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Development of fluid-particle coupled simulation method in the Stokes flow regime: toward 3-D geodynamic magma simulatio

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A fluid-particle two-phase flow has been widely studied in geodynamics, because particle-saturated fluid layer is important for understanding the dynamics of solidifying and melting process in the magma chamber or magma ocean. In order to deal with such particle-fluid systems as the geodynamical modeling in 3-D geometry, we develop a new coupled simulation code of Finite Difference method (FDM) for fluid flow and Discrete Element method (DEM) for solid particles. Although this type of numerical method has been well developed in the engineering field to investigate the fluidized bed especially for the high Reynolds number in short time scales, the method for the low Reynolds number over long time scales has not yet been fully addressed.

In the geodynamic modeling with highly viscous fluid, the fluid motion can be treated as the Stokes flow. We employ empirically derived a coupling term between fluid flow and particle motion providing good fit with experimental data of the creeping flow. When this coupling force is directly introduced to the normal DEM equation of particles, we have to numerically solve dumped oscillation with a small time step dt ˜1/eta for high fluid viscosity eta. Thus the normal DEM does not seem to be suitable solution method for our target problems. We therefore propose to drop off the inertial term from the governing equation of DEM based on the Stokes flow approximation and solve the force balance equation as same as that for the fluid. With this approach, we can employ the large dt˜eta for the problems with highly viscos fluid.

Since our original solution algorithms for both of FDM and DEM are designed for the massively vector parallel architectures with two characteristic numerical techniques, we can solve large size of problems in 3-D geometry. 1. The geometric multi grid method of our robust Stokes flow solver is implemented with agglomeration technique to enhance the parallel efficiency in coarse grid operations. 2. Our DEM utilizes the parallel algorithms for a summation of contact force and search of particle pairs using particle labels sorted by the cell number to improve computational efficiency of the code.

We introduce details of our coupled model treatment of the granular medium and demonstrate the validation test with an analogue experiment.

Keywords: magma flow, DEM, Stokes flow, particle-fluid coupled simulation