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Microplastics contaminate the deepest part of the world's ocean

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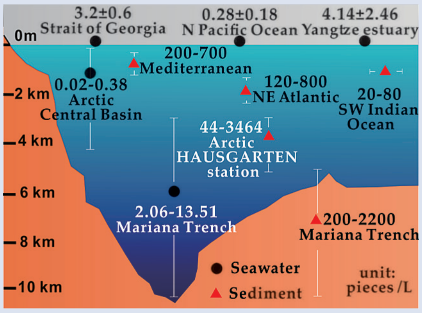
Abstract



Millions of metric tons of plastics are produced annually and transported from land to the oceans. Finding the fate of the plastic debris will help define the impacts of plastic pollution in the ocean. Here, we report the abundances of microplastic in the deepest part of the world's ocean. We found that microplastic abundances in hadal bottom waters range from 2.06 to 13.51 pieces *per* litre, several times higher than those in open ocean subsurface water. Moreover, microplastic abundances in hadal sediments of the Mariana Trench vary from 200 to 2200 pieces *per* litre, distinctly higher than those in most deep sea sediments. These results suggest that manmade plastics have contaminated the most remote and deepest places on the planet. The hadal zone is likely one of the largest sinks for microplastic debris on Earth, with unknown but potentially damaging impacts on this fragile ecosystem.

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Letter

Plastics are worldwide marine pollutants, accumulating in seawater and sediments (Hammer *et al.*, 2012; Cózar *et al.*, 2014; Ivar do Sul and Costa, 2014). It was estimated that between 4.8 and 12.7 million metric tons of plastic waste entered the ocean in 2010 and this mass could increase by one order of magnitude by 2025 (Jambeck *et al.*, 2015; Geyer *et al.*, 2017). Besides the ocean surface (Thompson *et al.*, 2004; Barnes *et al.*, 2009; Van Sebille *et al.*, 2015; Chae and An, 2017), potential sinks for plastics include deep sea biota (Oliveira *et al.*, 2012), the water column (Courtene-Jones *et al.*, 2017; Kanhai *et al.*, 2018) and sediments (Bergmann *et al.*, 2017), where broken plastics exist as microplastics (<5 mm in size) (Arthur *et al.*, 2009; Hidalgo-Ruz *et al.*, 2012). So far, however, microplastics in the deepest ocean remain largely unexplored.

The hadal zone, which is the deepest region (6000-11000 m) of the oceans lying within trenches, represents 1-2 % of the global benthic area (Jamieson *et al.*, 2010). Although it was reported that toxic anthropogenic pollutants (*e.g.*, persistent organic pollutants) have reached the deepest ocean on Earth (Jamieson *et al.*, 2017; Dasgupta *et al.*, 2018), little is known about the nature of anthropogenic microplastics in this deep and remote environment. To evaluate the abundance, distribution, and fate of microplastics in the hadal zone, we collected bottom water samples and sediment samples at depths of 2500-11000 m and 5500-11000 m, respectively, from the southern Mariana Trench, where the Challenger Deep, the deepest point on Earth, is situated (Fujioka *et al.*, 2002) (Fig. 1).

Identification by optical microscope and Raman spectrometer confirmed that microplastics are abundant in hadal bottom water (Fig. S-1). The microplastics are fibrous, rod-like, and roundish in shape, and mostly blue, red, white, green, and purple in colour. Plastic microfibres dominate in all the microplastics and are commonly 1-3 mm in length in seawater samples and mostly 0.1-0.5 mm in sediment samples (Table S-4). The microplastic abundances in bottom waters range from 2.06 to 13.51 pieces *per* litre and become more concentrated with depth (Fig. 2) with one exception at depth of 6802 m, reaching 13.51 pieces *per* litre. At 10903 m, the microplastic abundance reaches 11.43 pieces *per* litre, which is four times higher than that reported in the subsurface water of open seas, including the NE Pacific Ocean (Desforges *et al.*, 2014), South Pacific subtropical gyre (Eriksen *et al.*, 2013), North Pacific Gyre (Goldstein, 2012), North Atlantic Ocean (Courtene-Jones *et al.*, 2017), and the Arctic Ocean (Bergmann *et al.*, 2017; Kanhai *et al.*, 2018) (Table 1). The high abundance of microplastics in hadal bottom water is also comparable to that reported in coastal waters, for example, in the Yangtze River and the Strait of Georgia, which are regarded as heavily polluted by microplastics (Desforges *et al.*, 2014; Zhao *et al.*, 2014).

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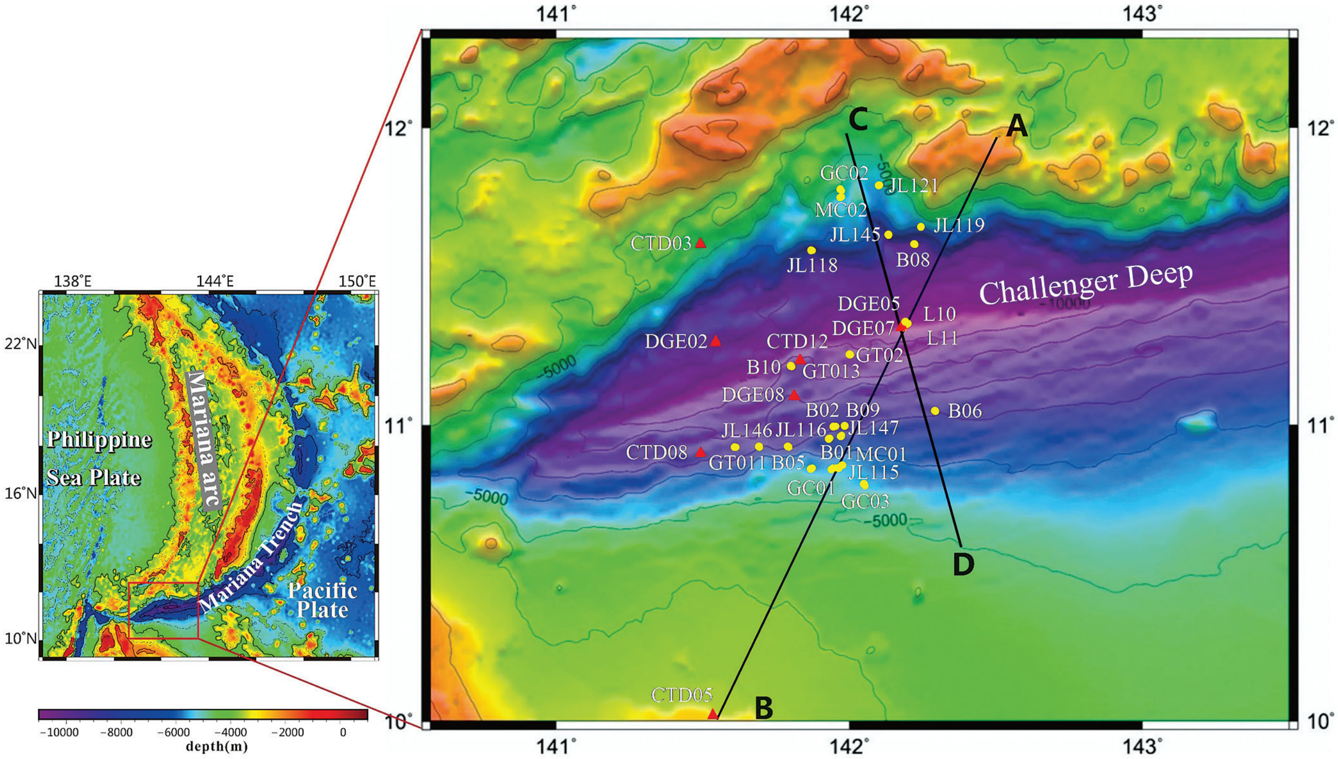

Figure 1 Sampling location map of Mariana Trench seawater (in red triangles) and sediments (in yellow circles). Please see Tables S-1 and S-2 for sampling details.

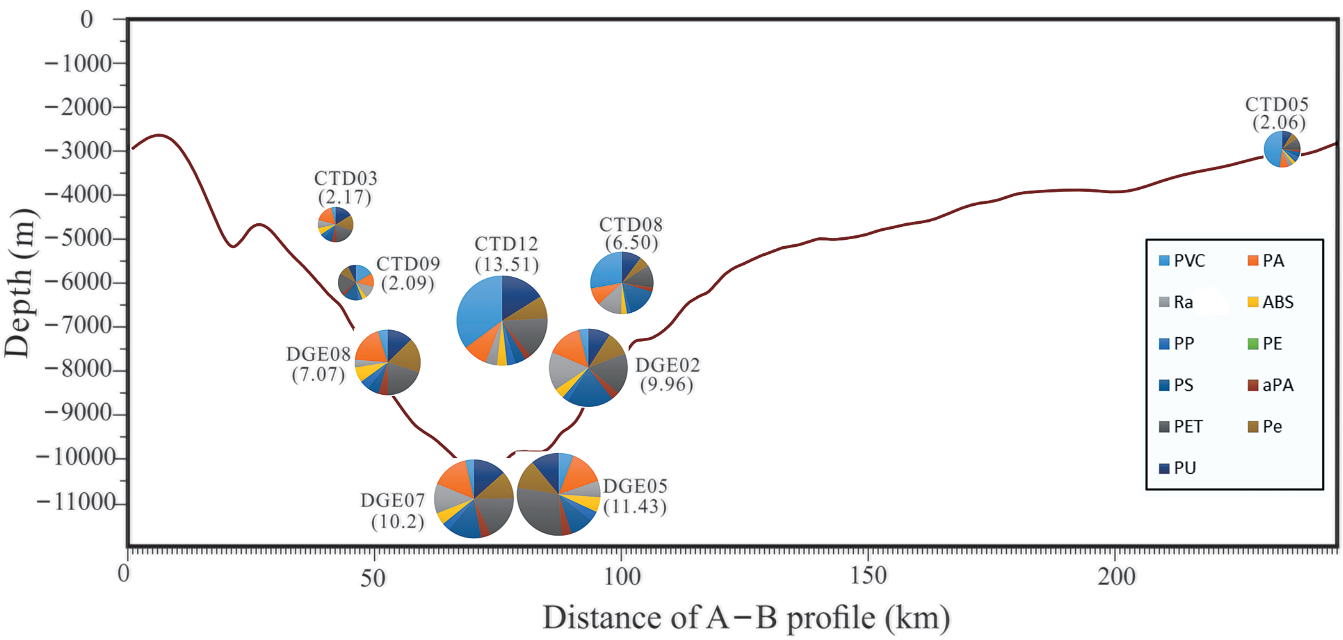

Figure 2 Profile of microplastic abundances and compositions in water samples from Mariana Trench. Pie charts represent the microplastic compositions and numbers in the bracket are the microplastic abundances with units of pieces *per* litre. PVC-polyvinyl chloride, PA-polyamide, Ra-rayon, ABS-acrylonitrile butadiene styrene, PP-polypropylene, PE-polyethylene, PS-polystyrene, aPA-aromatic polyamide, PET-polyethylene terephthalate, Pe-polyester, PU-polyurethane. The X-axis corresponds to the crossline from point A (12 °N, 142.5 °E) to point B (9.8 °N, 141.43 °E) in Figure 1.

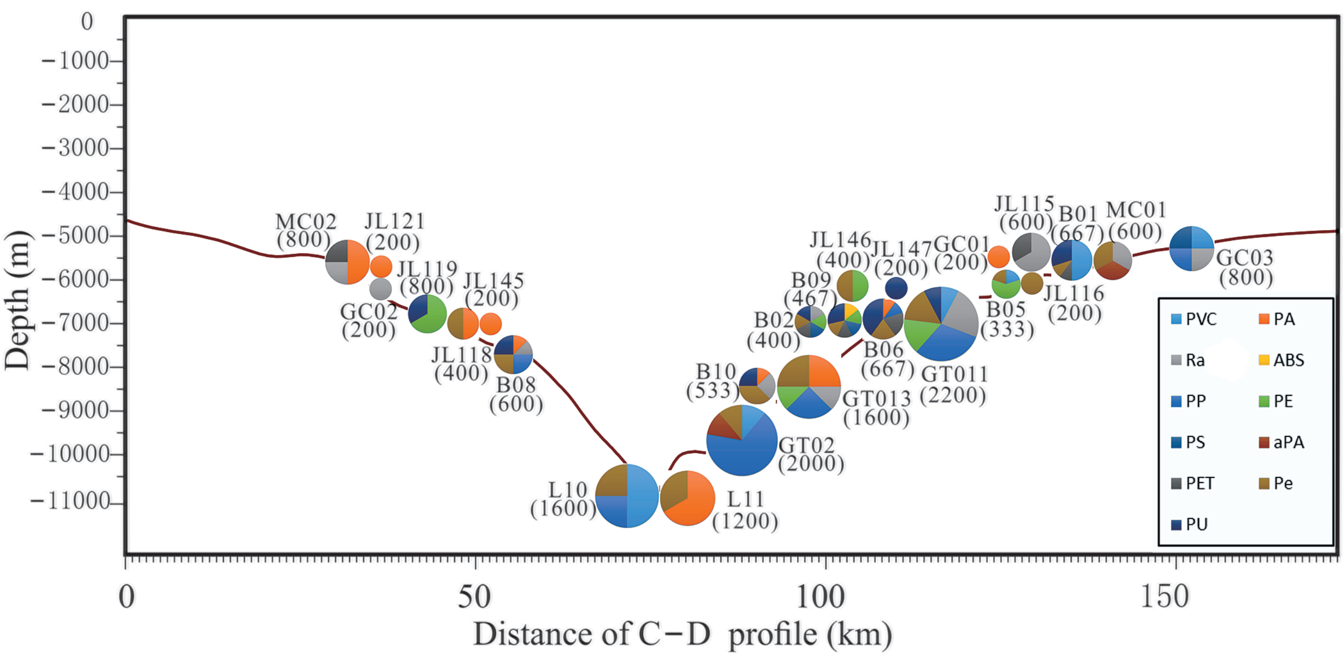

Figure 3 Profile of microplastic abundances and compositions in sediment samples from Mariana Trench. Pie charts represent the microplastic compositions and numbers in the bracket are the microplastic abundances with units of pieces *per* litre. PVC-polyvinyl chloride, PA-polyamide, Ra-rayon, ABS-acrylonitrile butadiene styrene, PP-polypropylene, PE-polyethylene, PS-polystyrene, aPA-aromatic polyamide, PET-polyethylene terephthalate, Pe-polyester, PU-polyurethane. The X-axis corresponds to the crossline from point C (12 °N, 141.9 °E) to point D (10.5 °N, 141.3 °E) in Figure 1.

Table 1 Abundance of microplastics in seawater and sediments in open oceans worldwide.

Sample type	Depth (m)	p (pieces)/L	Study area	References
seawater	2673-10908	2.06-13.51	Mariana Trench	This study
seawater	4.50	3.20±0.60	Strait of Georgia	Desforges *et al.* (2014)
seawater	1	4.14±2.46	Yangtze estuary	Zhao *et al.* (2014)
seawater	1	0.02 (p/m^2)	South Pacific subtropical gyre	Eriksen *et al.* (2013)
seawater	4.50	0.28±0.18	NE Pacific Ocean	Desforges *et al.* (2014)
seawater	2227	0.07	Rockall Trough	Courtene-Jones *et al.* (2017)
seawater	50-4369	0.02-0.38	Arctic Central Basin	Kanhai *et al.* (2018)
sediment	5108-10908	200-2200 (0.27-6.20 p/g)	Mariana Trench	This study
sediment	2783-5570	44-3463.71 (0.04-6.59 p/g)	HAUSGARTEN observatory in the Arctic	Bergmann *et al.* (2017)
sediment	900-1000	28-80	SW Indian Ocean	Woodall *et al.* (2014)
sediment	1400-2200	120-800	NE Atlantic	Woodall *et al.* (2014)
sediment	300-1300	200-700	Mediterranean	Woodall *et al.* (2014)
sediment	2419-4881	0-40	Polar Front of the Southern Ocean	Van Cauwenberghe *et al.* (2013)

The colourful microplastics were also widely identified in hadal sediments (Fig. 3). Like the bottom water, microfibres were abundant in the sediments (Table S-4). Microplastic abundances in hadal sediments ranged from 200 to 2200 pieces *per* litre. Higher abundances were commonly found in deeper hadal sediments, especially at depths of 7000-11000 m. The maximum value reached 2200 pieces *per* litre at the depth of 7180 m, followed by 2000 pieces *per* litre at 9373 m. We compared the microplastic abundances of our sediment samples with that in deep sea sediments reported from other studies (Van Cauwenberghe *et al.*, 2013; Woodall *et al.*, 2014; Bergmann *et al.*, 2017) (Table 1). The maximum abundance of microplastics detected in the Mariana sediments is twice as high as that reported in deep sea sediments from the Atlantic Ocean and the Mediterranean Sea (70-800 pieces *per* litre, Woodall *et al.*, 2014), and twenty times more than that in deep sea sediments from the SW Indian Ocean and the Southern Atlantic (Van Cauwenberghe *et al.*, 2013; Woodall *et al.*, 2014). However, it is comparable to Arctic deep sea sediments, where the highest abundance of microplastics recorded was 3463.71 pieces *per* litre, at a depth of 2783 m (Bergmann *et al.*, 2017).

Eleven different polymers, including polyvinyl chloride, polyamide, rayon, acrylonitrile butadiene styrene, polypropylene, polyethylene, polystyrene, aromatic polyamide, polyethylene terephthalate, polyester, and polyurethane were identified from the Mariana samples (Fig. 2). Polyethylene terephthalate accounted for the largest proportion (19 %) in hadal bottom waters, followed by polyamide (14 %), polyvinyl chloride (13 %), polyurethane (12 %), polyester (11 %), polystyrene (11 %), and rayon (9 %) (Fig. 2). In the sediments, polyester accounted for the largest proportion (19 %), followed by polypropylene (15 %), polyurethane (14 %), polyamide (12 %), polyamide (12 %), polyvinyl chloride (10 %), rayon (10 %), and polyethylene (9 %) (Fig. 3). Microplastic compositions from our study are different from those previously reported in other deep sea environments. For example, polypropylene and polyethylene are most abundant in the water column of the North Pacific Ocean (Rios *et al.*, 2007). Polyester, followed by acrylic fibres dominate in sediments from the deep NE

Atlantic, Mediterranean, and SW Indian Ocean (Woodall *et al.*, 2014), while chlorinated polyethylene, polyamide and polypropylene account for 76 % in Arctic sediments (Bergmann *et al.*, 2017). Such compositional differences probably reflect the differences in the source of microplastics in various deep sea areas, and/or the difference in the vertical transport processes among various microplastics. Although polymer type in this study does not unequivocally establish the source of plastic particles, it could provide useful information. All the synthetic polymers found in this study could be derived from textiles, ropes, fishing gear (nets, lines *etc.*), plastic beverage bottles, and packaging materials (Andrady, 2011; Claessens *et al.*, 2011; Napper and Thompson, 2016), while rayon may also be used in personal hygiene products and cigarette filters (Woodall *et al.*, 2014).

The high abundance of microplastics in Mariana bottom water and sediments may be derived from industrialised regions in the Northwest Pacific (Jamieson *et al.*, 2017) and the North Pacific Subtropical Gyre, so called "Great Pacific Garbage Patch" (Kaiser, 2010), where the Pacific surface circulation, *i.e.* the Eastern Subtropical Mode Water and Subtropical Mode Water, may lead to long distance transport of microplastics to Mariana trench, respectively (Tseng *et al.*, 2016). Except for polypropylene and polyethylene, all the polymer types recorded in this study are negatively buoyant (Andrady, 2011) and would eventually sink. Colonisation by organisms, adherence to phytoplankton, and aggregation with organic debris and small organic particles will eventually enhance settling (Zarfl and Matthies, 2010; Katija *et al.*, 2017). It was reported that the vertical transportation rate of surface-derived material can be up to 64-78 m *per* day in the Japan Trench (Oguri, 2013). A relatively rapid deposition of sediments has also been reported in the hadal zone of Mariana Trench (Glud *et al.*, 2013), probably due to erratic downslope sediment transport triggered by occasional earthquakes and/or repeated resuspension and deposition of material (Itou *et al.*, 2000), which could result in increased accumulation of microplastics in the hadal zone. In addition, the narrow V-shaped topography of the trench may also enhance the downslope flux of microplastics into the hadal zone (Nunoura *et al.*, 2015). Bottom currents, together with propagating internal tides, may further enhance the downwelling of particles and foster the accumulation of microplastics in the Mariana Trench (Taira *et al.*, 2004; Turnewitsch *et al.*, 2014).

Our results confirm the presence of microplastics throughout the bottom water and sediments of the Southern Mariana Trench. We suggest that a part of the 'missing' microplastics in the ocean could have been transferred to the deep ocean. Given the vastness of the hadal zone and the high abundance of microplastics in all of the bottom water and sediments, the hadal zone could be one of the largest microplastic sinks on Earth. It has been demonstrated that microplastics could be available to every level of the food web (Cedervall *et al.*, 2012; Rillig, 2012; Mattsson *et al.*, 2014; Avio *et al.*, 2017). Ingestion of microplastics may result in adverse health effects, such as internal blockage and endocrine dysfunction (Wright *et al.*, 2013, Kershaw *et al.*, 2015). Recently, microplastics were reported to be found in crustaceans from the deep trenches (A.J. Jamieson in *The Guardian* newspaper report by Taylor, 2017). Further work to evaluate the impacts of microplastics on fragile hadal ecosystems is urgently needed in the future.

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Additional Information

Supplementary Information accompanies this letter at http://www.geochemicalperspectivesletters.org/article1829.

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