Critical Transitions in Particulate Density Currents

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Much effort has been expended on the differentiation of various types of particulate density current and the transitions between them, particularly that between flows with Newtonian and non-Newtonian (typically Herschel-Bulkley) rheologies. The deposits of such flows are classified as hybrid or transitional. Non-Newtonian behaviours have been associated with high fractions of cohesive material and with overall high density. The behaviour of high concentration non-cohesive flows has often been differentiated on the basis of a ‘Bagnold limit’, i.e. a grain concentration of roughly 9%. In fact there is no abrupt change from an an approximately Newtonian regime dominated by the properties of the interstitial fluid and with a stress/strain-rate dependency that is linear, to a grain-inertia regime in which grain collisions dominate, and where the stress/strain-rate dependency follows a power law; there is a transitional regime between Bagnold numbers of about 40 and 450 in which both play a part. Apart from grain concentration the Bagnold number is also dependent on the grain-size and shear rate. In other words, the behaviour of high-concentration dispersions (inertial/non-Newtonian, transitional, or macro-viscous/Newtonian) cannot be specified in terms of grain concentration alone. It is also likely to change from one regime to another as the shear strain rate changes. Lastly, dispersive pressure is likely to be a far more effective mechanism of grain support in the grain-inertia regime than in the macro-viscous regime, especially under high rates of shear. Changing rates of shear are thus a critical control on behavioural transitions in high-concentration particulate density currents.

The other critical transitions are those that relate to the passage of water from the ambient to the flow and vice versa, i.e. both entrainment into the flow, and detrainment from it. The transition from entraining flows to non-entraining flows (with and without Kelvin-Helmholtz instabilities, respectively) allows them to propagate long distances on the ocean floor without inflation and with little drag. The transition, involving increase in gradient Richardson number, is dependent principally upon gradient and mud content, either or both of which may change along the flow pathway.

Detrainment involves the loss of buoyant interstitial water from flows into colder or more saline ambient, via double-diffusive instabilities. This detrainment, if sustained over long enough distances, has the potential to transform hyperpycnal flows into ‘normal’ turbidity currents. High shear rates at the upper boundary suppresses these instabilities, either to be replaced by Kelvin-Helmholtz instabilities or, in the case of high gradient Richardson numbers, reducing fluid exchange in both directions, which might explain the propagation of some hyperpycnal flows over distances of 700 km.

Keywords: high-concentration, entrainment, detrainment