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Anthropogenic pollution in deep-marine sedimentary systems—A geological perspective on the plastic problem

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While surveying a deep-marine canyon to examine seafloor bedforms, Zhong and Peng (2021, p. 581 in this issue of *Geology*) made a shocking discovery. The results show large litter piles (mostly plastic) closely associated with geomorphological features of the nearly 2-km-deep canyon floor. While this is not the first paper to document trash on the seafloor (e.g., Goldberg, 1997; Thompson et al. 2004; Pham et al. 2014), the spatial distribution of these piles, constrained by high-resolution geological and geomorphological data, allow inferences to be made of the flow processes responsible for transporting and depositing the waste.

Environmental pollution caused by uncontrolled human activity is occurring on a vast and unprecedented scale around the globe. Of the diverse forms of anthropogenic pollution, the release of plastic into nature, and particularly the oceans, is one of the most recent and visible effects (Eriksen et al. 2014). Direct measurement and monitoring of plastic contamination and flux in terrestrial environments has advanced (e.g., Hurley et al., 2018), but despite a developing understanding of the fluvial delivery of plastic to the oceans (e.g., Lebreton et al., 2017), and recent advances in seafloor data collection, the dispersal of pollutants in the deep sea remains largely obscured. A few studies have related the plastics incorporated within seafloor sediment to the processes that transported and deposited them: for example, Pierdomenico et al. (2019) showed how flash floods generated litter-bearing hyperpycnal flows that entered a submarine canyon; Brandon et al. (2019) were able to reconstruct an exponential increase in microplastics sequestered within millimeter-scale seafloor laminae of the Santa Barbara channel (offshore California, USA); Kane et al. (2020) showed how vast quantities of microplastic fibers and fragments were transported by bottom currents and deposited within contourite drifts.

Marine litter is defined as "any persistent, manufactured, or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (UNEP, 2009); marine litter includes wood, metals, glass, rubber, textiles, and paper. Plastic is generally considered to be the dominant component of marine litter, due to its durability and the large volume produced (Andrady, 2011). As well as 'solid' litter, particulates and solutes such as persistent organic pollutants (POPs) (Jamieson et al. 2017) and pesticides such as DDT (dichloro-diphenyl-trichloroethane) (Paull et al., 2002) are a growing problem in deep-sea sediments.

Plastics are versatile, durable, inexpensive to manufacture, and ubiquitous in modern society. Unfortunately, the properties that make plastics useful also means that they are often considered to be disposable, and are long-lived in the natural environment. Much plastic waste is not disposed of responsibly, from the individual consumer to societal and governmental levels. As a consequence, discarded plastic is found on the highest mountains (e.g., Allen et al. 2019), in the deepest ocean trenches (e.g., Bergmann et al. 2017), and everywhere else in between. Nano- and microplastics are a particularly insidious form of anthropogenic pollutant: tiny fragments and fibers may be invisible to the naked eye, but they are ingested with the food and water we consume, and absorbed into the flesh of organisms. Owing to their small size and relatively large surface area they act as preferential vectors for other contaminants such as POPs, and biofilms, which can accumulate over decades on their surfaces (e.g., Caruso, 2018).

GEOSCIENCES ARE VITAL TO UNDERSTAND PLASTIC DISTRIBUTION AND PLAN MITIGATION EFFORTS

What has this got to do with geoscientists? Geoscientists are perhaps uniquely placed to understand the long-term fate of plastic waste, and other pollutants, in the natural environment. Geomorphologists, sedimentologists, stratigraphers, and geochemists are all involved in the study of the sedimentary record: nature's canonical book of past conditions, climates, and Earth movements. This record provides a way to understand the present and look into the future to predict the fate of sediment and pollutants. Anthropogenic pollutants such as plastic become another type of sedimentary grain and deposit, moving in flows and deposited according physical properties; e.g., size, density, and shape (e.g. Pohl et al. 2020).

The recent publication by Zhong and Peng triggered this Focus article (and our outcry), showing that even a submarine canyon ~150 km from the coast can receive large amounts of plastic litter. The litter is eventually delivered to and accumulates in a submarine canyon, starting its largely unknown journey into the deepest reaches of our oceans (Fig. 1).

There is still a common view in many studies that plastic deposited on the seafloor remains buried. And some undoubtedly does, but as geoscientists we know that sediment storage is often transient; e.g., in submarine canyons, slopes, and channels, sediments (and pollutants) keep moving, often episodically over tens to many thousands of years, until they reach their final resting place and become part of the stratigraphic record (e.g., Fildani, 2017; Vendettuoli et al., 2019). Recent work from modern deep-sea fans show that these features capture sediment (and pollutants) from the whole of their associated catchment, recording changes over millennial (10^3–10^4 yr.) time scales (Hessler and Fildani, 2019). Accordingly, we do not know the final resting place of much of the seafloor plastic.

As plastics degrade, they can leach out toxic substances from plasticizers, such as phthalates. However, studies of chemical and biological plastic degradation in deep seafloor sediments are almost entirely lacking (e.g., Krause et al. 2020). If some plastics can survive for >1000

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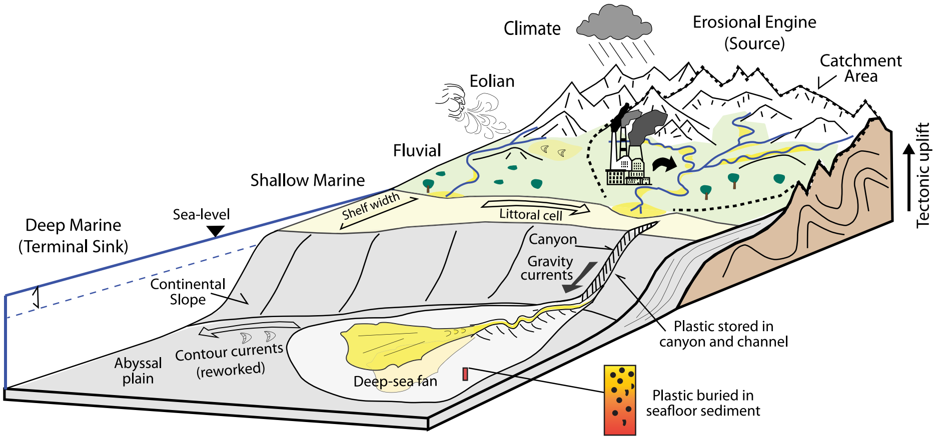

Figure 1. Pollutants, including plastic, reach deep-sea fans through linked sediment routing systems, as well as from outside the associated catchment(s), via near-shore and shelfal currents (i.e., littoral cells), eolian transport, surface currents, and direct input from oceanic sources such as shipping and fishing. Modified from Hessler and Fildani (2019).

years in terrestrial environments, how long do they last in ocean trenches that are kilometers deep, dark, cold, and at high pressure? How long does it take macroplastic to break down into microplastics and nanoplastics in the deep sea? What is the impact of this degrading plastic, toxic surface coatings, and biofilms on the biota living on the seafloor and below?

OUR OPPORTUNITY: GEOSCIENCES CAN MAKE A DIFFERENCE

It is not practical to extract the existing microplastics or larger plastics from the seafloor—to do so could be more damaging than to leave them in place, possibly akin to the scale of devastation caused by deep-sea mining. While it is incumbent on policy makers to take action now to protect the oceans from further harm, we recognize the roles that geoscientists can play. Legacy plastic pollution has led to its present-day distribution on the seafloor and in the sedimentary record. If plastic pollution stopped today, microplastics would still be created for many decades by plastic breakdown. The techniques we can use to understand that legacy can also be used to record the downstream effects of mitigation efforts, and to predict the future of seafloor plastics. We do not suggest that this is an entirely geological problem, but the broad global effort on marine pollution, and to an extent terrestrial pollution, is often lacking the insights that geoscientists can offer. We understand the biases of spot sampling in sedimentary systems; we understand the spatial variability in sedimentation and burial rates, the transient nature of the stratigraphic record and its surprising preservation, and the unique geochemical environments found in deep-sea sediments. Our source-to-sink approach to elucidate land-to-sea linkages can identify the sources and pathways that plastics take while traversing natural habitats, and identify the context in which they are ultimately sequestered, and the ecosystems they affect. This will happen by working closely with oceanographers, biologists, chemists, and others tackling the global pollution problem.

There are undoubtedly significant challenges ahead for geology, which is often portrayed as an applied science focused around exploitation and management of Earth's resources. However, we can, and should, be part of the solution. Our deep-time perspective is critical to addressing many societal challenges, such as the behavior of fluids in the subsurface (CO_2, water), and predicting the future effects of climate change based on the geological record; we can add to that our unique insights into the long-term fate of anthropogenic waste sequestered in the sedimentary record.

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This contribution is not intended as a complete review, and for that reason there are many important contributions that we could not include.

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