Geophysical Research Abstracts
Vol. 14, EGU2012-13396, 2012
EGU General Assembly 2012

On the interaction between fluid turbulence and particle loading: numerical simulation of turbidity currents and prediction of deep-sea arenites

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Turbidity currents are water-particle flows able to move large distance over the seafloor, and the deep-sea arenitic facies of their deposits often represents an important class of hydrocarbon reservoirs. Coupling flow behavior and the resulting deposits may thus help finding new reservoirs, as well as reconstructing the sediment transport mechanisms from the continental shelf to the abyssal plain.
There is a broad literature of turbidity currents, which includes field, theoretical, experimental, and numerical studies on flow dynamics and associated deposits. Generally, the field and theoretical approaches focus on the scale of actual deposits and currents, respectively, whereas experimental and numerical approaches are often restricted to the laboratory scale and relatively low-Reynolds number, respectively. Fully resolved simulations that incorporate complex bathymetry, large-scale flow, multiphase and 3D effects, are computationally expensive and require closure schemes.
Here, a 2D numerical model of turbidity current is proposed, which is based on the Euler-Lagrange formulation of multiphase physics, and on the Reynolds-averaged Navier-Stokes closure of turbulence. This strategy has been recently used in volcanology to simulate the gas-particle flow of pyroclastic density currents, in order to predict their deposits.
The incompressible conservation equations of mass and momentum are solved for the water, and the equation of particle motion is solved for the sediment, which for this example, has an initial concentration of 1 % of 0.5 mm sand particles. The equations are solved numerically with the finite-volume method of Ansys Fluent software, and particle and fluid motion are two-way coupled during calculation, which means that the particles are tracked on the basis of water solution, then are allowed to affect the liquid turbulence through a momentum exchange. The Reynolds (turbulent) stresses, which dominate over the viscous ones in the turbidity current, are calculated with a two-equation model (RNG k-ε) solving for the turbulent kinetic energy and the turbulent dissipation rate.
The simulated seafloor is represented by a ramp 8 km long and 3° steep, over which the particles rebound inelastically, in order to capture the bed-load of the current. Although the sediment is mainly transported as suspended-load (this makes the flow "turbid"), the ground-hugging processes play a fundamental role in the emplacement of deposits, as well as in the flow behavior. A highly refined grid of 0.2 m at the base is thus used to solve for these processes.
After 6750 s of flow time, sedimentation rates of 4 and 0.5 kg/m2 s are calculated over the seafloor in proximal (1 km) and medial (4 km) regions, respectively. These values are converted to deposit thickness, resulting in arenitic turbidite sequences of 14.5 and 1.8 m, respectively. Turbulence intensities of 54 and 66 %, respectively in the same areas, indicate the water is further made turbulent by the sediment (water-sand interaction), so the sand moves in suspension toward the deep-sea, where is able to deposit. Richardson numbers of 0.79 and 0.58, respectively, show how the water entrainment in the current increases with distance.