Forum Reply

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Channel-levee evolution in combined contour current-turbidity current flows from flume tank experiments

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We appreciate the opportunity that the Comment by Gong et al. (2020) provides us to further develop the discussion about the sedimentary features resulting from the interaction of gravitational processes and oceanic circulation. The flume-tank experiments we performed (Miramontes et al., 2020) represent the first physical measurements of combined contour current and turbidity current flows, and prove for the first time that synchronous mixed processes can be at the origin of asymmetric channel-levee systems. Our results confirm the interpretations of Fonnesu et al. (2020) and Fuhrmann et al. (2020), which were based on a robust and complete data set including seismic data, sediment cores, and *in situ* contour-current measurements, and which suggested that asymmetric channel-levee systems in the northern Mozambican continental slope migrate against the direction of the contour-current flow. Although our flume-tank experiments satisfactorily reproduced the characteristics of this system, we agree that our results may not be representative of all natural mixed systems. It is entirely possible, and indeed worthy of pursuit, that different sedimentary features will be encountered under conditions that were not tested in our initial experiments. Here, we detail more broadly the conditions that we deem most interesting, and potentially fruitful, to test.

(1) **Temporal and spatial interaction of flows:** Mixed contourite-turbidite systems can result from different types of interactions (Fonnesu et al., 2020): (1) passive interaction: contour currents and turbidity currents coexist on a slope but the processes do not directly interact, leading to both types of depositional systems; (b) phased interaction: bottom currents and turbidity currents are active in the same area but not at the same time; or (c) synchronous interaction: turbidity currents and bottom currents flowing alongslope occur simultaneously. Although the processes controlling the formation of these three different types of mixed systems are completely different, they are often not clearly differentiated in the literature, resulting in confusing interpretations. Our flume-tank experiments simulated solely the synchronous interaction.

(2) **Characteristics of bottom currents:** In our study, and in this Reply, we only consider mixed systems that result from the interaction with bottom currents that flow along the slope (contour currents). Other types of bottom currents could also affect turbidity currents and rework their deposits; for instance, internal tides flowing across-slope in canyons. However, across-slope currents would not deflect turbidity currents along-slope and therefore, would not generate asymmetric channel-levee systems.

(3) **Structure of turbidity currents:** The ratio of the velocity of contour currents and turbidity currents has to be high enough to generate a combined flow with a significant along-slope velocity component and a related asymmetric channel. Therefore, mixed systems are more likely to develop in areas where turbidity currents are relatively slow, allowing contour currents to significantly modify their trajectory. However, it is a mistake to simplify turbidity current structure to a single value for maximum velocity only, because this neglects the recognized critical role of the sediment concentration profile, compound velocity-density parameters such as the Froude and Richardson numbers, and the variability these parameters can display within a single turbidity current, within a system, and between different systems.

(4) **Degree of confinement of turbidity currents:** Turbidity currents with large flow heights relative to the channel depth are more susceptible to overspill the channel and thus be exposed to entrainment by contour currents. Contrastingly, submarine canyons and channels often deeply incise the upper continental slopes, limiting overspill and the interaction with contour currents. Some of the submarine channels that have been suggested to migrate in the direction of contour currents (e.g., Gong et al., 2018) are located in such environments. In these cases, the interaction of bottom currents with gravity flows and seafloor topography may result in different processes and sedimentary products, as is the case reproduced in our experiments, which exhibited well-developed channel-overspill flow.

(5) **Coriolis force and/or contour currents:** Another factor to consider is the relative importance of the Coriolis force within the turbidity current, and the interaction of turbidity currents with bottom currents in the generation of asymmetric channels and canyons. Some of the examples of asymmetric channels were observed in zones close to the Equator (e.g., Gong et al., 2018), where the Coriolis force is weak, suggesting that the asymmetry of these type of channels does not rely solely on internal Coriolis forcing. However, the role of Coriolis forcing in mixed systems, especially at higher latitudes, is unquestionable, even if vastly understudied.

Future research will need to investigate how all the above-mentioned factors influence the interaction of contour currents and turbidity currents and their related sedimentary deposits. Such research requires integration of (i) new physical measurements, obtained from the monitoring of active natural flows; (ii) descriptions of the full suite of recent and ancient mixed system deposits; (iii) flume-tank experiments; and (iv) numerical modeling. We hope that this Reply brings more clarity to the discussions of mixed contourite turbidite systems, and that it will motivate the necessary future research to solve the outstanding questions..

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