Migrating subaqueous dunes capture clay flocs

de Lange, Sjoukje I.; van der Wilk, Anne; Chassagne, Claire; Ali, Waqas; Hoitink, Ton; Born, Maximilian P.; Brodersen, Kristian; Waldschläger, Kryss

Publication date
2025

Document Version
Final published version

Published in
Crossing boundaries

Citation (APA)
de Lange, S. I., van der Wilk, A., Chassagne, C., Ali, W., Hoitink, T., Born, M. P., Brodersen, K., & Waldschläger, K. (2025). Migrating subaqueous dunes capture clay flocs. In V. Chavarrias, & A. M. Van den Hoek (Eds.), *Crossing boundaries: NCR DAYS 2025 Proceedings, Book of Abstracts* (pp. 41-42). NCR (Netherlands Centre for River Studies).

Migrating subaqueous dunes capture clay flocs

Sjoukje I. de Lange[a, b], Anne van der Wilk[a], Claire Chassagne[c], Waqas Ali[c], Ton Hoitink[a], Maximilian. P. Born[d], Kristian Brodersen[d], Kryss Waldschläger[a]

[a]*Hydrology and Environmental Hydraulics, Department of Environmental Sciences, Wageningen University, Wageningen, the Netherlands*

[b]*HKV lijn in Water. Lelystad, the Netherlands*

[c]*Section of Environmental Fluid Mechanics, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands*

[d]*Institute of Hydraulic Engineering and Water Resources Management, RWTH-Aachen University, Aachen, Germany*

Keywords — flocculation, subaqueous dunes, laboratory experiments

Introduction

Recent research highlights the abundance of floccule (flocs) in rivers (Nicholas, A. & Walling , 1996; Bungartz & Wanner, 2004; Lamb et al, 2020; Fetweis, 2008) formed by aggregation of clay particles with organic matter (Droppo, 2024; Dyer, 1989; Winterwerp, 2002; Mietta et al., 2009; Lasereva & Parfenova, 2023; Safar et al., 2022; Deng et al., 2019). These flocs affect the transport and the eventual fate of clay. Flocs exhibit distinct behaviour from the unflocculated sedimentary counterparts: they can deform and break, and have higher settling velocities (Lamb et al, 2020), which may in turn cause flocs to deposit and possibly interact with the riverbed (Lamb et al, 2020; Winterwerp et al., 2021; Baas et al., 2016)

Methods

Here, we conducted systematic experiments in an annular laboratory flume (Figure 1a, b) to identify the mechanisms by which flocs and bedforms interact. Different amounts of flocculant and various shear stress conditions (0.3 and 0.5 N/m^2) were applied, and the resulting floc characteristics and bedform geometry were measured. Bedform geometry was measured with an acoustic depth profiler (Figure 1c), and floc size was measured in a settling column (Figure 1d).

Results and Discussion

Under lower shear conditions, the flocs were larger, and transport rates were lower than under high shear conditions. However, under both shear conditions, flocs were transported via saltation and in suspension, and they became integrated within the sediment bed via deposition and burial in the lee of a dune, either as single flocs, clusters, or strings (Figure 2a). Deposition occurred predominantly on the leeward side of the dune, revealing distinct stratigraphy patterns (Figure 2a). The presence of flocs had a negligible impact on the actual geometry of the bedforms.

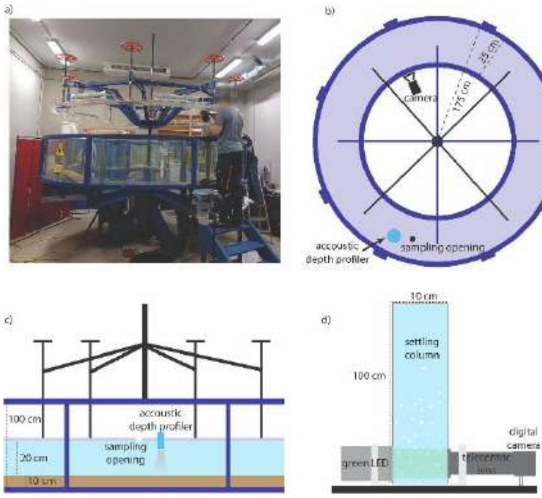

Figure 1. A picture (a), schematised top-view (b) and schematised side view (c) of the annular flume. d Side-view of the settling column setup. Subfigure (b–d) are not to scale for visualisation purposes. From de Lange et al. (2024).

The interaction of clay with the bed is summarised in Figure 2b. The variability in shear stress due to the geometrical complexity of the bed allows for the trapping of flocs. Floc transport occurs over the dune stoss, where shear stresses are larger, while floc deposition is concentrated in areas with low shear stresses (dune trough). At the top of the dune, where shear stresses are greatest, the fate of flocs is determined as flocs are either resuspended or trapped in the lee.

Conclusion and Implications

This investigation highlights the active role of flocculated clay particles in sediment transport in riverine systems, contrary to the general assumption that clay particles behave passively as wash load. This finding has the potential to affect sediment transport rates of fines, contaminants, and entangled microplastics (Ongley et al., 1992, Milligan & Loring, 1997; Laursen et al., 2022; Andersen et al., 2021; Yan et al., 2021) and could have far-reaching impacts on the interpretation of mud deposits in the sedimentary rock record

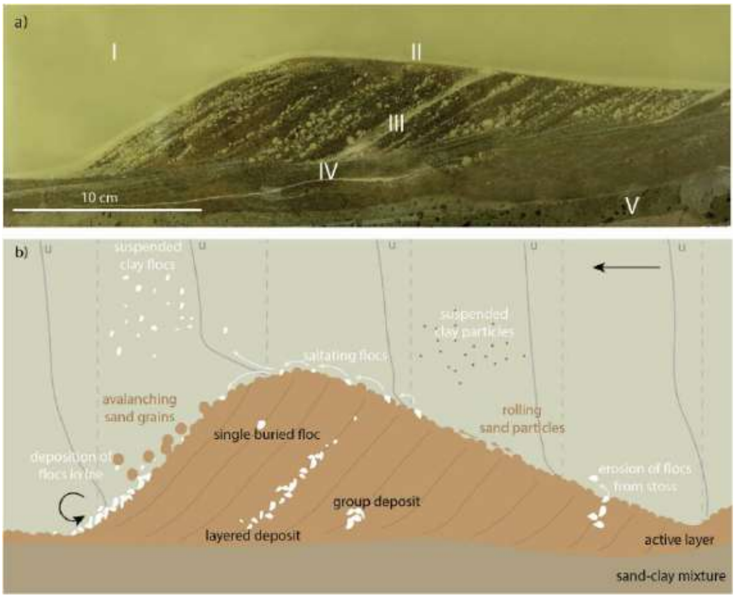

Figure 2. a Capturing of flocs in a bedform, in which five regimes are indicated, I: suspension, II: recent deposition, III: drapes within a dune, IV: drapes below the active surface (remnant), V: homogeneously mixed conditions (initial experiment conditions). The image is taken seconds after the flow has halted. In this time a depositions layer of flocs has formed on the dunes. The image is slightly adjusted to reduce reflections. b Schematic of the suspended and bed load transport of clay particles and flocs, and the subsequent trapping in the sediment bed. Velocity profiles (u indicates the flow velocity, dotted line indicates zero m s^{-1}) are schematised based on the measurements in Kirca et al. (2020). Image taken from de Lange et al. (2024).

(Schieber et al., 2007). For modelling and predicting mud transport in river systems a comprehensive understanding of the transport mechanisms of clay flocs is essential and should be considered (van Kessel et al., 2011; van Rijn et al, 2018)

References

Andersen, T. J., Rominikan, S., Olsen, I. S., Skinnebach, K. H. & Fruergaard, M. Flocculation of PVC microplastic and fine-grained cohesive sediment at environmentally realistic concentrations. Biol. Bull. 240, 42–51 (2021).

Baas, J. H., Best, J. L. & Peakall, J. Predicting bedforms and primary current stratification in cohesive mixtures of mud and sand. J. Geol. Soc. 173, 12–45 (2016).

Bungartz, H. & Wanner, S. C. Significance of particle interaction to the modelling of cohesive sediment transport in rivers. Hydrol. Process. 18, 1685–1702 (2004)

de Lange, S.I., van der Wilk, A., Chassagne, C. et al. Migrating subaqueous dunes capture clay.

Deng, Z., He, Q., Safar, Z. & Chassagne, C. The role of algae in fine sediment flocculation: In-situ and laboratory measurements. Mar. Geol. 413, 71–84 (2019).

Droppo, I. G. Rethinking what constitutes suspended sediment. Hydrol. Process. 15, 1551–1564 (2001). Commun Earth Environ 5, 729 (2024).

Dyer, K. R. Sediment processes in estuaries: future research requirements. J. Geophys. Res. 94, 14327–14339 (1989)

Fettweis, M. Uncertainty of excess density and settling velocity of mud flocs derived from in situ measurements. Estuar. Coast. Shelf Sci. 78, 426–436 (2008).

Kirca, V. S. O., Saghebian, S. M., Roushangar, K. & Yagci, O. Influence of surface roughness of dune bedforms on flow and turbulence characteristics. Int. J. Sediment. Res. 35, 666–678 (2020).

Lamb, M. P. et al. Mud in rivers transported as flocculated and suspended bed material. Nat. Geosci. 13, 566–570 (2020).

Lasareva, E. V. & Parfenova, A. M. Influence of organic matter on the transport of mineral colloids in the river-sea transition zone. in Oceanography - Relationships of the Oceans With the Continents, Their Biodiversity and the Atmosphere, 4th edn, Ch. 4 (IntechOpen, London, 2023).

Laursen, S., Fruergaard, M. & Andersen, T. Rapid flocculation and settling of positively buoyant microplastic and fine-grained sediment in natural seawater. Mar. Pollut. Bull. 178, 113619 (2022).

Mietta, F., Chassagne, C., Manning, A. J. & Winterwerp, J. C. Influence of shear rate, organic matter content, pH and salinity on mud flocculation. Ocean Dyn. 59, 751–763 (2009).

Milligan, T. & Loring, D. The effect of flocculation on the size distributions of bottom sediment in coastal inlets: implications for contaminant transport. Water Air Soil Pollut. 99, 33–42 (1997).

Nicholas, A & Walling, D. The significance of particle aggregation in the overbank deposition of suspended sediment on five floodplains. J. Hydrol. 186, 275–293 (1996).

Ongley, E. D., Krishnappan, B. G., Droppo, G., Rao, S. S. & Maguire, R. J. Cohesive sediment transport: emerging issues for toxic chemical management. Hydrobiologia 235-236, 177–187 (1992).

Safar, Z. et al. Characterization and classification of estuarine suspended particles based on their inorganic/organic matter composition. Front. Mar. Sci. 9, 896163 (2022).

Schieber, J., Southard, J. & Thaisen, K. Accretion of mudstone beds from migrating floccule ripples. Science 318, 1760–1763 (2007).

van Kessel, T., Vanlede, J. & de Kok, J. Development of a mud transport model for the Scheldt estuary. Cont. Shelf Res. 31, S165–S181 (2011).

van Rijn, L. C. & Grasmeijer, B. Effect of channel deepening on tidal flow and sediment transport–part II: muddy channels. Ocean Dyn. 68, 1481–1501 (2018).

Winterwerp, J. C., van Kessel, T., van Maren, D. S. & van Prooijen, B. C. Fine Sediment in Open Water. From Fundamentals to Modeling (Advanced Series on Open Engineering - volume 55. World Scientific., Singapore, 2021).

Winterwerp, J. On the flocculation and settling velocity of estuarine mud. Cont. Shelf Res. 22, 1339–1360 (2002).

Yan, M., Wang, L., Dai, Y., Sun, H. & Liu, C. Behavior of Microplastics in Inland Waters: Aggregation, Settlement, and Transport. Bull. Environ. Contam. Toxicol. 107, 700–709 (2021).