MARINE BIOGEOCHEMISTRY

Phytoplankton in a witch's brew

Natural seafloor hydrocarbon seeps are responsible for roughly half of the oil released into the ocean. As these oils and gases rise to the surface, they transport nutrients upwards, benefiting phytoplankton in the upper sunlit layer.

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Potent brews have been associated with witch's curses at least since Shakespeare wrote in *Macbeth* "Double, double toil and trouble; Fire burn, and cauldron bubble", but a brew of hydrocarbons rising from the ocean's floor appears more a blessing than a curse to phytoplankton in the Gulf of Mexico. We are all familiar with the devastating impacts of catastrophic oil spills. Natural seafloor petroleum releases, however, occur much more slowly and can have very different impacts on marine ecosystems. Hydrocarbon seeps are common along continental margins and contribute roughly half of the oil released to the ocean each year[1]. Energy-rich compounds emerging from these seeping vents stimulate adjacent benthic sediment communities. As the oils and gases rise towards the surface — often over 1000 metres — they also fuel microbial communities in the overlying water column. Writing in *Nature Geoscience*, D'souza and colleagues[2] report that these deep hydrocarbon emissions can even influence the phytoplankton living in the topmost layer illuminated by sunlight.

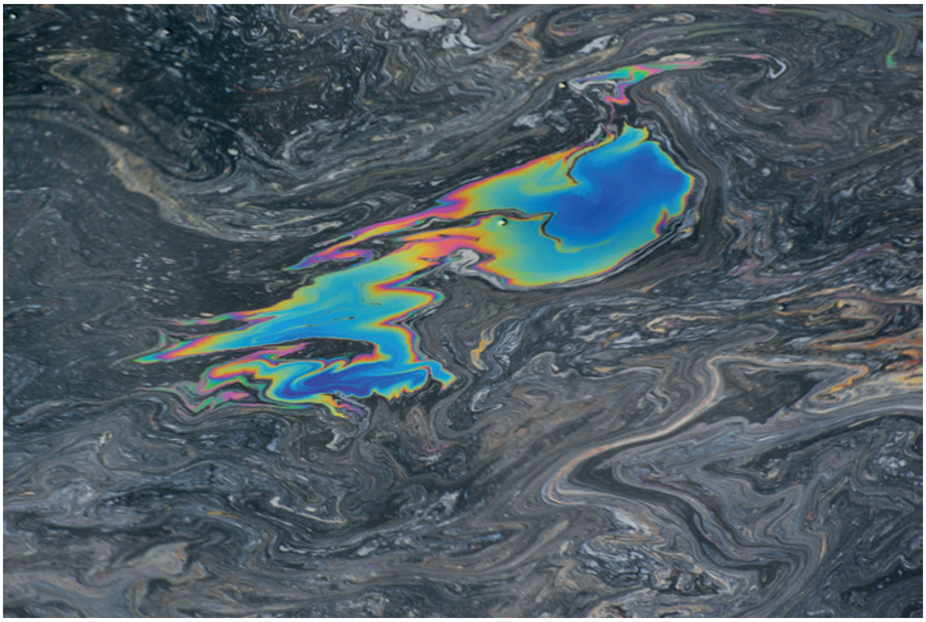

Figure 1 | A natural seafloor hydrocarbon seep on California's continental margin creates a surface oil slick reflecting sunlight in a rainbow of colours. D'souza and colleagues[3] show that a plume of hydrocarbons rising from the seafloor can stimulate phytoplankton chlorophyll levels thousands of metres above.

Phytoplankton are single-celled organisms that live a divided life, in the sense that they require sunlight from above and nutrients from below. In 70% of the global ocean area, the surface sunlit layer is permanently stratified[3], meaning that a warm and buoyant layer of nutrient-poor water resides over a colder and more dense layer of nutrient-rich water. Under such conditions, phytoplankton chlorophyll concentrations are low in the upper layer and then show a distinct peak in the lower layer, referred to as the deep chlorophyll maximum. Chlorophyll concentrations can be high here because phytoplankton need more chlorophyll to take advantage of the available nutrients under the lower light, or because the nutrients allow the phytoplankton to become more abundant[4]. The deep chlorophyll maximum is aligned with the nutricline, a steep gradient in nutrient concentrations that marks the transition between nutrient-limited growth above and light-limited growth below. Thus, the depth of the nutricline is not simply determined by light level, but also by the severity of nutrient limitation in the upper water column.

In addition to these basic nutrient and light needs, phytoplankton populations are regulated by loss processes, such as viral infection, parasitism and grazing by zooplankton herbivores. For phytoplankton concentrations to change over space or time, one or more of these constraints (light, nutrients or losses) must be altered.

D'souza and colleagues[2] focus on the effects of natural seeps on ocean phytoplankton in the region of the Gulf of Mexico's continental shelf just south of the Mississippi river outflow. Deep hydrocarbon seeps are common in this region and they create surface ocean oil slicks (Fig. 1) that can be detected from space using a synthetic aperture radar (SAR). D'souza *et al.* use SAR data to divide their study region into areas where surface slicks are frequent and infrequent. They then evaluate the impacts that these seeps have using ship-based measurements of phytoplankton within the water column and satellite measurements of ocean colour, which provide regional maps of phytoplankton chlorophyll at the surface.

The ship measurements show that deep in the sunlit zone, nutrient concentrations are higher in waters that are above a seafloor hydrocarbon seep relative to non-seep locations. They attribute this difference to turbulence-based physical transport of nutrient-enriched deep ocean water that is facilitated by buoyant plumes of bubbles originating at the seafloor seep. Consistent with this view, they find that water temperatures where nutrients are enriched over seep sites are colder than water temperatures at the same depths over non-seep sites. These temperature differences suggest that deep, cold water has risen to the sunlit zone above the seep sites. D'souza *et al.* then show that this nutrient enhancement in the lower sunlit zone is paralleled by roughly a doubling in phytoplankton chlorophyll.

The reason for this chlorophyll response is fascinating. The first part of the story is that the nutricline and deep chlorophyll maximum over non-seep sites in the study by D'souza and colleagues were located at a depth of approximately 100 metres. In contrast, over a hydrocarbon seep, the nutricline and deep chlorophyll maximum were about 20 metres shallower. The reason for this change in depth is that increased vertical nutrient transport over the seep allowed phytoplankton populations in the 80 to 100 metre layer to grow faster. Since faster cell division requires more sunlight energy to drive photosynthesis[5], the deep chlorophyll maximum increased in size and moved closer to the surface. The second part of the story is that increases in phytoplankton growth rate are paralleled by increases in phytoplankton grazers and the predators that eat these grazers. The net effect of this altered food web is an increase in phytoplankton biomass[6]. Thus, the hydrocarbon seep is influencing light, nutrient and loss conditions for the phytoplankton.

D'souza and colleagues' other main finding — that chlorophyll concentrations at the surface rather than just at the chlorophyll maximum are elevated over seep sites — is more difficult to reconcile with a simple cause–effect relationship. The problem here is that the enhanced nutrient transport causing a larger and shallower deep chlorophyll maximum apparently does not extend to the shallowest depths detected by satellite ocean colour sensors. For the emerging hydrocarbon plume to alter chlorophyll levels in these high-light, low-nutrient phytoplankton, another mechanism must be at play. D'souza *et al.* argue that the apparent change is not an artefact of oil slicks impacting the satellite retrieval of chlorophyll concentration, but a definitive explanation remains to be found.

We do know, however, that in the Gulf of Mexico, hydrocarbons in the surface layer are rapidly degraded by a diversity of bacteria. If a portion of the energy gained from hydrocarbon metabolism by these bacterial communities is used for nitrogen fixation, then it seems plausible that the phytoplankton community may benefit from this new nutrient source as it is recycled through the microbial food web. Alternatively, a rise in bacterial abundance may shift the feeding preferences of microzooplankton, which are the dominant grazers of phytoplankton in the area studied by D'souza *et al.*, towards bacteria. The true answer to this mystery awaits future investigation.

Hydrocarbon seeps have long been known to support unusual communities of organisms on the seafloor. D'souza *et al.*[2] demonstrate that these seeps can also have much more distant impacts on phytoplankton at the surface of the Gulf of Mexico. With hydrocarbon seeps common along many continental margins, and even under Antarctic ice shelves, it will be interesting to see how this bubbling deep ocean brew is altering surface phytoplankton dynamics in other regions of the world's ocean. ❐

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