeads, which are tiny plastic spheres used in many cosmetics. Water treatment plants can't filter them out, so they all end up in rivers.

In 2014, the state of Illinois passed the world's first ban on microbeads, after studies showed that the tiny plastic particles are a common pollutant floating on the surface of the Great Lakes. US senator Kirsten Gillibrand is pushing for legislation that will ban microbeads in all US cosmetics. Some manufacturers have already acted: Unilever, Colgate-Palmolive, Procter & Gamble and Johnson & Johnson have all committed to eliminating these beads from their products.

Meanwhile, some groups are hoping to harvest plastic from the gyres. Last year, an organisation called The Ocean Cleanup completed a trial of a floating boom system in the Atlantic near the Azores. Based on the results, the group estimates that floating debris in a single gyre could be cleared in five to 10 years without harming wildlife. The organisation is now raising funds for a pilot project which could begin in 2018.

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