Microplastics: What Can We Learn from Clastic Sediments?

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Chapter 15
Microplastics: What Can We Learn from Clastic Sediments?

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15.1 Introduction

Microplastics research is a comparatively young discipline that only gained momentum at the beginning of the twenty-first century. Research on clastic sediment, on the other hand, has been conducted for almost a hundred years [1–3] and provides valuable insights to guide future microplastic studies. Comparing publication numbers in the Web of Science also highlights the head start that sediment

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research (*sediment* transport*: 62,617 publication) has over microplastic research (*microplastic* transport*: 1352 publications). Based on the hypothesis that publications equal knowledge, we have analyzed the comparability of microplastics with natural sediments regarding their particle properties, transport processes, sampling techniques and ecotoxicology in an interdisciplinary review paper [4]. The paper

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identifies seven research goals that should be focused on in the future to enhance our knowledge on microplastics in the freshwater environment. This extended abstract presents the core message from the review paper, but for a detailed insight, please refer to the original paper [4].

15.2 Particle Properties

15.2.1 Background

Describing the physical nature of microplastic particles continues to present many difficulties [5, 6]. Currently, size, density or polymer type and shape of particles are predominantly used to describe microplastics. However, a closer look shows that this is not as straightforward as one might assumed (Table 15.1).

One of the most common definitions of microplastic is "a particle smaller than 5 mm". However, the details of how this particle **size** is determined are generally not discussed. Officially, this upper size limit for microplastics refers to the longest particle side [8]. In practice, particles can be defined by their three main dimensions

Table 15.1 Comparison of microplastic and sediment particle properties. Microplastic characteristics based on Waldschläger et al. [4], size classes for clastic sediment based on the Udden-Wentworth scale [7]

Characteristics	Microplastics	Clastic sediment
Size	0.005–5 mm	Clay: < 0.004 mm Silt: 0.004–0.063 mm Sand: 0.063–2 mm Gravel: 2–63 mm
Density	0.02–2.3 g/cm^3	2.65 g/cm^3
Shape	Pellets, fragments, foams, foils, fibers	Granular

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(long axis, L; intermediate axis, I; short axis, S), which complicates the determination of the particle size of irregular, three-dimensional microplastic particles. Lower size limits are often related to the measurement technique, but do not indicate the longest particle side, e.g., using nets to collect water samples will influence the lower detection limit of the mean particle size. The same holds true for analytical methods used: while a sieve-based particle size is defined by the mean axis, sedimentation analyses depend on both the longest and the mean (e.g., largest projected surface area) or on all dimensions [9]. Manual size measurements are highly subjective, while imaging techniques capture only two of the three particle sides and therefore do not provide a comprehensive picture either [5, 10]. In sediment research, these particle-based descriptions are rarely used; instead, mass-based values (D_{50}, D_{90}) are applied [11, 12]. This is much more straightforward for clastic sediments, since they are mainly considered as particle mixtures of equal density. Particle size distributions based on sieve analyses have not been used for microplastics because the different particle densities complicate a mass-based analysis and the general interest has so far been on individual particles or particle counts [13].

Determining the **density** of microplastics is also not straightforward, as the particles can exhibit three different densities: (1) the initial polymer density, (2) the environmental density, which includes biofouling, aggregation with environmental substances [14] and fragmentation/degradation [15] and 3) the density determined in the lab after cleaning off the biofouling and the environmental substances [16]. Although this has also been observed for natural sediments, the influence on density and especially transport processes does not seem to be as pronounced there, as the original density of sediments (~2.65 g/cm^3 [17]) is considerably heavier than the density of water, so that a change in density has less impact [18]. Which density is most useful for describing microplastics will need to be discussed in the future. However, we must be aware that determining the polymer type of a particles alone does not determine the particle density.

Over the past 20 years, several **shape** categories for microplastics have evolved: pellets, fragments, fibres, foams and films [5]. These categories can be used to identify the origin of particles by dividing them into primary (pellets) and secondary (fragments, fibres, foams and films) microplastics, but they also pose some problems: Since these categories are not based on geometric standards, it is difficult to compare different studies [19]. One study might label a particle as foam, another as a fragment. Moreover, these shape categories are not practical for modelling the transport behaviour of these particles, as they are not parameterized and thus cannot be implemented into models. With this problem in mind, a look at sediment research may be helpful. Sediments are described using either geometric standards (e.g., ellipsoid, cylinder) [20] or shape descriptors that use the three main dimensions of the particles and their ratio (e.g., Corey shape factor) or at least a standardized matrix to categorize shape (e.g., flatness, roundness) [10, 21]. Whether these shape descriptors can also be used for microplastics remains to be investigated in detail, but measuring the three principal dimensions seems to be a first step to improve the comparability of different studies [22, 23].

15.2.2 Research Goals and Tasks

Based on the presented shortcomings that currently still exist in the description of microplastic particles, the following research objective was defined.

RG1: To improve and standardize descriptions of microplastic particles

Achieving this goal will improve the comparability of individual studies and allow us to understand the effects of particle properties on transport and particle ecotoxicology. To reach this goal, four main tasks need to be accomplished: The determination of particle size and main dimensions of non-spherical microplastics needs to be improved, e.g., by using shape descriptors developed for clastic sediments. The suitability of the currently used shape categories (pellets, fragments, films, fibres) needs to be evaluated and, if necessary, new shape categories need to be developed. The impact of different shapes and the deformability of microplastic particles on their transport behaviour needs to be studied in more detail, and the implications of the density of microplastics being close to that of water and its changes in the environment need to be evaluated.

15.3 Transport Processes

15.3.1 Background

Historically, transport modelling has often considered microplastics as artificial sediment by applying transport descriptions originally developed for natural sediments to microplastics [24]. This transfer from sediment research, which in contrast to microplastics research has been conducted for many decades (e.g., [1, 2]), may provide important insights for our understanding of microplastics. However, it needs to be examined whether this transfer leads to appropriate results (Fig. 15.1).

In the fluvial environment, microplastics can either be transported downstream or deposit due to sedimentation. Transport can occur as surface, suspended or bed load, with surface load being a new transport mode compared to clastic sediment. The diversity of particle properties leads to greater difficulty in describing the vertical distribution of microplastics in the water column – which has been studied theoretically [25] and with few field studies [26–28], but not with systematic studies on the influence of different environmental conditions on the vertical distribution. An important factor affecting the vertical distribution are the settling and rising velocities, which have often been calculated in the past based on sedimentological theory. However, it became clear that these calculations are not suitable for microplastics due to their asymmetric shapes [29–31]. Important influences on vertical velocities that are not yet fully understood include biofouling, degradation/fragmentation, and particle aggregation with natural substances—all processes that occur for natural

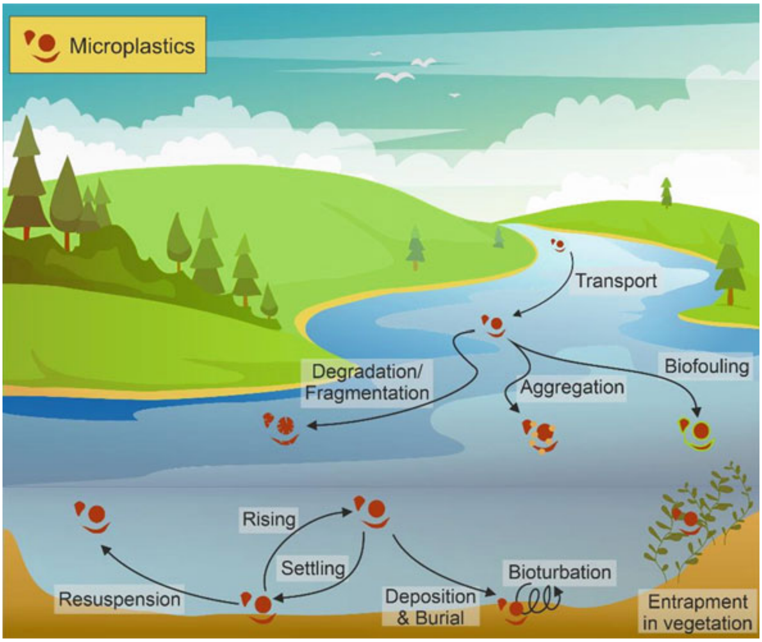

Fig. 15.1 Transport processes of microplastics in the fluvial environment

sediment too, but that are not as important due to the higher particle densities of sediments in comparison to microplastics. As for downstream transport, resuspension thresholds are highly important, which are also not well described by using calculations from sediment transport (e.g. Shields Diagram) [32]. The resuspension is additionally influenced by the burial and bioturbation of microplastics, which points to another topic that remains understudied in the microplastic context: the influence of flora (e.g. entrapment in vegetation) and fauna (e.g. ingestion and excretion) on transport behaviour [33, 34]. These shortcomings in our current understanding of microplastic transport are also relevant to numerical fate modelling. While zero to threedimensional models are available at various scales, appropriate parameterizations for various processes (e.g., particle properties, settling/rising velocities, resuspension thresholds, aggregation, biofouling, fragmentation and beaching) are still lacking.

15.3.2 Research Goals and Tasks

We have identified four transport-related research objectives that need to be addressed. Achieving these goals will enable better implementation of time-dependent changes in numerical models (RG 2) and improve our understanding of microplastic transport under different influences (RG 2, 3, 4, 5), as well as the reliability of environmental monitoring (RG 3).

RG2: To understand and quantify time variable particle property changes and interactions with other environmental substances and their impact on microplastic transport
RG3: To evaluate the vertical distribution of aquatic microplastic and their transport in the water column
RG4: To evaluate differences in the erosion and deposition behaviour between microplastics and sediments
RG5: To understand and quantify the impact of biota on microplastic transport

To address these research goals, several tasks need to be performed. This includes investigating time-dependent changes in particle properties, particularly due to biofouling, degradation/fragmentation, and aggregation, as well as parameterizing their influence on transport behaviour. Based on the concepts of sediment transport, the distribution of the total microplastic transport as surface, suspended, and bedload transport needs to be quantified, and the mechanisms of bedload transport of microplastics described. The influence of particle properties (e.g., shape, surface properties) on the onset of motion needs to parameterized and the resuspension of aggregated particles, both for microplastics-microplastics and microplastics-sediment mixtures needs to be determined. Finally, vegetation-induced sedimentation of microplastics needs to be compared to that of natural sediments, and the effects of biota on resuspension thresholds and bedload transport need to be quantified.

15.4 Monitoring Methods

15.4.1 Background

While the initial focus was primarily on the marine environment, the fluvial environment appears to be as heavily polluted as the oceans and may well be considered a temporary sink of microplastics [35, 36]. Despite this, the Water Framework Directive (WFD) adopted by the European Union in 2000 to assess the ecological status of watercourses does not include pollution limits or monitoring requirements for microplastics. This may be due to the lack of studies on microplastic concentrations in rivers prior to 2010 [35], as, in comparison, the 2008 Marine Strategy Framework Directive already lists plastic as a hazard and calls for a reduction in emissions to the oceans. It is therefore probably only a matter of time before microplastics are included in the monitoring framework of the WFD.

However, representative monitoring would hardly be possible at present due to the lack of a sound sampling concept. Representative sampling in the fluvial environment remains difficult due to dynamic flow characteristics, spatial and temporal limitations in sampling, neglect of the influence of hydrology, consideration of only one environmental compartment (e.g., surface water or sediment), and size- or shape-selective sampling [4]. As a result, it is difficult to estimate the concentration throughout the water column [25, 37].

Regarding sampling methods for the benthic environment, we often rely on techniques from sediment sampling, such as Ponar or Van Veen grabs, coring, trapping and drilling [38–40]. In the aquatic phase, one has to differentiate between surface samples, samples of suspended particles in the water column or samples of the bedload transport. For surface sampling, we cannot refer to sediment techniques. However, for sampling suspended transport, sediment traps [41–44] and Van Dorn samplers [45] can be transferred to microplastic sampling. For more advanced sampling as well as identification techniques, the reader is hereby referred to the original paper [4] due to space limitations in this abstract.

15.4.2 Research Goals and Tasks

With respect to field monitoring techniques, we have identified a research objective that will provide representative descriptions of the occurrence and types of microplastics in the fluvial environment and improve the comparability of results from different studies:

RG6: To improve and standardize sampling methods

To achieve this goal, we need to develop refined sampling techniques and parameters for sample collection, preparation and analysis, taking into account the transport mechanisms of microplastics. Furthermore, the application of sediment sampling methods such as flow-integrated sampling or the development of innovative techniques such as remote sensing, hyperspectral imaging, acoustics or laser diffraction methods for microplastics research must be explored.

15.5 Ecotoxicology

15.5.1 Background

In terms of ecotoxicology, the main difference between microplastics and clastic sediments is probably their composition: while sediments are inert, microplastics may contain toxic chemical contaminants (e.g., additives and by-products of their degradation) [46], which can leach in the aquatic environment or after ingestion [47]. In contrast to the chemical toxicity, toxicity due to their physical properties and the comparison to the ecotoxicity of natural substances has only recently been studied [48–50]. Additionally, the influence of particle shape and diameter on their ecotoxicity has not yet been sufficiently explored. For a more detailed analysis of the current state of knowledge on this topic, the reader is referred to the original review paper [4].

15.5.2 Research Goals and Tasks

In addition to the potential harm due to chemical contamination of microplastics, the physical impact of these particles needs to be studies in comparison to the effect of naturally occurring particles such as sediment. This led to the following research goal:

RG7: To study the drivers of microplastic toxicity in comparison with sediment particles

Investigating these factors will improve our knowledge of the relative importance of the polymers themselves, the plastic-associated chemicals, and the physical nature of the particles to their ecotoxicity compared to other particles in the environment. To achieve this goal, experimental design and toxicity tests must be improved by using natural particles similar to the microplastics under study as reference materials.

15.6 Conclusions

It is often assumed that the paradigms used in sediment research are also applicable to describe the transport of microplastics, as they can be considered as a type of artificial sediment that behaves similarly in the aquatic environment. However, microplastic particles are diverse and characterized by highly variable densities, particle sizes, and shapes, which distinguishes them from natural sediments. Therefore, our descriptions of microplastic particles need to be improved and standardized to gain insight into how particle properties affect the transport of microplastics in the environment and to improve the comparability of different studies. Particle description methods from sedimentology, such as the use of shape descriptors, should be further evaluated for microplastics research. In addition to the high variability of microplastic particles, environmental changes in particle properties, such as biofouling, aggregation or fragmentation, complicate the understanding of their behaviour and particle description. These processes, which have received little attention in the sediment field, could be significant for microplastic transport and require further research.

The classification of sediment transport into suspended sediment and bedload transport has already been applied to microplastics research and extended to include a third class, surface transport. For bedload transport, there are still many unanswered research questions, such as the flow conditions that lead to particle movement near the bottom, the amounts transported, and the interactions of particles with the sediment bed. Shifts between these transport modes, usually estimated from particle size and density of natural sediments, are still poorly understood for microplastics and require the development of metrics that relate particle properties and hydrology to transport mode. Particle properties and transport processes are important aspects to consider when developing representative monitoring strategies for defining microplastic concentrations. Detailed knowledge about environmental concentrations is essential to validate transport models, to use environmentally relevant concentrations and particle properties in toxicological assessments and to develop targeted mitigation strategies. In the future, ecotoxicology should not only focus on the chemical effects of microplastics, but also on particle-related effects, which must be evaluated in comparison to naturally occurring particles.

To conclude, even after 20 years, microplastics research remains a comparatively young research field that has many open questions to answer, but can certainly learn from other disciplines and thus accelerate progress significantly

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