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

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Mixed siliciclastic-bioclastic sediments and systems represent an analogue to understanding the behaviour and impact of plastic sediments in natural environments. The integration of knowledge derived from different mixed systems can enhance our comprehension of depositional processes, bedform morphology, and plastic distribution as well as assess the potentiality of siliciclastic-bioclastic reservoirs suitable for CO_2 storage.

Plastic debris represents one of the major concerns for terrestrial and marine ecosystems, from the highest mountains to the deepest ocean trenches. Understanding how plastic particles influence depositional processes and sediments distribution is fundamental to predict where plastic hotspots are located (Kane et al., 2020; Chiarella and Hernández-Molina, 2021). Plastic intrinsic properties like durability mean that they are long-lived in the natural environment (Kane and 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. Recent studies (e.g., Russell et al., 2023) show that plastic particles also influence depositional processes producing novel bedform morphologies having a potential impact on river ecosystems and wider landscapes.

The introduction of plastic fragments in an environment characterised by the transport and deposition of sandy clastic material produces a compositional mixing (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 to be set in motion an average velocity higher than platy particles of the same grain size (miller et al., 1977; Allen, 1984; Komar, 1987). This is also valid for particles having the same shape and grain-size but different composition/density. The different response to the same force may affect transport rates as well cause differential sediment entrainment, and lead to the formation of specific stratification varieties in mixed deposits (Komar, 1987; Longhitano, 2011; Chiarella and Longhitano, 2012). Accordingly, the study of sediments characterised by a mixed composition presents a more complex bedform dynamic than pure mono-compositional sediments requiring a different approach (Chiarella et al., 2017; Russell et al., 2023).

Flume tank experiments (Russell et al., 2023) show that the presence of plastic particles mixed with sand affects the grain-to-grain mechanics of the sand transport offering a new perspective to understand current-dominated unidirectional processes in systems with sediment having a compositional mixing. The interaction between heterogeneous particles will also be instrumental to further our knowledge on how mixed sediments impact the downflow evolution of bedforms. As such, studies can model how heterogeneous particles characterised by different shapes and densities are distributed in the sediment, and organised in layers, laminae, and lenses. That is important for correctly sampling sediments to observe the real composition and percentage of the two components in heterogeneous deposits. The 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. Additionally, all the above aspects are fundamental to assess the internal properties of potential mixed siliciclastic-bioclastic reservoirs suitable for carbon capture and storage projects.

Mixed sediments and systems are not an exception in natural environments (Chiarella et al., 2017). The comprehension of the influence of plastic particles on 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 rooted in traditional models that does not consider the variability in percentage composition of the two heterogenous particles typical of mixed systems, and its impact on the studied processes. Also, neglecting mixed siliciclastic-bioclastic systems we miss the opportunity to strengthen our models using a natural analogue as well as 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 what observed for plastic. Moreover, siliciclastic-bioclastic systems show different types of mixing and relative proportion of the two heterolithic fractions (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 conducted using mixed siliciclastic-plasticlastic sediments (Fig. 1).

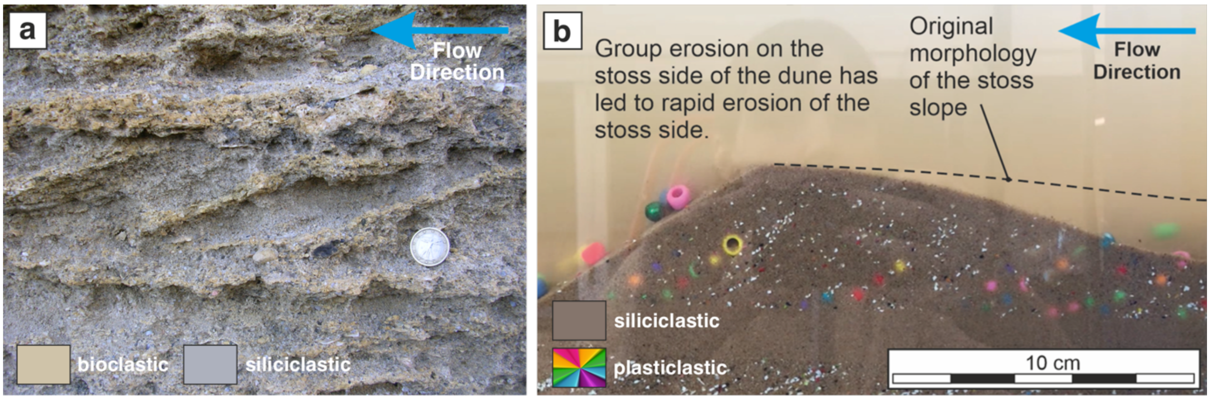

Fig. 1 Comparison of different types of mixed sediments showing a similar heterogeneity. Siliciclastic-bioclastic (**a**) and siliciclastic-plasticlastic (**b**) mixed deposits producing the segregation of the two heterogeneous fractions in cross-stratified deposits under the action of a unidirectional current. (**b** modified from Russell et al., 2023).

Different environments (e.g., fluvial *versus* beach) and depositional processes (e.g., steady *versus* unsteady current) respond differently if dealing with mixed sediments. However, there are aspects like the segregation of heterogeneous particles (Fig. 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 siliciclastic-plasticlastic sediments represent two faces of the same medal making worth investigating if and how studies on both mixed types of sediments can help and support each other.

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- and basin-scale distribution. This approach could also answer for example what is the minimum percentage of mixture 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 and Longhitano, 2012). Is it valid for plastic as well?

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

References

Allen, J.R.L. Sedimentary Structures: Their Character and Physical Basis. Development in Sedimentology 30, Unabridged One-volume. Elsevier, p. 1256 (1984).

Chiarella, D., Longhitano, S.G. Distinguishing depositional environments in shallow-water mixed bio-siliciclastic deposits on the base of the degree of heterolithic segregation (Gelasian, Southern Italy). *J. Sediment. Res.* **82**, 962-990 (2012).

Chiarella, D., Hernández-Molina, F.J. Go with the flow: the role of gateway and straits on plastic distribution. *Geology Today* **37**, 66-69 (2021)

Chiarella, D., Longhitano, S.G. & Tropeano, M. Types of mixing and heterogeneities in siliciclastic-carbonate sediments. *Mar. Pet. Geol.* **88**, 617-627 (2017)

Kane, I.A. & Fildani, A. Anthropogenic pollution in deep-marine sedimentary systems—A geological perspective on the plastic problem. *Geology* **49**, 607-608 (2021)

Kane, I.A., Clare M.A., Miramontes, E., Wogelius, R., Rothwell, J.J., Garreau, P. & Pohl, F. Seafloor microplastic hotspots controlled by deep-sea circulation. *Science* **368**, 1140-1145 (2020)

Komar, P.D. Selective grain entrainment by a current from a bed of mixed sizes: a reanalysis: *J. of Sediment. Petrol.* **57**, 203–211 (1987).

Longhitano, S.G. The record of tidal cycles in mixed silici-bioclastic deposits: examples from small Plio-Pleistocene peripheral basins of the microtidal Central Mediterranean Sea. *Sedimentology* **58**, 691-719 (2011).

Miller, M.C., McCave, I.N. & Komar, P.D. Threshold of sediment motion under unidirectional currents. *Sedimentology* **24**, 507-527 (1977).

Mount, J.F. Mixed siliciclastic and carbonate sediments: a proposed first-order textural and compositional classification. Sedimentology 32, 435-442 (1985).

Rieux, A., Weill, P., Mouazé, D. & Tessier, B. Influence of sediment composition on morphology and internal structure of mixed siliciclastic–bioclastic coastal barriers: Contribution of flume experiments. *Sedimentology* **70**, 1580-1600 (2023).

Russell, C.E., Fernández, R., Parsons, D.R. & Gabbott, S.E. Plastic pollution in riverbeds fundamentally affects natural sand transport processes. *Commun. Earth Environ.* https://doi.org/10.1038/s43247-023-00820-7 (2023)