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.

Letter

Plastics are worldwide marine pollutants, accumulating in seawater and sediments (Hammer et al., 2012; Cözar 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 (Jamieson 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 (Fujikawa et al., 2002) (Fig. 1).

Identification by optical microscope and Raman spectrometer confirmed that microplastics are abundant in hadal bottom water (Fig. S-I). 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.
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 polystyrene (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

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

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Depth (m)</th>
<th>p (pieces/L)</th>
<th>Study area</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>seawater</td>
<td>2673-10908</td>
<td>2.06-13.51</td>
<td>Mariana Trench</td>
<td>This study</td>
</tr>
<tr>
<td>seawater</td>
<td>4.50</td>
<td>3.20-6.60</td>
<td>Strait of Georgia</td>
<td>Desforges et al. (2014)</td>
</tr>
<tr>
<td>seawater</td>
<td>1</td>
<td>4.14-2.46</td>
<td>Yangtze estuary</td>
<td>Zhao et al. (2014)</td>
</tr>
<tr>
<td>seawater</td>
<td>1</td>
<td>0.02 (g/m²)</td>
<td>South Pacific Subtropical gyre</td>
<td>Eriksen et al. (2013)</td>
</tr>
<tr>
<td>seawater</td>
<td>4.50</td>
<td>0.28-0.18</td>
<td>NE Pacific Ocean</td>
<td>Desforges et al. (2014)</td>
</tr>
<tr>
<td>seawater</td>
<td>2227</td>
<td>0.07</td>
<td>Rockall Trough</td>
<td>Courtey-Jones et al. (2017)</td>
</tr>
<tr>
<td>seawater</td>
<td>50-4369</td>
<td>0.02-0.38</td>
<td>Arctic Central Basin</td>
<td>Kanhai et al. (2018)</td>
</tr>
<tr>
<td>sediment</td>
<td>5108-10908</td>
<td>200-2200 (0.04-0.59 p/g)</td>
<td>Mariana Trench</td>
<td>This study</td>
</tr>
<tr>
<td>sediment</td>
<td>2783-5570</td>
<td>44-3637.71 (0.04-0.59 p/g)</td>
<td>HAUSBARTEN Observatory in the Arctic</td>
<td>Bergmann et al. (2017)</td>
</tr>
<tr>
<td>sediment</td>
<td>900-1000</td>
<td>28-80</td>
<td>SW Indian Ocean</td>
<td>Woodall et al. (2014)</td>
</tr>
<tr>
<td>sediment</td>
<td>1400-2200</td>
<td>120-800</td>
<td>NE Atlantic</td>
<td>Woodall et al. (2014)</td>
</tr>
<tr>
<td>sediment</td>
<td>300-1300</td>
<td>200-700</td>
<td>Mediterranean</td>
<td>Woodall et al. (2014)</td>
</tr>
<tr>
<td>sediment</td>
<td>2419-4881</td>
<td>0-40</td>
<td>Polar Front of the Southern Ocean</td>
<td>Van Cauwenberghe et al. (2013)</td>
</tr>
</tbody>
</table>
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 North West 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 (Zarl 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 (Ghd et al., 2016), probably due to erratic downslope sediment transport triggered by occasional earthquakes and/or repeated resuspension and deposition of material (Ito 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., 2013), probably due to erratic downslope sediment transport triggered by occasional earthquakes and/or repeated resuspension and deposition of material (Ito 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).

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Additional Information

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References


