

Editorial

Challenging Issues in Microplastic Transport by Submarine Turbidity Currents

Yang Lu¹, Xiaolei Liu^{*1,2}, Thorsten Stoesser³, Eckart Meiburg⁴, Dongfang Liang⁵,
Xingsen Guo^{1,3,5}

1. Shandong Provincial Key Laboratory of Marine Environment and Geological Engineering, Ocean University of China, Qingdao 266100, China

2. Laboratory for Marine Geology, Qingdao Marine Science and Technology Center, Qingdao 266237, China

3. Department of Civil, Environmental and Geomatic Engineering, University College London, London WC1E 6BT, United Kingdom

4. Department of Mechanical Engineering, University of California at Santa Barbara, Santa Barbara CA 93106, United States of America

5. Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, United Kingdom

0 INTRODUCTION

Microplastics are defined as small plastic debris (1 μm – 5 mm), which have complex properties of wide-range densities (0.05–2.3 g/cm³), diverse shapes (e.g., beads, fibers, foam and pellets) and low degradability (Harris, 2020; Chubarenko et al., 2016). Their global distribution spans estuaries, coastal zones, continental shelves, and deep-sea sediments, posing escalating ecological threats (Thompson et al., 2024). Research efforts have focused on shallow-water regions, where investigations demonstrate that microplastic spatiotemporal distributions are controlled by both their physical characteristics and ocean dynamic conditions (wind, waves, tides, thermohaline gradients, and the influence of benthic sediments) (Zhang, 2017). However, accumulating evidence suggests that deep seafloor sediments serve as the ultimate sink for microplastics, and the abundance of microplastics in seafloor sediments may far exceed that in surface waters and the water columns (Auta et al., 2017). The gravitational settling of particles through the water column represents the most intuitive mechanism for microplastic accumulation in seafloor sediments. If this mechanism were predominant, predicting the distribution of microplastics in the deep-sea environments would be relatively straightforward, albeit requiring some consideration of biochemical processes. However, the spatial distribution of microplastic hotspots on the seafloor does not consistently correlate with surface garbage patches, suggesting that vertical settling alone may not fully explain the transport mechanisms (Kane et al., 2020).

Recent studies have proposed that submarine turbid-

ity currents play a crucial role in transporting large volumes of microplastics to the deep sea (e.g., trenches, canyons, and abyssal plains) (Pohl et al., 2020). This hypothesis is supported by the fact that submarine canyons, which serve as primary conduits for turbidity currents, are also recognized as one of the hotspots for microplastics. Furthermore, field observations in the Whit-tard Canyon have revealed that turbidity currents in submarine canyons worldwide are far more active than previously anticipated (Heijnen et al., 2022), which further strengthens the argument that turbidity currents may constitute a key transport mechanism for microplastics. Simultaneously, it also emphasizes the critical need to elucidate the physical processes governing the transport of microplastics via turbidity currents, as such an understanding would be crucial for predicting the distribution of microplastics in deep-sea environments. It is worth noting that the fate of microplastics involves not only their initial transport by turbidity currents but also the subsequent reworking and redistribution by bottom currents, such as those driven by thermohaline circulation (Kane et al., 2020). Within the scope of this study, we focus primarily on the former process.

Figure 1 illustrates how turbidity currents transport microplastics, leading to environmental pollution and potential risks to human health. Specifically, vast quantities of microplastics are delivered to the deep sea by powerful turbidity currents, where they are subsequently ingested by various marine organisms at different trophic levels, ultimately entering the human food chain and impacting human health. Unfortunately, the significant hazards posed by marine microplastic pollution stand in stark contrast to our limited understanding of its transport and distribution mechanisms. In particular, the physical processes governing microplastic transport by turbidity currents have only begun to receive increased attention over the past five years. Compared to microplastic studies in estuarine and coastal environments, the investigation of mi-

*Corresponding author: xiaolei@ouc.edu.cn

© China University of Geosciences (Wuhan) and Springer-Verlag GmbH Germany, Part of Springer Nature 2025

Manuscript received January 15, 2025.

Manuscript accepted April 4, 2025.

croplastic transport by deep-sea turbidity currents presents distinct challenges due to significant differences in hydrodynamic conditions, transport media, and topographical settings. Consequently, research methodologies established for estuarine microplastic studies cannot be directly extrapolated to deep-sea environments, as conventional approaches may either be inapplicable or require substantial modification and validation. Given these considerations, this paper focuses on assessing the potential challenges that may arise in the future investigation of microplastic transport by turbidity currents, drawing upon the distinctive characteristics of both turbidity currents and microplastics themselves. Based on the assessment, we propose targeted recommendations to address these challenges.

1 MAJOR CHALLENGES

1.1 Direct Observations

A growing number of *in-situ* observations have been carried out worldwide to dig into the internal flow structures of turbidity currents and understand their transport processes (Talling et al., 2023; Wells and Dorrell, 2021), but few of them are designed to capture the events that involve microplastics. To the authors' knowledge, only two events have been reported publicly, of which one was observed on the levee of Gaoping Canyon (Zhang et al., 2024), and the other was in the Whittard Canyon (Kane et al., 2024). These two studies provided direct evidence demonstrating that turbidity currents create microplastic hotspots in deep-sea environments and regulate the seaward transport and settling flux of microplastics. Nevertheless, *in-situ* observations of microplastic transport via turbidity currents have not received adequate attention within the broader scientific community. In the limited published studies available, microplastics have been treated merely as ancillary components in turbidity cur-

rent monitoring programs. Clare et al. (2020) synthesized decades of experience in turbidity current monitoring, describing two principal observation approaches with their respective advantages and limitations, which include benthic monitoring platforms and mooring systems (Figures 2a and 2b). These monitoring systems typically employ various instruments to capture turbidity current dynamics, while sediment grains are collected through sediment traps mounted on moorings (Figure 2c). However, a significant technical challenge persists as conventional acoustic and optical instruments struggle to distinguish microplastic particles from sediment grains within turbidity currents. This limitation underscores the urgent need for innovative technological solutions and instrumentation specifically designed to address the methodological gap in microplastic transport studies.

A promising approach lies in the modification of sediment traps. Traditional sediment traps used in turbidity current monitoring, such as McLane-type and Anderson-type traps, have been instrumental in collecting sediment grains for post-event analysis, including concentration calibration and grain size distribution assessment (Clare et al., 2020). However, these instruments predominantly capture vertically settling particles while performing poorly in collecting horizontally transported particles. Furthermore, our limited understanding of microplastic behaviors within turbidity currents presents additional complexities. For instance, the distinct shapes and densities of microplastic particles compared to sediment grains result in markedly different settling velocities, making direct comparisons difficult. Coupled with the potential of biofilms to grow on microplastic particles, which can drastically change their physicochemical properties and behaviors (Moyal et al., 2023; Song et al., 2022), analyzing vertically settled particles alone may lead to misinterpretation of the transport process. Recent innovations have led to the

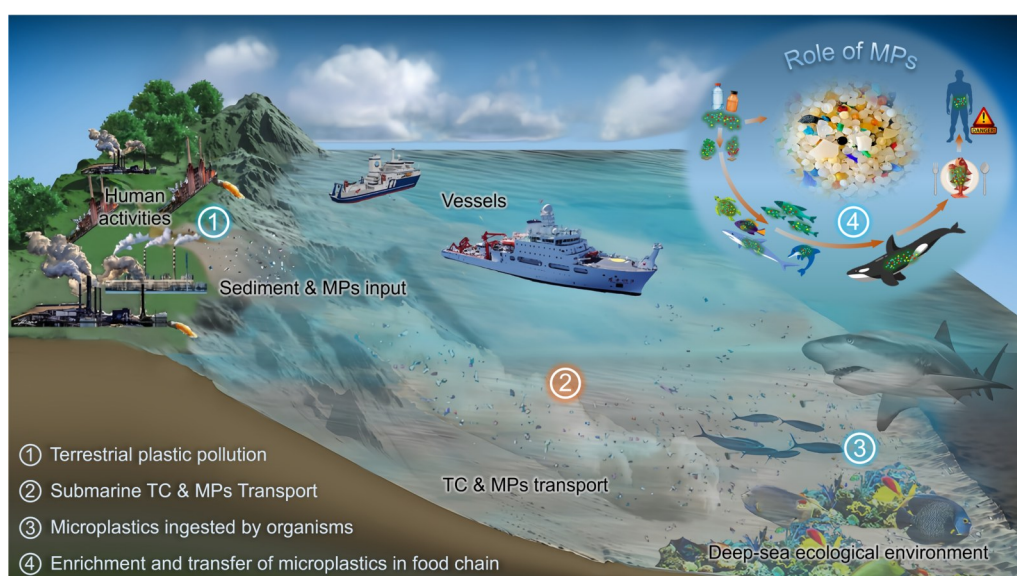


Figure 1. Conceptual framework illustrating the process of microplastic (MP) transport by turbidity currents (TCs) from land to deep sea, and its cascading impacts on human health.

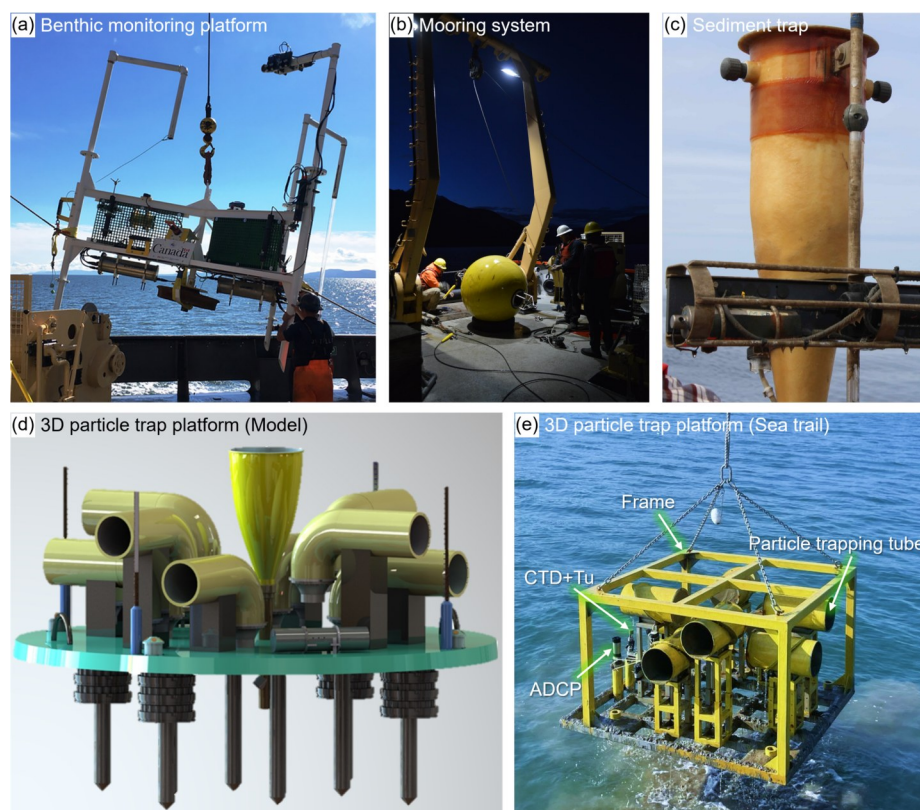


Figure 2. Existing instrumentation for monitoring turbidity currents and sediment transport (modified after Guo L et al. (2023) and Clare et al. (2020)), including the (a) benthic monitoring platform, (b) mooring system, (c) Anderson-type sediment trap, (d) design model of 3D particle trap platform and its (e) sea-trail photograph.

development of 3D particle trap platforms capable of collecting particles in both horizontal and vertical directions (Figures 2d and 2e) (Guo L et al., 2023). Through laboratory-calibrated computational models, the platform enables temporal comparative analyses of particle concentrations and size distributions across different orientations. This advancement potentially offers valuable insights into decomposing microplastic transport processes within turbidity currents. The research team developing this 3D particle trap platform is reportedly conducting sea trials, with plans to optimize the design based on trial results for future applications in monitoring submarine turbidity currents and mining plumes.

1.2 Physical Modeling and Numerical Simulations

Physical modeling and numerical simulations provide valuable insights into the physical processes of microplastic transport by turbidity currents. However, unlike microplastic transport in water columns, turbidity currents can mobilize enormous sediment loads and propagate rapidly into deep-sea environments under gravitational forces and topographic influences (Meiburg and Kneller, 2010). Their rheological properties and dynamic behaviors are greatly more complex, and consequently, existing models and theories fall short in describing these unique physical phenomena. Only a limited number of physical modeling studies have investigated microplastic transport by turbidity currents. The pioneering work of

Pohl et al. (2020) documented the transport of microplastic fragments and fibers in laboratory flumes, highlighting the susceptibility of microplastic fibers to preservation and burial within seafloor sediments. Complementing these findings, Soler et al. (2025) revealed through lock-exchange experiments that turbidity currents with higher sediment concentrations and finer sediments could enhance microplastic transport. By further incorporating seabed topography into experimental designs, Bell et al. (2021) identified preferential deposition patterns of microplastic fragments in levee structures and lateral basin floor fringe positions. This contrasts with the recent work of Meng et al. (2025), who suggested that microplastics predominantly accumulate within wavy turbidites in canyon topographies. The divergence in these experimental results presents an intriguing complexity, particularly as both findings can be supported by evidence in real-world scenarios. Consequently, investigating microplastic transport by turbidity currents continues to present multiple challenges. Drawing from existing experimental studies, several critical considerations emerge: (i) Establishing the correspondence between experimental setups and natural systems is essential. For example, it is crucial to determine whether turbidity currents are introduced from the continental shelf or triggered directly at the canyon head. (ii) An appropriate flow scaling criterion (e. g., Shields or Froude scaling approach) is needed for experiments as it fundamentally governs the outcome. (iii) Mi-

croplastic properties, especially particle morphology, require precise characterization given the marked differences in transport behaviors between fragments and fibers.

Similarly, numerical simulations of microplastic transport by turbidity currents remain scarce, with only one published study addressing marine litter transport by turbidity currents (Yang et al., 2024). The complexity of modeling microplastic movement in fluids stems from their diverse physical properties. For instance, microplastics exhibit significant variations in density, size, and morphology, with some even possessing flexible characteristics, such as film-like or fiber forms, which are particularly challenging to incorporate into numerical models. Through a review of existing literature, it is evident that current methods for simulating microplastics in aquatic environments primarily employ Eulerian-Eulerian and Eulerian-Lagrangian approaches (Wickramarachchi et al., 2025). However, these methodologies have inherent limitations, as they either fail to fully account for the diverse physical properties of microplastics or rely heavily on empirical formulations to describe particle behaviors. While empirical and semi-empirical models, such as drag models, provide fundamental frameworks for calculating particle transport in fluids, they lack universal applicability for non-spherical or flexible particles (Francalanci et al., 2021). Furthermore, the frequent interparticle contacts between sediments and microplastics in turbidity currents present additional modeling challenges. This complexity is further amplified by the irregular geometries of many microplastic particles, making their contact mechanics dif-

ficult to parameterize, and the challenge becomes even more pronounced when considering deformable microplastics and microplastic aggregation due to the biofilm effects. Recently, Russell et al. (2025) proposed treating microplastics as sediments, advocating for a comprehensive classification system for microplastics. Building on this concept, we suggest the necessity of developing robust mathematical foundations for both contact models between microplastic-sediment particles and fluid-particle interaction models discussed earlier.

Computational efficiency presents another critical challenge. As illustrated in Figure 3, direct numerical representation of particle morphology leads to prohibitively high costs (Figure 3a) (Wang et al., 2024). Simplifying particles into spheres or using the unresolved method can reduce computation time to a certain extent (Figure 3b) (Lu et al., 2024; Vowinckel et al., 2019), while treating particles as a fluid phase enables large-scale simulations (Figure 3c) (Wan et al., 2024; Guo X S et al., 2023). Nevertheless, such improvements in computational efficiency often come at the cost of reduced simulation accuracy. In response to this challenge, we propose a chain simulation concept comprising three stages: (i) Development of universal models (e.g., drag and contact models) accounting for unique microplastic properties through extensive bottom-up simulations, potentially leveraging machine learning algorithms given the complexity of microplastic characteristics, (ii) implementation of these models into larger-scale numerical methods (e.g., unresolved CFD-DEM models) through parameterization and (iii) sim-

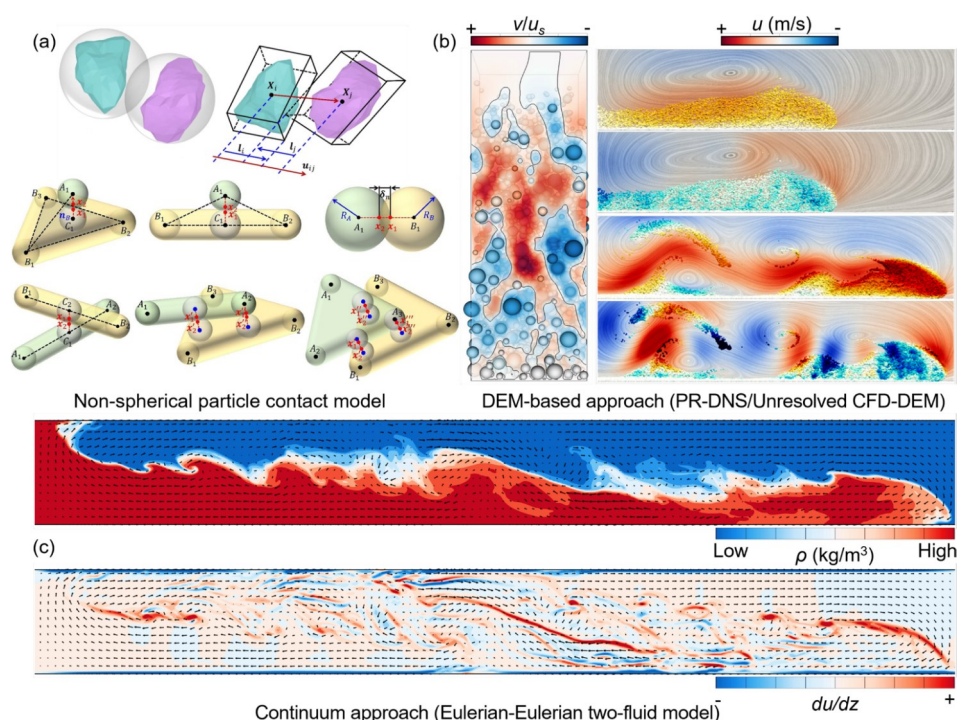


Figure 3. Details in bottom-up numerical method for particle-laden flows (modified after Lu et al. (2024), Wang et al. (2024), Guo X S et al. (2023) and Vowinckel et al. (2019)), containing (a) non-spherical particle contact model (e.g., film and fiber microplastics), (b) DEM-based particle-fluid coupling method (e.g., Particle Resolved-Direct Numerical Simulation and Unresolved Computational Fluid Dynamics-Discrete Element Method), and (c) purely continuum approach (e.g., two-fluid model).

plification of microplastic-sediment interactions to accommodate engineering-scale simulations (e.g., using Eulerian-Eulerian two-fluid approaches).

2 CONCLUSION AND FUTURE DIRECTIONS

Research on microplastic transport by turbidity currents remains in its infancy. Given the growing recognition of microplastic pollution as a significant environmental concern, it is imperative to investigate and understand this potentially dominant transport mechanism. By synthesizing current research challenges, we aim to outline key directions for future investigations. From the perspectives of in situ observations, physical modeling, and numerical simulations, there is a notable lack of mature or effective methods to fully understand the physical processes governing microplastic transport by turbidity currents. At this critical juncture, we propose that research priorities should focus on methodological development, encompassing: (i) Optimized redesign of sediment traps, (ii) development of microplastic transport models in both Newtonian and non-Newtonian fluids, (iii) establishment and simplification of interaction models among sediment, microplastic particles and ambient fluid, and (iv) application of machine learning algorithms in numerical model optimization. It merits attention that the fundamental principle underlying these research directions is the necessity to treat microplastics as true sediment particles, rather than as shapeless, non-deformable, or even massless and un-volumetric materials simply following the fluid motions.

ACKNOWLEDGMENTS

This research was jointly funded by the National Natural Science Foundation of China (No. 42277138), the National Key Research and Development Program of China (Nos. 2024YFF0506803 and 2024YFC2815400), the Fundamental Research Funds for the Central Universities (Nos. 202441003 and 202513032), the Shandong Province National-Level Leading Talent Supporting Project (No. 2022GJLJRC-15), and the European Commission (Nos. HORIZON MSCA-2024-PF-01, 101200637). The final publication is available at Springer via <https://doi.org/10.1007/s12583-025-0194-5>.

Conflict of Interest

The authors declare that they have no conflict of interest.

REFERENCES CITED

- Auta, H. S., Emenike, C. U., Fauziah, S. H., 2017. Distribution and Importance of Microplastics in the Marine environment: A Review of the Sources, Fate, Effects, and Potential Solutions. *Environment International*, 102: 165 – 176. <https://doi.org/10.1016/j.envint.2017.02.013>
- Bell, D., Soutter, E. L., Cumberpatch, Z. A., et al., 2021. Flow-Process Controls on Grain Type Distribution in an Experimental Turbidity Current deposit: Implications for Detrital Signal Preservation and Microplastic Distribution in Submarine Fans. *The Depositional Record*, 7(3): 392–415. <https://doi.org/10.1002/dep2.153>
- Chubarenko, I., Bagaev, A., Zobkov, M., et al., 2016. On Some Physical and Dynamical Properties of Microplastic Particles in Marine Environment. *Marine Pollution Bulletin*, 108(1/2): 105 – 112. <https://doi.org/10.1016/j.marpolbul.2016.04.048>
- Clare, M., Lintern, D. G., Rosenberger, K., et al., 2020. Lessons Learned from the Monitoring of Turbidity Currents and Guidance for Future Platform Designs. In: Georgiopoulou, A., Amy, L. A., Benetti, S., et al., eds., Subaqueous Mass Movements and their Consequences: Advances in Process Understanding, Monitoring and Hazard Assessments. *Geological Society, London, Special Publications*, 500(1): 605–634. <https://doi.org/10.1144/sp500-2019-173>
- Francalanci, S., Paris, E., Solari, L., 2021. On the Prediction of Settling Velocity for Plastic Particles of Different Shapes. *Environmental Pollution*, 290: 118068. <https://doi.org/10.1016/j.envpol.2021.118068>
- Guo, X. S., Luo, Q. Y., Stoesser, T., et al., 2023. Evolution of High-Density Submarine Turbidity Current and Its Interaction with a Pair of Parallel Suspended Pipes. *Physics of Fluids*, 35(8): 086608. <https://doi.org/10.1063/5.0160650>
- Guo, L., Fei, Z. H., Liu, T., et al., 2023. An Experimental Study on Monitoring of Marine Sediment Transport by Using a 3D Sediment Trap. *Frontiers in Marine Science*, 10: 1290527. <https://doi.org/10.3389/fmars.2023.1290527>
- Harris, P. T., 2020. The Fate of Microplastic in Marine Sedimentary Environments: A Review and Synthesis. *Marine Pollution Bulletin*, 158: 111398. <https://doi.org/10.1016/j.marpolbul.2020.111398>
- Heijnen, M. S., Mienis, F., Gates, A. R., et al., 2022. Challenging the Highstand-Dormant Paradigm for Land-Detached Submarine Canyons. *Nature Communications*, 13: 3448. <https://doi.org/10.1038/s41467-022-31114-9>
- Kane, I. A., Clare, M. A., Miramontes, E., et al., 2020. Seafloor Microplastic Hotspots Controlled by Deep-Sea Circulation. *Science*, 368(6495): 1140–1145. <https://doi.org/10.1126/science.aba5899>
- Kane, I., Chen, P., Clare, M., et al., 2024. Large Volumes of Microplastics Are Transported to the Deep Sea by Turbidity Currents. *Research Square*. Preprint. <https://doi.org/10.21203/rs.3.rs-4675640/v1>
- Lu, Y., Liu, X. L., Xie, X. T., et al., 2024. Particle-Scale Analysis on Dynamic Response of Turbidity Currents to Sediment Concentration and Bedforms. *Physics of Fluids*, 36(3): 033316. <https://doi.org/10.1063/5.0191219>
- Meiburg, E., Kneller, B., 2010. Turbidity Currents and Their Deposits. *Annual Review of Fluid Mechanics*, 42: 135–156. <https://doi.org/10.1146/annurev-fluid-121108-145618>
- Meng, Q., Xie, X., Lu, Y., et al., 2025. Sedimentary Characteristics of Microplastics Transported by Turbidity Currents in a Straight Canyon Topography. *Journal of Marine Environmental Engineering*. In press
- Moyal, J., Dave, P. H., Wu, M. J., et al., 2023. Impacts of Biofilm Formation on the Physicochemical Properties and Toxicity of Microplastics: A Concise Review. *Reviews of Environmental Contamination and Toxicology*, 261(1): 8. <https://doi.org/10.1007/s44169-023-00035-z>

- Pohl, F., Eggenhuisen, J. T., Kane, I. A., et al., 2020. Transport and Burial of Microplastics in Deep-Marine Sediments by Turbidity Currents. *Environmental Science & Technology*, 54(7): 4180–4189. <https://doi.org/10.1021/acs.est.9b07527>
- Russell, C. E., Pohl, F., Fernández, R., 2025. Plastic as a Sediment—A Universal and Objective Practical Solution to Growing Ambiguity in Plastic Litter Classification Schemes. *Earth-Science Reviews*, 261: 104994. <https://doi.org/10.1016/j.earscirev.2024.104994>
- Soler, M., Colomer, J., Pohl, F., et al., 2025. Transport and Sedimentation of Microplastics by Turbidity Currents: Dependence on Suspended Sediment Concentration and Grain Size. *Environment International*, 195: 109271. <https://doi.org/10.1016/j.envint.2025.109271>
- Song, J., Beule, L., Jongmans-Hochschulz, E., et al., 2022. The Travelling Particles: Community Dynamics of Biofilms on Microplastics Transferred along a Salinity Gradient. *ISME Communications*, 2: 35. <https://doi.org/10.1038/s43705-022-00117-4>
- Talling, P. J., Cartigny, M. J. B., Pope, E., et al., 2023. Detailed Monitoring Reveals the Nature of Submarine Turbidity Currents. *Nature Reviews Earth & Environment*, 4(9): 642–658. <https://doi.org/10.1038/s43017-023-00458-1>
- Thompson, R. C., Courtene-Jones, W., Boucher, J., et al., 2024. Twenty Years of Microplastic Pollution Research-What Have We Learned? *Science*, 386(6720): ead12746. <https://doi.org/10.1126/science.adl2746>
- Vowinckel, B., Biegert, E., Luzzatto-Fegiz, P., et al., 2019. Consolidation of Freshly Deposited Cohesive and Noncohesive Sediment: Particle-Resolved Simulations. *Physical Review Fluids*, 4(7): 074305. <https://doi.org/10.1103/PhysRevFluids.4.074305>
- Wan, Y., Xu, J. D., Pan, B., et al., 2024. Volcanic Hazard Mapping for Changbaishan-Tianchi Region, China. *Journal of Earth Science*, 35(6): 2030–2044. <https://doi.org/10.1007/s12583-021-1569-x>
- Wang, S. Q., Liu, L., Xu, Q. W., et al., 2024. A Unified Minkowski Sum Model for Largely Deformed Granular Materials with Arbitrary Morphologies. *Computer Methods in Applied Mechanics and Engineering*, 432: 117427. <https://doi.org/10.1016/j.cma.2024.117427>
- Wells, M. G., Dorrell, R. M., 2021. Turbulence Processes within Turbidity Currents. *Annual Review of Fluid Mechanics*, 53: 59–83. <https://doi.org/10.1146/annurev-fluid-010719-060309>
- Wickramarachchi, C., Niven, R. K., Kramer, M., 2025. Numerical Plastic Transport Modelling in Fluvial systems: Review and Formulation of Boundary Conditions. *Water Research*, 273: 122947. <https://doi.org/10.1016/j.watres.2024.122947>
- Yang, Y. P., Wang, D. W., Kneller, B., et al., 2024. How Does Plastic Litter Accumulate in Submarine Canyons? *Geophysical Research Letters*, 51(18): e2024GL110767. <https://doi.org/10.1029/2024GL110767>
- Zhang, H., 2017. Transport of Microplastics in Coastal Seas. *Estuarine, Coastal and Shelf Science*, 199: 74–86. <https://doi.org/10.1016/j.ecss.2017.09.032>
- Zhang, X. D., Liu, Z. F., Li, D. J., et al., 2024. Turbidity Currents Regulate the Transport and Settling of Microplastics in a Deep-Sea Submarine Canyon. *Geology*, 52(9): 646–650. <https://doi.org/10.1130/G52116.1>