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# Influence of bed age and flocculation dynamics on turbidity current propagation

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In this study, the influence of a bed on turbidity current propagation and flocculation dynamics has been investigated using a lock-exchange setup. Experiments were performed in saltwater using sediments sampled from a deep-sea mining location in the Clarion Clipperton Zone (CCZ). Results showed that the presence of a bed influenced the propagation velocity of turbidity currents. Flocs were denser and larger than those observed when no bed was present. The floc settling velocities also increased in the presence of a bed. Additionally, in the case of a (freshly) formed bed, sediment resuspension occurred due to the disturbance of organic matter, which contributed to flocculation. This study also sheds light on the role of the age of the bed on turbidity current propagation, with (freshly) formed beds being efficient in reducing sediment spread. These findings are important for predicting the spread of a turbidity current during deep-sea mining activities.

## KEYWORDS

abyssal sediment, deep-sea mining, flocculation, lock-exchange, turbidity current

## Highlights

- The presence of a bed and its age impact turbidity current propagation.
- Flocculation was enhanced when a bed was present, resulting in the formation of denser and larger flocs with higher settling velocities.
- Sediment resuspension played an important role in turbidity current propagation, affecting both its velocity and floc characteristics.

## 1 Introduction

The growing demand for clean energy technologies has increased the need for metals such as manganese, nickel, copper, and cobalt that are essential for producing wind turbines, solar panels, and electric vehicles. A significant amount of these metals is present in potato-shaped deposits known as polymetallic nodules found in the vast abyssal plains in the deep-sea. They are found at a depth of 4,000–6,000 m in the Pacific Ocean in an area known as the Clarion Clipperton Fracture Zone (CCFZ/CCZ).

One of the main concerns during the extraction process of polymetallic nodules is the dispersion of sediment and suspended matter beyond the Sea-floor Mining Tool (SMT) trajectory, as sideways propagating turbidity currents (Elerian et al., 2021). Turbidity

currents are a subclass of gravity currents (also known as density currents). The transport, driven by gravity, primarily takes place due to the difference in density between the turbidity current and the surrounding fluid (Middleton, 1993). The difference in density, in shallow waters, may arise due to variations in temperature (between the turbidity current and the ambient water) or solute concentrations. In this article, we concentrate on turbidity currents which originate from the density difference between the suspended sediment and ambient water. In the case of turbidity currents, the sediment is held in suspension by fluid turbulence (Middleton, 1993).

During a deep-sea mining operation, excess water and sediment discharged from the SMT move through various flow stages before settling (Elerian et al., 2021; van Grunsven et al., 2018). Initially, the discharge behaves as a turbulent jet (Stage 1). It then entrains more water, thus increasing in mass and reducing in velocity, where it enters stage 2. At this point, the jet is known as a plume and is driven mainly due to the density difference between the plume and the ambient fluid, which sinks and impinges and might result in seabed erosion and deposition (Stage 3). In the final stage, the flow evolves into a turbidity current (Stage 4) moving along the seafloor. Results obtained from sediment plume dispersion modeling showed that the area of influence varied between 4 and 9 km, depending on whether normal conditions prevailed or an eddy had passed through the study location (Gillard et al., 2019).

El Mousadik et al. (2024) conducted *in situ* measurements on turbidity flows caused by an SMT. They showed that the particle size and settling velocity distribution were influenced by the kind of disturbance to which the sediments were exposed. This disturbance was a function of various factors such as the SMT's operations, hydrodynamic processes, and the time elapsed after discharge. It was found that in a certain type of maneuver (selfie), the Particle size distribution (PSD) was different for the detrained sediment from the gravity current compared to that from the turbulent wake. The PSD is also influenced by the position within the plume and the time elapsed since its discharge, but most significantly by the subsequent fluid dynamic processes. Their results indicate that flocculation is likely to occur, especially close to the SMT where the turbidity flow is still at a higher sediment concentration.

The PSD is expected to change over distance due to the segregation of particles. However, Gazis et al. (2025) showed that flocculation occurred during deep-sea sediment plume propagation as they found an increase in median particle size with distance. These results are based on measurements taken at further distances from the same vehicle disturbance as described by El Mousadik et al. (2024). Gillard et al. (2019) also proved that flocculation occurred in laboratory experiments using deep-sea sediments, which similarly changed the PSD and median particle size. In this case, the author used a fixed volume of sediment and water, mixed at a constant rate. The conditions in this case are steadier and do not account for the rapid dilution of sediment concentration as in the case of a turbidity current, which is more dynamic.

Elerian et al. (2023) developed a numerical near field model that included flocculation. The flocculation parameters were calibrated with the flocculation parameters based on the laboratory work of Gillard et al. (2019). From the numerical evaluation, it was clear that flocculation readily occurs (within the

first 100 m from the SMT), forming larger particles and thus higher settling velocities at distances beyond the first 100 m from the SMT. Although the hydrodynamics in the near-field are not yet affected by the generation of flocs, the PSDs of the sediment and hence their settling velocities changed, compared to the initial discharge concentration.

Sea-floor sediment typically consists of clay, sand, fragments of rock, and organic material (BGR, 2019; Lang et al., 2019; Zawadzki et al., 2020). This organic material comes from aggregates of organic detritus that sink through the water column. The aggregates are altered on their way down by grazing, microbial degradation, and chemical processes (Karl et al., 1988). The ones larger than 500  $\mu\text{m}$  are called marine snow (Allredge and Silver, 1988). The leftover materials that make it to the deep-sea floor include less degradable substances such as cellulose, chitin, and other proteinaceous structural compounds (Boetius and Lochte, 1994).

In the work of Ali et al. (2024a), the flocculation between organic matter and mineral sediment coming from deep-sea clay has been studied in detail. The CCZ sediments sampled from two different regions were studied as a function of mixing time, shear, and sediment concentration. It was found that the organic matter had amphiphilic properties, which are in line with the composition of deep-sea organic matter. The results showed that flocculation occurred in all situations in less than 2.5 min and that sizes could increase by 3–6 times compared to unflocculated materials.

In a previous study (Wahab et al., 2025), it was shown that flocculation occurred in a propagating turbidity current using illite clay and an anionic polyacrylamide flocculant, which similarly flocculates within seconds. These experiments were performed in a lock exchange flume, where the turbidity current propagated on the plexiglass bottom in the absence of a bed. Turbidity current lock exchange experiments conducted by (Nogueira et al., 2013) investigated the role of roughness on the front propagation velocity. The roughness imparted by the freshly deposited bed reduces the turbidity current propagation.

Apart from flocculation, which has proven to reduce sediment spread, it thus remains to be investigated whether the presence of a (disturbed) bed would or would not reduce sediment spread.

For any deep-sea mining activity, the first run would take place on an undisturbed ocean bed. The propagation of turbidity currents will likely differ between an undisturbed bed and the one that has already undergone mining and the materials have settled. In this article, the difference in propagation between turbidity currents under different bed scenarios were studied. Experiments were performed using deep-sea sediments in saltwater, first using a plexiglass bottom, then a 1-day old bed and finally a 3-day old bed. The bed was made by leaving the materials from a turbidity run on the plexiglass bottom.

## 2 Materials and methods

### 2.1 Materials

#### 2.1.1 Clay

The clay used here was from the Clarion Clipperton Fracture Zone in the Pacific Ocean specifically from the NORI-D license

area. The density of the material was found to be  $1,166 \text{ kg/m}^3$ . The  $d_{50}$  obtained from Malvern Mastersizer 3000 was found to be  $26.3 \mu\text{m}$ . The clay was obtained from the top 30 cm of the bed, collected with box cores. However, it is worth mentioning that the top few centimeters of the bed was unavailable for this study. The loss of the topmost layer also resulted in the loss of the highest concentration of organic matter, with the subsequent layers having a comparatively lesser amount of organic matter. The water depth at which the sediment was sampled was approximately 4,000 m. It was then stored in a 150 L barrel under wet, dark, and room temperature conditions.

### 2.1.2 Saltwater

All the experiments were conducted in saltwater, which was used to simulate deep-sea conditions. Additionally, the study by Ali et al. (2022) demonstrated that saltwater enhances the flocculation behavior of clay. The salt (Sodium Chloride, NaCl), being the primary salt in seawater, was used in this context. The electrical conductivity of the prepared saltwater was kept at  $34.7 \text{ mS/cm}$ , comparable to that of water at the abyssal plains (Ali et al., 2024a). The PSD of CCZ clay is shown in Figure 1.

## 2.2 Methods

The setup and equipment were provided by the Dredging Laboratory of TU Delft.

### 2.2.1 Set up: lock exchange flume

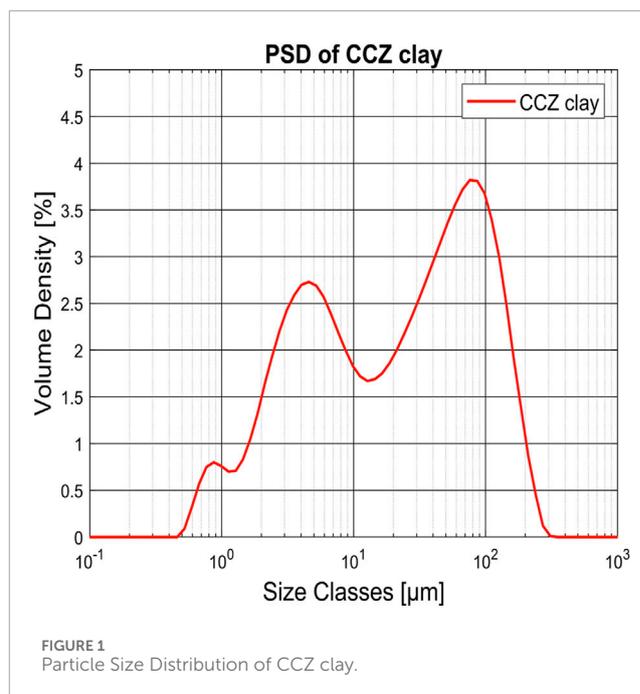
The experimental setup consists of a lock exchange flume with dimensions of  $3 \text{ m} \times 0.2 \text{ m} \times 0.4 \text{ m}$  (shown in Figure 2). The dimension of the lock is  $0.2 \text{ m} \times 0.2 \text{ m} \times 0.4 \text{ m}$ . The setup was equipped with a 4 mm diameter siphon (at 3 cm from the bottom) to collect samples from the body of the turbidity current for floc analysis. A 4 MHz UVP transducer was used in the lock exchange flume. The siphon and the transducer were used one at a time.

### 2.2.2 Ultrasonic velocity profiler (UVP)

The UVP is a device used for measuring instantaneous velocity profiles in a liquid flow. The principle used here is the Doppler shift frequency of echoed ultrasound as a function of time (Met-Flow SA, 2002). A Metflow UVP device was used here to measure the velocity profiles of particles inside the turbidity current. A 4 MHz transducer was mounted inside the flume at an angle of  $20^\circ$  relative to the vertical, pointing in the direction of the flow (Figure 3), which recorded 1-D velocities of the particles.

### 2.2.3 FlocCAM

The FlocCAM (Figure 4) is an in-house video microscopy device designed to measure floc size and settling velocities of flocs larger than  $20 \mu\text{m}$  (Manning et al., 2007; Ye et al., 2020; Shakeel et al., 2021). It consists of a settling column ( $10 \text{ cm} \times 10 \text{ cm} \times 30 \text{ cm}$ ). A 5 MP CMOS camera with a resolution of  $2,592 \times 2,048$  pixels and a Global Shutter that captures flocs in high-resolution images. Flocs were introduced into the settling column by carefully collecting them from a sampling beaker (where the flocs were formed) with a pipette. Videos were recorded and then analysed using the SAFAS software package (Ryan MacIver, 2019) to determine the floc sizes and settling velocity.



### 2.2.4 Pre-existing bed

Three types of beds were used for the Lock exchange experiments.

1. No bed: The turbidity current directly propagated on the plexiglass bottom of the flume. This case was used as the controlled condition.
2. 1-day bed: This type of bed was constructed by leaving the sediments at rest overnight from a previous run for approximately 16–18 h (Figure 5).
3. 3-day bed: This bed was constructed by leaving sediments at rest over the weekend for approximately 68 h. The durations of beds (16 h/68 h) were chosen to ensure the practicality of the experiments. The construction of both beds is described in Section 2.2.5.

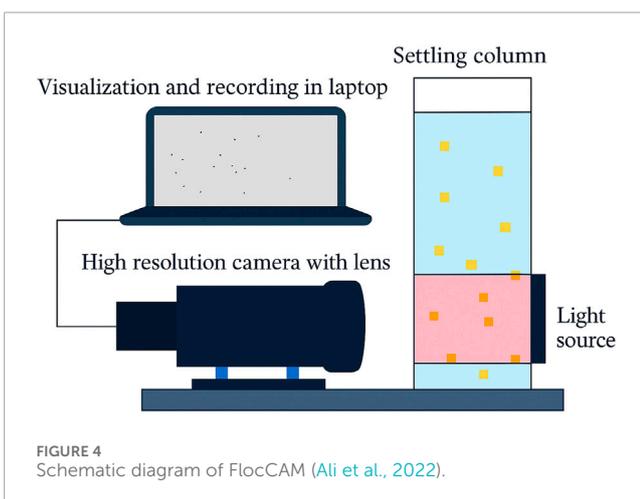
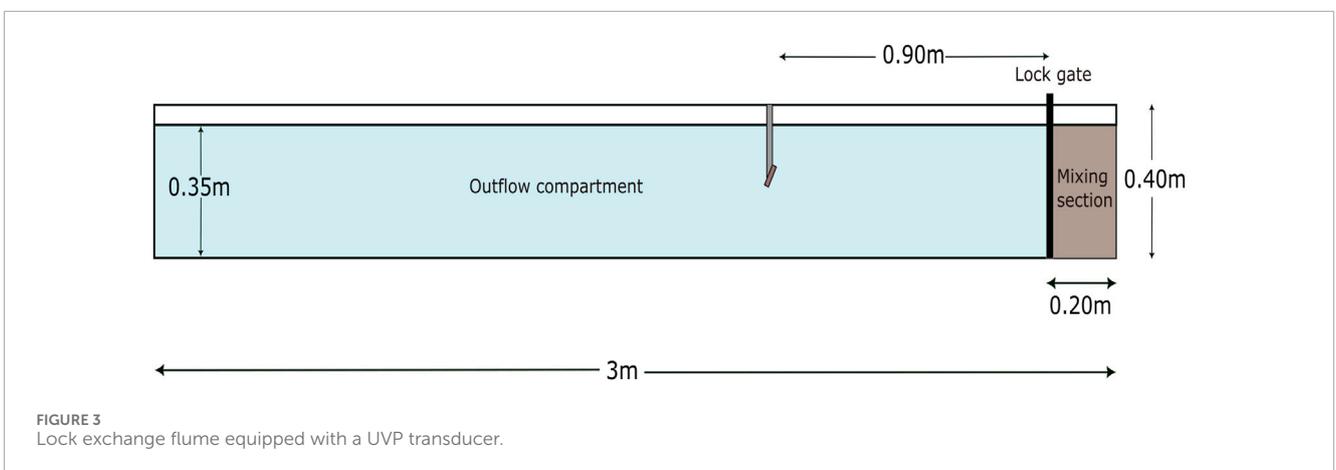
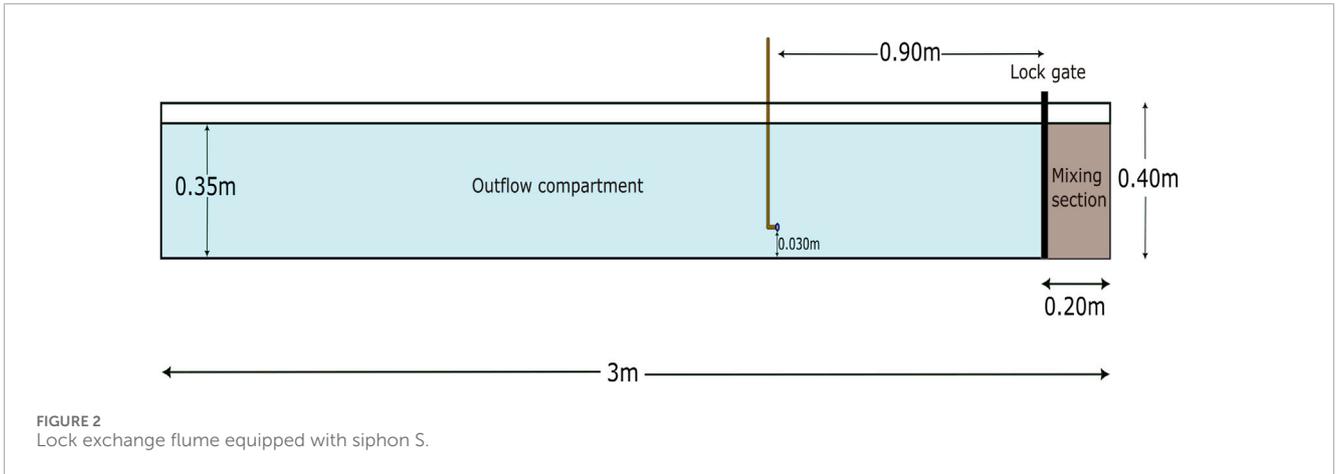
The lock exchange experiments were carried out using three different initial concentrations of CCZ sediments (2.5, 5, and  $10 \text{ g/L}$ ) in the mixing compartment. The setup was similar to what was used in the previous works of Wahab et al. (2025).

The experimental matrix for the lock exchange experiments is shown here Table 1.

### 2.2.5 Experimental protocol

The following protocol was adopted for these experiments.

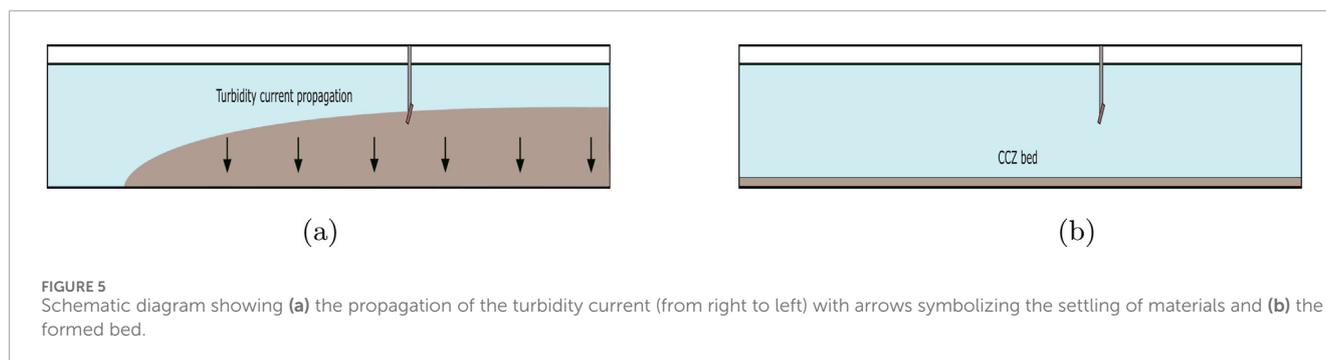
1. The lock exchange flume was filled with saltwater to a fixed height (in this study, 35 cm).
2. The volume of CCZ sediment was measured by first determining the dry mass fraction in 100 mL of the sediment sample. Depending on the target concentration, the required mass of dry sediment was calculated, and then the corresponding volume of sediment suspension was measured accordingly to be added to the mixing section of the flume. The mixture was then mixed for 20 min using an overhead stirrer



3. In case of the “No bed” scenario, upon release of the lock gate, the sediment was released into the outflow compartment. Thus, leading to the formation of a turbidity current that propagated on the plexiglass bottom until it reached the end of the flume.
4. After the experiment had ended, the sediment and water were left undisturbed in the flume for 16–18 h or 68 h,

depending on whether a “1-day bed” or a “3-day bed” was desired.

5. The next day(s), the flume bottom was lined with a layer of sediment, which is referred to as the “1-day bed/3-day bed”.
6. The lock gate was placed back in position, and the lock section was filled with sediments and then released. The turbidity current, in this case, propagated on top of a bed.
7. The propagation was recorded using a GoPro Hero 11 camera. The videos were then analyzed to obtain the front velocity using Tracker software (Version 6.1.3) (Douglas et al., 2008).
8. The particle velocity inside the turbidity current was recorded by a 4 MHz UVP transducer mounted in the flume. The transducer was kept at a fixed position throughout all the experiments. The velocity data was collected from the head of the turbidity current when it reached a distance of 120 cm from the lock gate.
9. The experimental matrix was repeated following the same procedure (Steps 1–6) to collect samples *via* siphons. The sample collection began when the head of the turbidity current was at 100 cm from the lock gate, i.e., at 10 cm from the siphon position. The collected samples were then analyzed using FlocCAM.



**FIGURE 5** Schematic diagram showing (a) the propagation of the turbidity current (from right to left) with arrows symbolizing the settling of materials and (b) the formed bed.

**TABLE 1** Experimental matrix with different bed types and concentrations.

Type of beds	Concentration [g/L]
No bed	2.5, 5, 10
1-day bed	2.5, 5, 10
3-day bed	2.5, 5, 10

## 3 Results

The results of the experiments that were conducted are presented in this section.

### 3.1 Front propagation analysis of turbidity currents

#### 3.1.1 Front analysis

Figure 6a shows the front positions of turbidity currents with CCZ sediments for different initial sediment concentrations (2.5, 5, and 10 g/L), considering three different bed scenarios. The associated velocities are shown in Figure 6b. The results indicate that the front velocity reduces due to the presence of the bed. The effect of the 1-day bed is especially pronounced at lower concentrations, where the momentum generated by the turbidity current is lower. In contrast, at higher concentrations, where the momentum is higher, the presence of a bed does not affect the front velocity. It was observed that the front velocity increased by 3% and 4% for 1-day and 3-day beds, respectively, relative to the no bed condition (for 10 g/L). In the presence of the 3-day bed, it is seen that the velocity is higher than that of the 1-day bed. As the beds age, the turbidity current velocity increases. One of the possible explanations could be that the organic matter in the water column takes longer to settle. In the case of the 3-day bed, this extended settling time allowed more organic matter to accumulate, leading to bed reformation, changes in the biofilm, and resulting in a smoother bed. Another explanation could be that due to the settling of organic matter over a prolonged duration, the bed gets compacted, making it difficult to erode and behave like a big entity of floc on its own.

In this scenario, it is crucial to understand the role of the bed, specifically how an older bed or one formed by newly deposited

materials influences the front propagation velocity of the turbidity currents. In deep-sea mining activities, the sediments disturbed by the SMT or the discharged materials will be deposited in the vicinity, with a chance to interact with passing turbidity currents. This newly created bed will influence the current's propagation.

Additionally, flocculation will also be influenced due to loose materials being picked up during the turbidity current propagation. Simultaneously, materials will also be dropped along the way due to the influence of the roughness of the freshly formed bed.

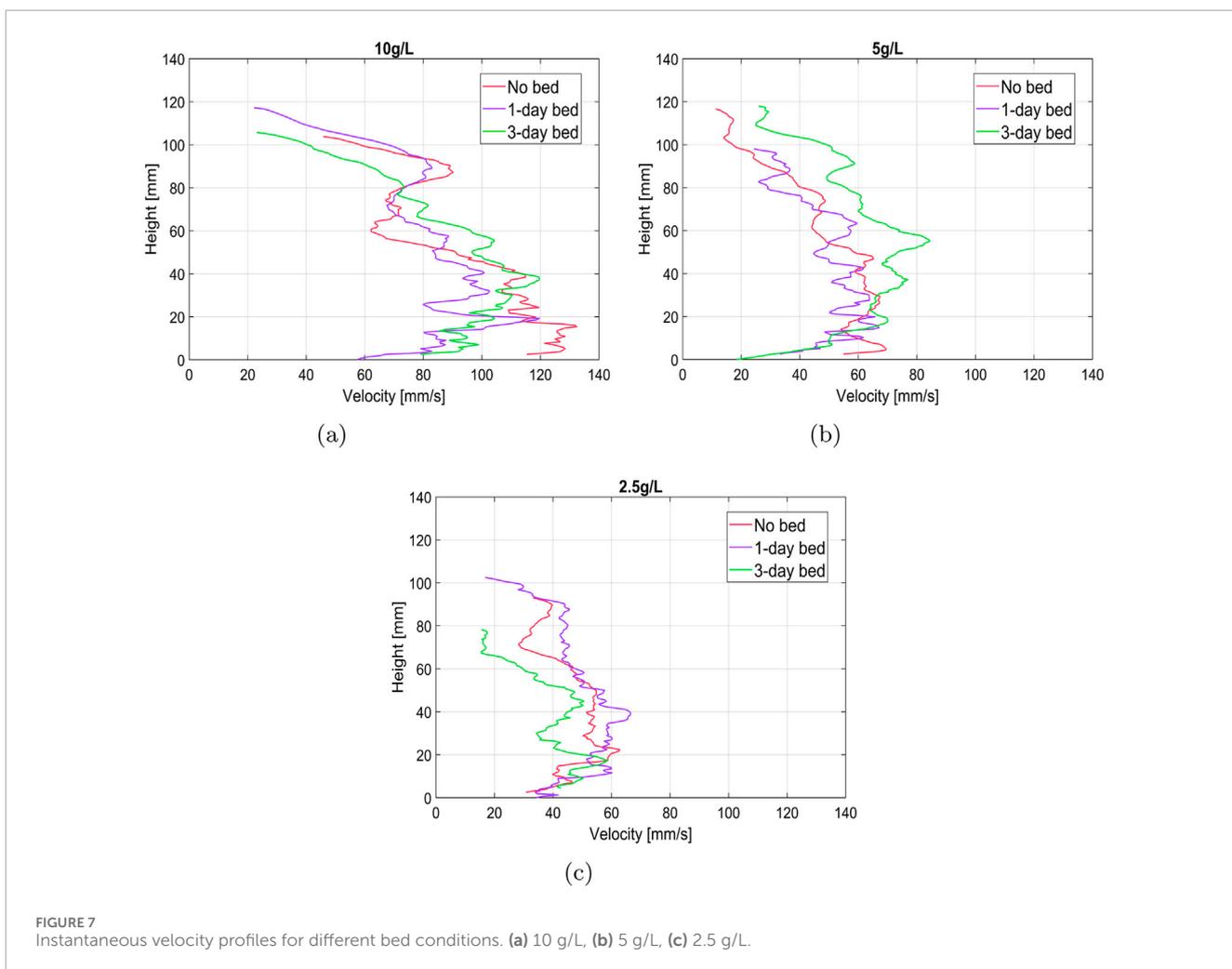
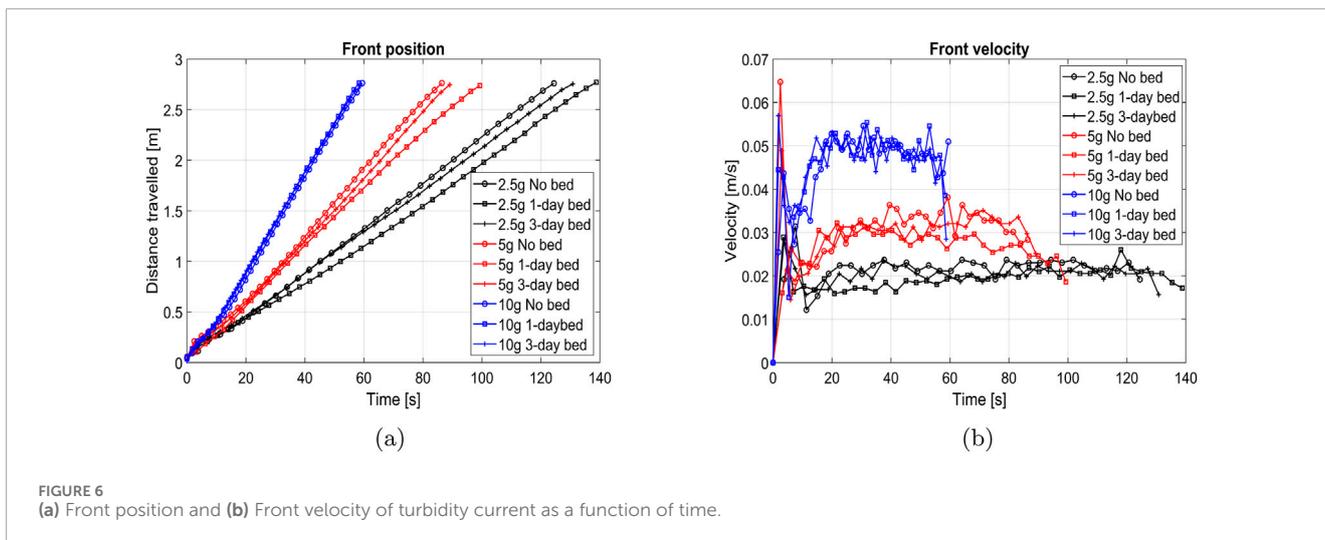
### 3.2 Ultrasonic velocity profiler (UVP)

Figure 7 shows velocity profiles recorded using a 4 MHz UVP transducer. The data presented here were extracted when the head of the current reached 120 cm from the lock gate (at 30 cm from the transducer). For 10 and 5 g/L, the instantaneous velocity profiles for “No bed” condition started with a higher velocity when compared to the 1 and 3-day bed cases. The velocity profiles for 2.5 g/L were comprised of noise due to fewer seeding materials being available. From the UVP data, it is seen that the turbidity current height was between 8 and 11 cm from the flume bottom for 2.5 g/L, whereas it was in the range of 10–12 cm for 5 and 10 g/L concentrations. The presented data is from the “head” position of the turbidity current as defined in (Sequeiros et al., 2018) when the head height is the maximum. The transducer also recorded the particle velocity at the body and tail of the turbidity current. The data was comprised of noise due to low seeding materials being left at those parts of the turbidity current.

### 3.3 FlocCAM

The sediment samples were collected *via* siphon and analyzed using the FlocCAM. The floc data obtained from video analysis using SAFAS software are presented here. Two types of beds are considered here: no bed and a 1-day bed, as described in Section 2.2.4.

The data in Figure 8 represent the settling velocities of particles as a function of their size, for three different sample concentrations. The isodensity lines indicate a relative density in the range of 1,600–16 kg/m<sup>3</sup>. Particles usually do not settle under Stokesian conditions in the FlocCAM experiments. As has been demonstrated in Ali et al. (2024b), Stokesian settling velocities can be observed when the distance between a particle and its closest



neighbor is high. Particles falling under these conditions are termed “individual” in the legend. Particles falling in the vicinity of others are termed “collective”. As expected, collective settling velocities are generally one decade higher than individual settling velocities.

From [Figure 8a](#), note that the particle’s settling velocity range is substantially wider than in [Figure 8c](#).

[Figure 9](#) presents the box plots for settling velocities under two different bed scenarios: no bed and 1-day bed. The flocs are

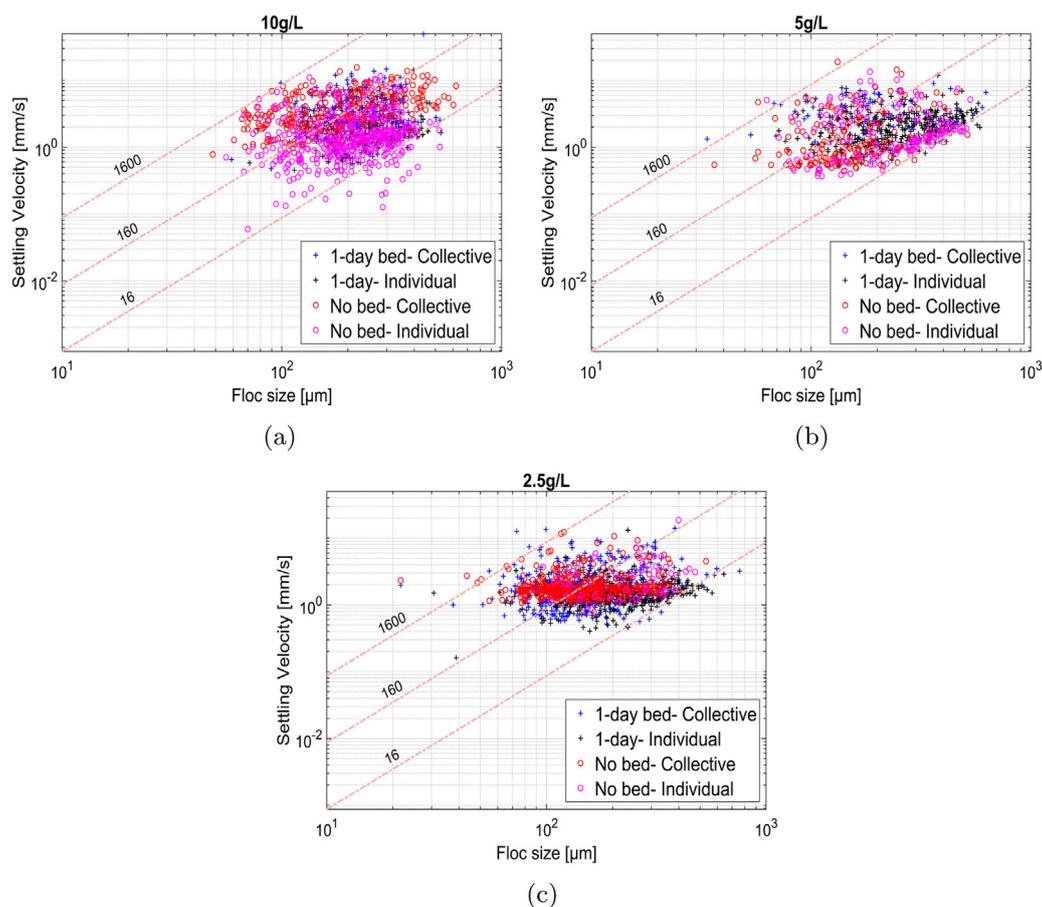


FIGURE 8

Floc size vs. Settling velocity of CCZ flocs. Isodensity lines (1600,160,16  $\text{kg}/\text{m}^3$ ) represent relative densities of flocs calculated from measured floc size and settling velocities using Stokes' law considering primary particle densities of 2,600, 1,160, and 1,016  $\text{kg}/\text{m}^3$ . These lines serve as reference lines for interpreting how floc density varies with floc size. (a) 10 g/L, (b) 5 g/L, (c) 2.5 g/L.

categorized into “individual flocs” and “individual and collective flocs”, as defined above. It is observed that the median settling velocities for the 1-day bed cases are higher when compared to their counterparts, the “No bed” cases.

The presence of a bed leads to larger flocs, which is evident from the median floc sizes shown in Figure 10. Median floc sizes were found to be 225, 220, and 190  $\mu\text{m}$  for 10, 5, and 2.5 g/L, respectively, which is higher than the “No bed” cases. The flocs, in both the cases, were found to be more open-structured. Also, the floc sizes depended on the sediment concentration, as found earlier in the work of Ali et al. (2024b). The snapshots presented in Supplementary Figures S11–S15 (Supplementary Materials) also confirm that larger flocs were being formed in the presence of a bed. These larger flocs have an influence on the propagation velocity of the turbidity currents.

## 4 Discussion

In this study, how a pre-existing sediment bed influences the dynamics of turbidity currents and the associated flocculation processes has been investigated in a lock exchange

environment using sediments from the Clarion Clipperton Zone (CCZ). The findings from this study shed light on the influence of the underlying bed on the hydrodynamics of the current.

In the study conducted by Wahab et al. (2025), flocs were formed with different flocculant dosages. A synthetic flocculant was added to a suspension of illite clay. The sediment concentration was kept constant with varying flocculant dosages. The flocs formed with a lower dosage of flocculant had higher settling velocities when compared to the flocs formed with a higher flocculant dosage. Due to the abundance of flocculant being available, larger, open flocs were formed compared to the case where flocculant was scarce. This caused the flocs to contain more sediment particles bound by a lesser amount of flocculant. Additionally, the particles that were smaller in size (less than 100  $\mu\text{m}$ ) were observed to have higher settling velocities. This could be attributed to the flocs falling in the wake of larger flocs, thus ending up having larger settling velocities (Ali et al., 2024b).

With more materials being available in the presence of a bed, denser flocs were being formed. More sediment particles from the bed were picked up during the turbidity current propagation, which led to denser flocs. It was also observed that the “Individual and

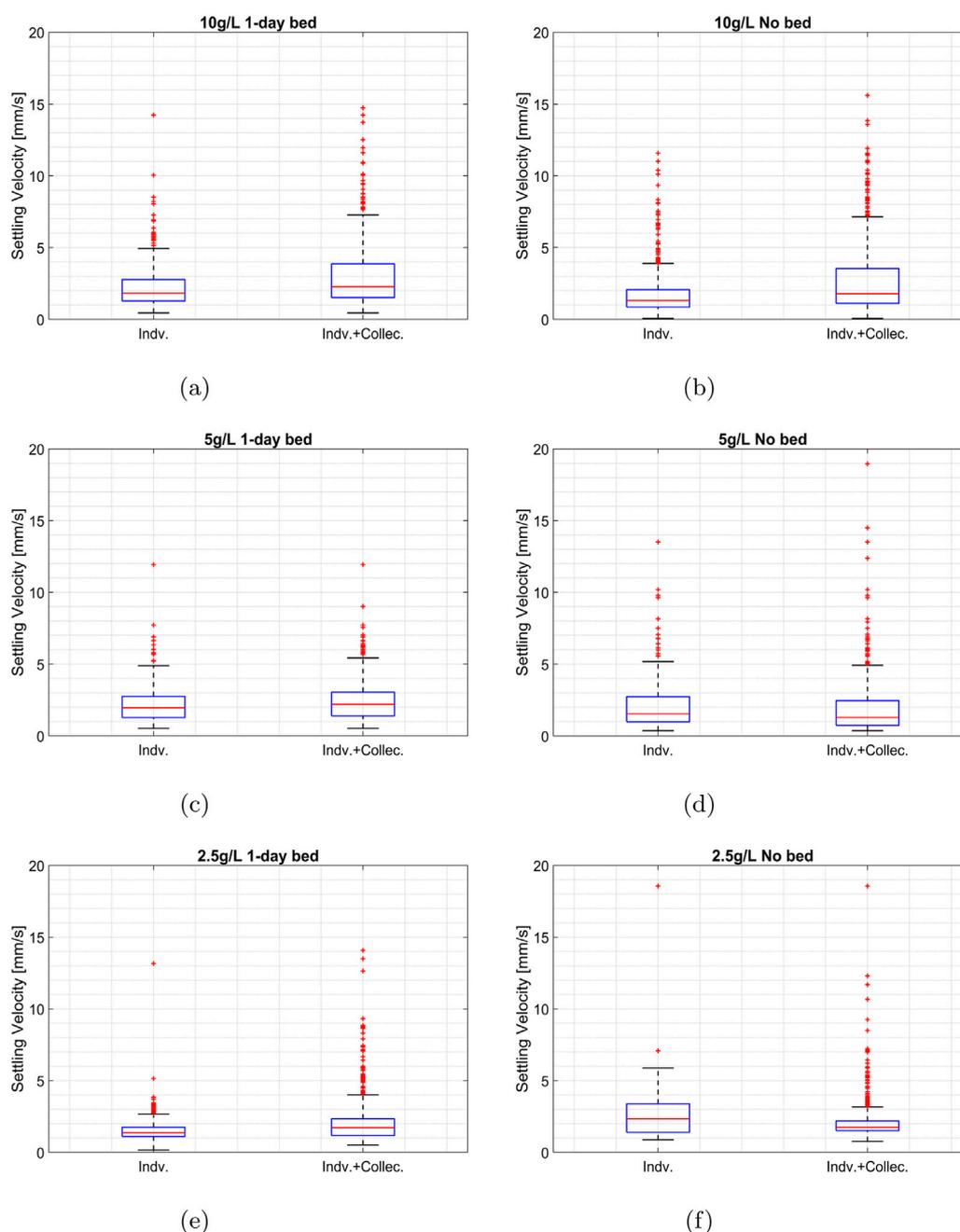


FIGURE 9

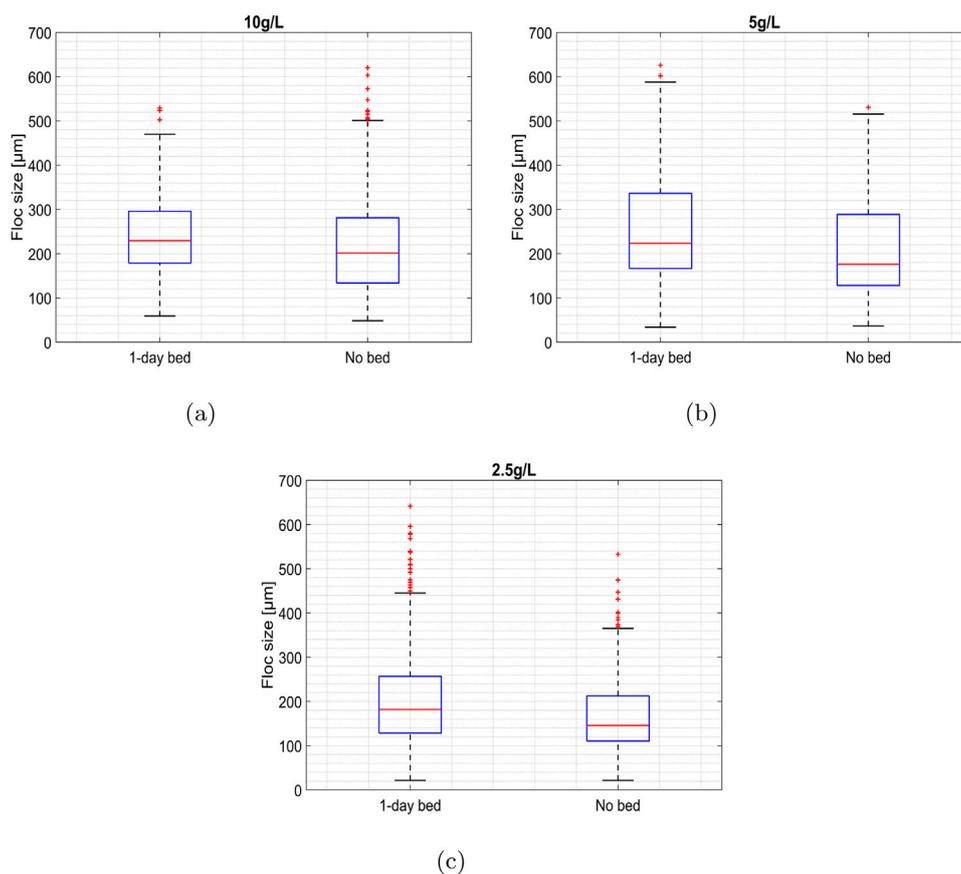
Box plots of settling velocity of flocs sampled from different types of beds. 1-day bed: (a,c,e) and no-bed: (b,d,f). The data were obtained from FlocCAM measurements.

collective flocs” had higher settling velocities in comparison to the “individual” flocs alone.

In the article of [Ali et al. \(2024a\)](#), it was observed that the floc sizes gradually increased over time (until day 10), followed by a decrease. Minimal disturbance was found to promote the growth of flocs that were previously not in contact. Additionally, after 10 days, flocs were breaking and/or reconfirming. In the case of a 1-day bed, the flocs within the turbidity current during propagation came into contact with the flocs lying on the bed, leading to an increase in size.

#### 4.1 Influence of a bed on turbidity current propagation

Studies conducted earlier explored a bed’s influence on turbidity current propagation ([Adduce et al., 2009](#); [Peters and Venart, 2000](#); [Tamay and Fischer, 2008](#)). The roughness of a bed influences the propagating velocity of a turbidity current. Turbidity currents produced during mining activity have the potential to travel far away from the mining source. This study investigates the



**FIGURE 10**  
Box plots of floc sizes of flocs sampled from different types of beds. The data were obtained from FlocCAM measurements. **(a)** 10 g/L, **(b)** 5 g/L, and **(c)** 2.5 g/L.

behavior of the turbidity current mechanism in the presence of a bed and how it behaves under different sediment concentrations. The findings indicate that the presence of a bed significantly alters the front velocity. In case of 2.5 and 5 g/L, the presence of a 1-day bed, reduced the front velocity by 9% and a 3-day bed by 3%. From instantaneous velocities recorded by a UVP transducer, the velocity near the flume bottom was found to be around 12 cm/s for 10 g/L, 6 cm/s for 5 g/L, and 3 cm/s for 2.5 g/L for no-bed condition. The variation in the initial velocities is due to the momentum of the turbidity currents.

According to the EIA report of The Metals Company (Gillard and Thomson, 2022), it was stated that erosion of the blanketing layer (newly formed bed) occurred at 9–10 cm/s velocities. The erosion was further increased at flow velocities of 15 cm/s. This was in the case when the blanketing layer was thin, formed with 0.5 and 0.25 g/L sediment concentration. In case of a blanketing layer formed with 1 g/L, no sediment resuspension was observed in the velocity range of 4–15 cm/s. So if the turbidity current flows with velocities in the range of 10–15 cm/s, there is a chance of erosion, where the materials will be incorporated in the propagating turbidity current, thus adding more materials and influencing flocculation. However, in this case, this velocity is not sufficient to cause erosion of the blanketing layer.

Jar tests were conducted (described in Supplementary Figures S11–S15) to confirm the erodibility of beds. The 3-day bed eroded faster compared to the 1-day bed. A similar behavior has been reported by Ali et al. (2024a). In this study, flocculation experiments on CCZ clay were performed in jars under mild stirring. When the stirring was stopped, flocs settled at the bottom of the jar and were left to age. It was found in line with the present study, that the median floc size decreased over time. The peculiar behavior was ascribed to the specific type of organic matter in the sample: because of the hydrophobic nature of the organic matter, flocs on top of the 3-day bed have reformed, become smaller in size, and hence are easily mobilized.

## 4.2 Influence of age of bed in turbidity current propagation

The results of this study show that the age of the bed plays a significant role in turbidity current propagation. The front velocities show that the 1-day bed has a stronger influence on the propagating turbidity current compared to the 3-day bed. This indicates that freshly deposited beds impart greater roughness and resistance to flow. As the bed ages, the flocs undergo reformation (Ali et al., 2024a), and the surface

becomes smoother, leading to a reduction in frictional resistance to flow. This behavior was also observed in the previous works of Nogueira et al. (2013) and Adduce et al. (2009), where the presence of a rough bed resulted in velocity reductions. The 3-day beds in this study have been smoothed due to deposition of materials over time, which yielded higher front velocities (Baghalian and Ghodsian, 2022; Rita Maggi et al., 2022). In our study, two beds were examined, and the results clearly showed a shift in turbidity current behavior. The findings imply that as the bed undergoes further aging beyond the timescales investigated here, its influence on front velocity may diminish once the bed surface reaches a more stable state.

### 4.3 Influence of bed on flocculation

The settling velocity range of particles at higher concentration is larger than that at lower concentration (Figure 8). This can be interpreted by the fact that at higher sediment concentration, particles have a larger collision frequency with both clay and organic matter, hence forming flocs that settle faster. At the same time, the turbidity current will propagate faster because of the higher momentum than at lower concentrations. Flocs formed at lower concentrations, on the other hand, will have a lower collision frequency, will travel for a longer period before reaching the siphon. Therefore, they are expected to have a more coiled (compact) structure, resulting in the elimination of flocs with low settling velocities, which exhibit a loose, organic-matter rich structure. One of the interesting mechanisms observed here was the characteristics of flocs changing upon the introduction of a bed. The settling velocities of flocs increased, which implied that denser flocs were formed. The initial concentrations were kept the same in both cases: no bed and 1-day bed. The increase in floc density and settling velocity in the presence of a bed indicates that materials were being picked up when the turbidity current was propagating on top of it. The floc sizes also increased. In deep-sea operations, it will prove in favor, as a freshly disturbed bed would enhance flocculation, thus leading to an early settlement of the plume.

## 5 Conclusion

New insights were gained through this study on the role of bed on turbidity current propagation, considering flocculation. It also pointed out the significance of the duration of beds, with freshly deposited beds imparting roughness to current propagation. The interaction of turbidity currents and sediment beds not only affected transport dynamics but also altered the floc behavior. The increase in floc size and density in the presence of a bed suggested that sediment resuspension and erosion play a crucial role in flocculation. These findings are particularly relevant for deep-sea mining operations, where freshly deposited sediments may enhance or hinder turbidity current spread. Future studies should explore a broader range of bed ages. These findings ultimately contribute to a better understanding of deep-sea sediment plume behavior and its spread.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

## Author contributions

SW: Validation, Visualization, Data curation, Software, Writing – original draft, Formal Analysis, Methodology, Conceptualization, Resources, Investigation, Project administration, Writing – review and editing. CC: Funding acquisition, Writing – review and editing, Conceptualization, Visualization, Investigation, Supervision. RH: Investigation, Visualization, Funding acquisition, Supervision, Writing – review and editing, Conceptualization.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2025.1720768/full#supplementary-material>