Sedimentologika

Opinion piece

Using mixed siliciclastic-bioclastic sediments as a natural analogue for plastic-rich systems

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Abstract | Mixed siliciclastic-bioclastic sediments and systems could represent useful analogues for understanding the behaviour and impact of plastic sediments in natural environments. Integration of knowledge derived from various mixed systems can enhance our understanding of depositional processes, bedform morphology, and sedimentary particles (*sensu latu*) distribution. Similarities in how the two heterogenous particles composing siliciclastic-bioclastic and lithoclastic-plasticlastic mixed sediments respond to depositional processes suggest that it could be worth investigating if and how knowledges coming from the two systems can benefit each other.

Lay summary | Plastic pollution represents a major threat to ecosystems. Understanding how plastic particles are transported, how they mix with natural rock fragments (i.e, sediment) and where they accumulate is fundamental. In this contribution, the use of knowledge acquired studying sediments composed of a mixture of siliciclastic and bioclastic rock fragments, naturally available in present-day and ancient environments, is suggested to better understand mixed lithoclastic-plasticlastic systems, and vice versa.

Keywords: Mixed sediments; Siliciclastic-bioclastic; Lithoclastic-plasticlastic; Analogue

Plastic debris represents one of the major concerns for terrestrial and marine ecosystems, from the highest mountains to the deepest ocean trenches (Kane & Fildani, 2021; Macleod et al., 2021; Bergmann et al., 2022; Leslie et al., 2022; Leonard et al., 2024). Understanding how plastic particles influence depositional processes and sediments distribution is fundamental to predict where plastic hotspots are located (Kane et al., 2020; Chiarella & Hernández-Molina, 2021). Plastic intrinsic properties like durability mean that they are long-lived in the natural environment (Kane & Fildani, 2021). Studies highlight that organisms started to interact and eat plastic particles with potential impact on human health when plastic enters the food chain (Lavers et al., 2019; Markic et al., 2019; Savoca et al., 2021). Recent studies (e.g., Russell et al., 2023; Russell et al., 2025) show that plastic particles are active components of depositional processes and systems. Plastic particles hydrodynamic behaviour could locally increase the speed of bedform morphological transformations with an impact on bed topography and dune erosion, as well as influence depositional processes (e.g., increase of sand transported in suspension) resulting in changes in the size and shape of bedforms (see Russell et al., 2023). As result, the increase in the amount of material transported downstream could produce a disequilibrium in the evolution of river ecosystems with a potential impact on the wider landscape.

The introduction of plastic fragments in an environment characterised by the transport and deposition of sandy clastic material produces a compositional mixing (sensu Chiarella et al., 2017) of lithoclastic and plasticlastic fragments similar to what is observed in nature in siliciclastic-bioclastic systems. In this context, mixed particles respond differently to a given flow or shear stress as a function of the mean grain-size, sorting, shape, and particle density. The different response represents a reaction to the traction that strictly depends on the morphometry and density of the clastic particles, with spherical clasts requiring on-average a higher velocity to be set in motion than platy particles of the same grain size (Miller et al., 1977; Allen, 1984; Komar, 1987). Higher entrainment velocity also applies for particles with the same shape and grain-size but different composition and density. Different responses to the same force may affect transport rates, cause differential sediment entrainment, and lead to the formation of specific stratification varieties in mixed deposits (Komar, 1987; Longhitano, 2011; Chiarella & Longhitano, 2012). Accordingly, the study of sediments characterised by a mixed composition presents a more complex bedform dynamic than pure mono-compositional sediments, therefore requiring a different approach (Chiarella et al., 2017; Russell et al., 2023).

Flume tank experiments (e.g., Russell et al., 2023) show that the presence of sand-grained to pebble plastic particles mixed with sand affects the grain-to-grain interaction of the sand transport, offering a new perspective to understand current-dominated unidirectional processes in systems with mixed-composition sediment. Interaction between heterogeneous particles will also be instrumental to further our knowledge on how mixed sediments impact the downflow evolution of bedforms. As such, additional studies that can model how heterogeneous particles characterised by different shapes and densities are distributed in the sediment, and organised in layers, laminae, and lenses are needed. Understanding the distribution of heterogeneous particles in the deposit is important for correctly sampling sediments to observe the real composition and percentage of the two components in heterogeneous deposits (Russell et al., 2023). Identification of the processes controlling the distribution of mixed sediments is also important to identify potential plastic repository hotspot and assess the impact of plastic pollution on biodiversity and the environment (Multiple ocean threats, 2023). Additionally, all the above aspects are fundamental to assess the internal properties and heterogeneities of potential mixed siliciclastic-bioclastic reservoirs suitable for carbon capture and storage projects. As recently suggested by Chiarella et al. (2024), in mixed systems the internal organisation of heterolithic particles could have an impact on the vertical and lateral permeability.

Mixed sediments and systems are common in natural environments (Chiarella et al., 2017). Understanding how plastic particles influence sand transport processes can benefit from mixed siliciclastic-bioclastic analogues widely distributed in the present and ancient record. One limitation of most current studies on plastic-rich sediments is that they are rooted in traditional models that do not consider variable percentage composition of the two heterogenous particles typical of mixed systems, and the impact on studied processes. Also, neglecting mixed siliciclastic-bioclastic systems we miss the opportunity to strengthen our models using a natural analogue to complement existing flume tank experiments based on compositional mixed sediments.

Bioclastic fragments provide a wide range of variability in terms of shape, size, and density, similar to the variability observed for plastic (Russell et al., 2025). Moreover, siliciclastic-bioclastic systems show different types of mixing (compositional versus strata) controlled by different allocyclic and autocyclic factors operating at different scale, and changes in the relative proportion of the two heterolithic fractions (*sensu* Chiarella et al., 2017). Bioclasts interact with siliciclastic sand and *vice versa* affecting the grain-to-grain sediment transport and final deposition (Komar, 1987; Mount, 1985; Rieux et al., 2023). Flume tank experiments run using mixed siliciclastic-bioclastic sediments under wave actions examined how the presence of heterogeneous fractions having different properties influences sedimentary processes, final deposits, and their evolution (Rieux et al., 2023). These studies highlight how the change in the percentage of the mixture of the two fractions impacts the final architecture of the deposits. Studies performed on outcrop analogues investigate the lateral and vertical evolution of mixed siliciclastic-bioclastic deposits documenting sedimentary structures and heterogeneity similar to the ones obtained in experiments

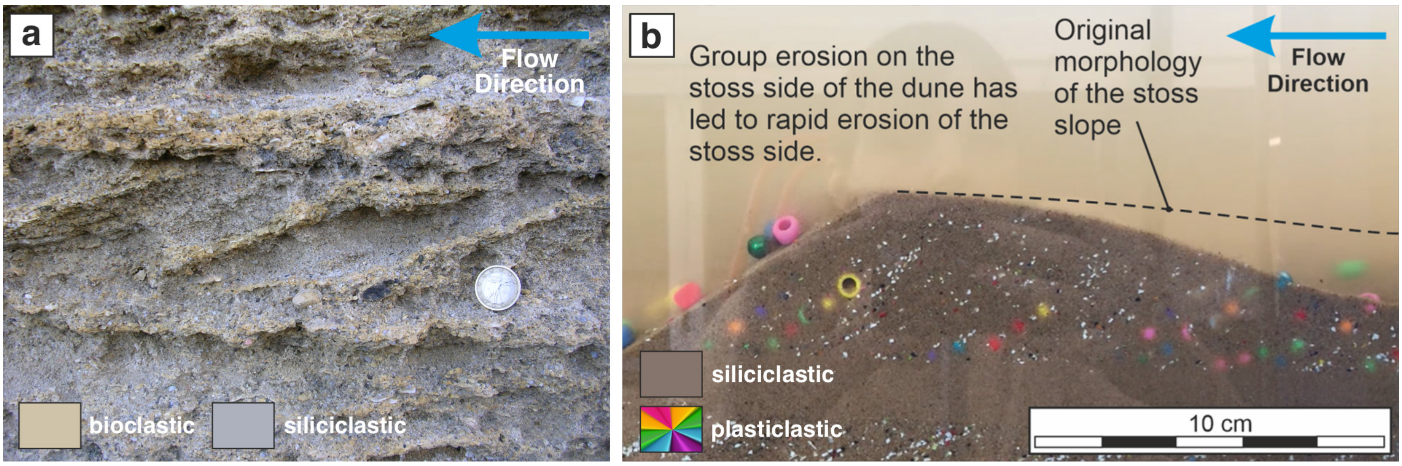

Figure 1 | Comparison of different types of mixed sediments showing a similar alternation between the two heterogeneous fractions along the migration path of the bedform. Siliciclastic-bioclastic (A) and siliciclastic-plasticlastic (B) mixed deposits producing the segregation of the two heterogeneous fractions in cross-stratified deposits under the action of a unidirectional current. (B modified from Russell et al., 2023).

conducted using mixed siliciclastic-plasticlastic sediments (Figure 1).

Different environments (e.g., fluvial *versus* beach) and depositional processes (e.g., steady *versus* unsteady current) could respond differently to mixed-composition sediments. However, there are aspects like the distribution of the two heterogeneous particles (Figure 1), and the impact on the final bedform morphology and evolution that seem to be valid across different environments and processes despite the specific focus and specific conditions of the study. So, siliciclastic-bioclastic and lithoclastic-plasticlastic sediments represent two types of mixed systems with common properties, making worth investigating if and how studies on both mixed types can help and support each other to advance knowledge in both fields.

Integration of knowledge related to these two types of mixed sediments would be the logical next step towards a unified interpretation of transport processes for compositional mixed sediments and their bed- to- basin-scale distribution. This approach could also determine, for example, the minimum percentage of mixed components required to produce the documented impact, and how variation in the plastic (or any other counterpart) percentage affects the process. Current studies on siliciclastic-bioclastic sediments indicate the minimum threshold to 10% of the antithetic component (Mount, 1985; Chiarella & Longhitano, 2012). Does this value apply for plastic as well?

Taken together, studies on mixed lithoclastic-plasticlastic and siliciclastic-bioclastic sediments could enhance our understanding of depositional processes in mixed systems. Continued investigation, improved laboratory experiments and numerical modelling, and dedication by the scientific community will be needed to refine our understanding of mixed sediments.

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Author contribution

Manuscript conceptualised, written, and reviewed by DC.

Data availability

Data sharing is not applicable to this article as no datasets were generated. Knowledges used in this paper are from cited references.

Conflict of interest

The author is co-founder of the journal and currently sit in the Steering Committee. The author had no access to the editorial process beside regular author-Editor correspondence.

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