Geophysical Research Abstracts, Vol. 9, 08025, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-08025

Modelling rheological and turbulence regimes in kaolinite-rich sediment flows

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Many flows in a wide range of environments, from estuaries to the deep oceans, transport clays and fine silts, which produce a change in the flow behaviour once the particle concentration exceeds a threshold value. Past work has shown how the presence of clay at low concentrations may reduce fluid drag. At high concentration, however, the clay minerals establish a network and develop enough cohesiveness to suppress turbulence and change the flow from Newtonian to non-Newtonian. Past research has indicated the great effect of high sediment concentrations in modifying a turbulent flow, first to a hyperconcentrated flow and then to non-Newtonian debris or mud flow, with potentially large changes in the resulting depositional bedforms.

Laboratory experiments carried out by Baas and Best (2002) demonstrated that an increasing concentration of kaolinite results in a distinct change in velocity and turbulence structure in flows transitional between Newtonian and non-Newtonian rheological behaviour. Such transitional flows develop a lower region of reduced velocity that is separated from the overlaying flow by a distinct shear layer.

In this work, a full rheological characterisation of kaolinite suspensions is presented. Dynamic and creep test are used to quantify the viscoelastic response of the kaolinite suspensions, to determine yield stresses and correlate it to sediment concentration, and to model structural processes and time-dependent recovery of such suspensions.

An 1-DV model is used to reproduce the large set of transitional flows investigated by Baas and Best (2002). The model solves the momentum and continuity equations in a shallow-water approach and supposes that the flow is horizontally uniform. The model provides a very detailed vertical structure of the flow. Its originality is the constitutive closure of the equations. Together with turbulence, the closure model integrates the complex rheological behaviour of kaolinite suspensions (elasticity, plasticity, viscosity and thixotropy).

The numerical reproduction of the experiments presented by Baas and Best (2002) validates the model as a useful tool to apprehend the complex and small-scale processes that determine the large-scale flow of clay-rich flows within sedimentary systems.

Baas, J.H. and Best, J.L., 2002. Turbulence modulation in clay-rich sediment-laden flows and some implications for sediment deposition. Journal of Sedimentary Research, vol. 72, No 3, May, 2002, pp. 336-340.