FLUIDIZED IMPACT EJECTA AND VOLCANIC BLAST SURGE – NUMERICAL MODELING.
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Introduction: Pyroclastic surges and impact ejecta in volatile-rich environment are dilute suspension currents in which particles are carried in turbulent flows under the influence of gravity. They have a lot in common, even if historically studied by different branches of geosciences with a few exceptions [1-3]. It seems reasonable to use impact cratering approaches in volcanology and vice versa for new progress in both. Numerical modeling of pyroclastic flows, checked against recent observations and young deposits, may be then a useful instrument for reconstruction of terrestrial craters’ ejecta, which are mostly eroded or buried; and for impact ejecta study on other planets (first of all – on Mars), where remote sensing data are still the only source of our knowledge.

We limit our consideration to a gas-particle mixture, in which direct particle-particle interactions are negligible because of low particle volume fraction. Pyroclastic surges commonly form after Plinian column collapse, during phreatomagmatic eruptions, and as a result of lateral blast [4]. Typical velocities are usually less than 300 m/s, temperatures may be less than 300 K (wet surge) and not higher than 1000 K (dry surge), solid/gas ratio ranges between 5-50 [4-6], particle size rarely exceeds a few cm, while the mass fraction of fine micron-sized particles is usually poorly defined. Impact ejecta parameters vary in a substantially wider range: distal ejecta velocities reach a few km/s, km-sized fragments are typical for large craters [7], gas content may be high enough for cratering in volatile rich (or water-covered) target [8-9] or in the presence of a dense atmosphere [10]. Important aspects of surge transport include its ability to deposit ejecta over a larger area than that typical of continuous ballistic ejecta, its deposition of multiple ejecta layers.

Numerical method: We model impact cratering, and high-velocity impact/volcanic ejecta motion using three-dimensional hydrocode SOVA [11] complemented by ANEOS [12] equation of state for geological materials. We use a tracer (massless) particle technique to reconstruct dynamic (trajectories, velocities), thermodynamical (pressure, temperature) and disruption (strain, strain rate) histories in any part of the flow. The motion of ejecta in a plume is described in the frame of two-phase hydrodynamics: every ejected fragment (or representative particle) is characterized by its individual parameters (mass, density, position, and velocity) and exchanges momentum, heat and energy with surrounding vapor-air mixture. Turbulent diffusion and viscosity are taken into account in a simplified manner [13]. Numerical technique used in this study differs substantially from previously used methods, in which solid/molten particles have been described as gas with specific properties [5,13]. Our technique, similar to [6], describes individual particles and their interaction with gas. This procedure allows us to vary particles sizes in a wide range (from a few m to a few microns) and to compare modeling deposits with geological observations (deposit thickness, granular composition, and particle velocity versus distance from the vent). A substantial advantage of our model is its three-dimensional geometry, allowing modeling of asymmetric ejecta after an oblique impact. While large (mm-cm sized) particles are deposited at proximal distances from the crater/volcano (in this case a direct comparison between geological data and numerical results is possible), finer particles are suspended in atmosphere for a long time, creating distal ejecta.

Lateral blast: Bezymianny volcano, Kamchatka: On 30 March 1956 a catastrophic directed blast took place at Bezymianny volcano. It was caused by the failure of a 0.5 km³ portion of the volcanic edifice. The blast was generated by decompression of intracrater dome and cryptodome that had formed during the preclimactic stage of the eruption. A violent pyroclastic surge formed as a result of the blast and spread eastwards affecting an area of 500 km² on the lower flank of the volcano. Thickness of the deposits, although variable, decreases with distance from the volcano from 2.5 m to 4 cm. The volume of the deposit is calculated to be 0.2–0.4 km³ [14]. Similar blast surges occurred at Mount St.Helens (1980), Mont Unzen, Japan (1991) and Soufriere Hills, Montserrat (1996) [4].

Fig. 1. Sketch map of the lateral blast deposits at Bezymianny [14] and modeled deposits of this blast.
Initial conditions: There are no direct observations of Bezymianny, 1956, eruption. However, we can combine geological data from Kamchatka with observations of Mount St. Helens eruption [5], as both events are similar in their duration, affecting area and deposits. Gas (water vapor) flow loaded by tephra particles in prescribed size range from 15 µm to 3.2 cm was ejected from 600-m-diameter vent with velocity of 100-200 m/s at 45° to horizon. Particles and gas are in thermodynamic equilibrium with temperature of 1000-1200 K. The particles/gas mass ratio ranged between 10-25. Discharge of pyroclastics lasted for 200 s with steady flux of 4.6⋅10^10 kg/s and total ejected pyroclastic volume of about 0.15-0.2 km³.

Preliminary results: Total deposited mass depends on the solid/gas mass ratio: at the highest value of 25-~80% of ejected mass is deposited within 10 minutes, while at lower mass ratio only 1/3 of ejecta is deposited (Fig.2). The rest is suspended in the atmosphere for minutes: final distribution of these (as a rule – finest) particles would be defined by local weather conditions. Modeled deposited area extends to 20-40 km from the vent and has a width of 10-15 km in a reasonable agreement with geological data – see Fig.1. Deposit thickness varies from several meters to undistinguishable values on the deposit edge.

Impact ejecta distribution is an important tracer of high-velocity impact, allowing us to speculate on impact direction, obliquity, and target properties.

Chicxulub: Surge-deposited impactites have been found within Chicxulub impact structure [15]. Studying shocked quartz ejecta from Chicxulub [Morgan et al, this volume], we found that ejection velocity of quartz is surprisingly low – in the range of 0.2-1.5 km/s. Simple estimates show that cm (or less) sized particles are decelerated practically immediately, during the first seconds. Even pure ballistic regime (no drag) gives a very short trajectory length, not exceeding 400 km. This is certainly in contradiction with the observations. I.e. the Chicxulub ejecta distribution is the result of plume-particle interaction with the atmosphere, not of ballistic sedimentation [16].

Martian craters: Several attempts have been made to quantitatively describe the process of ejecta emplacement in formation of ramparts [17-19]. They dealt mainly with propagation of fluidized ejecta initially deposited ballistically and included rheologic models for Newtonian or Bingham materials based on observations (runout distance, height of the distal ridge). More recent studies of instabilities in viscous flows [20] or in impact-induced atmospheric vortex rings [21] also use oversimplified estimates of the initial conditions (in the flow or in the vortex). Our model establishes better initial conditions for ejecta flow formation and will provide estimates for the properties of fluidized ejecta directly on the basis of the particles/gas ratio, particle size, and temperature-density conditions in the ejecta. We also plan to verify the new idea of impact origin of sediments at the Opportunity landing site on Mars [3].