Abstract

Analogue and numerical modelling in geosciences is an excellent tool for studying complex spatio-temporal relationships in mass and energy transfer. Recent developments and advances in the plate tectonics and planetology require a combination of both approaches to simulate processes that cannot be studied directly in-situ. Advanced physical models are complemented by deformation analysis which is based on image velocimetry and photogrammetry, while numerical simulations utilize both modern and traditional methods to solve corresponding equations in complex domains.

This work compiles several models that are focused on deformation analysis associated with material and heat transfer in large accretionary systems. The second subject of the thesis represent the investigation of the formation and propagation of large mudflows in martian atmospheric conditions.

In the first part of the work we present a general overview of the problems of analogue and numerical modelling including scaling theory, governing equations, individual methods and history. In the second part of the thesis we deal with laboratory and numerical simulations of collision-indentation tectonics associated with the emergence of large accretionary systems on Earth. The last part of the thesis is devoted to experiments designed for the study of the formation and development of mudflows, which arise as a result of supposed cryovolcanic activity on the surface of Mars.

The first models involves oroclinal buckling of an accretionary belt and continental ribbon in the post-subduction stage related to the indentation of a cratonic system at an orthogonal direction. The results of the individual experiments showed a complex flow of the material of the lower crust and the upper mantle in the axial plane of both progressively buckled interlimb areas. This ductile flow is associated with the deformation response of the upper crust and with the emergence of large pop-up and pop-down domains, local faults and shear zones. The correlation of the results from the surface deformation analysis and from the deformation analysis of the orthogonal sections of the model confirms the significant exhumation of the continental and oceanic mantle in the proximal hinge area. This exhumation is correlated with the existence of a significant gravimetric anomaly in the Hangai region of the Tuva-Mongol orocline which is located within the CAOB (Central Asian Orogenic Belt).

The second series of experiments is focused on the study of the melt amount and migration style effect on the dynamics of detachment folding in the pre-indentative part of crustal domain. This thermally dependent model produces a series of folds over a thin layer of the melt that migrates along the shortening direction and is simultaneously sucked into the inter-limb zones of the resulting fold-dome structures. A method for quantifying the divergence of the PIV based velocity field in the target sub-regions of the model domain was developed to balance the inflow and outflow of this material. The correlation of the time evolution of the divergence and the amount of the melt in the individual folds internal structures revealed the polyphase development of each fold. The systematic change in the height of the folds and the modal melt content of the individual locked folds is proportional to the rate of inflow of the melt into their cores. Overpressure of the melt in locked folds leads to its extrusion back into the source layer, where it can be further transferred along the shortening direction and support further detachment folding.

Since these models are produced in an unscaled gravitational field, potential diapiric exhumation of the lower crust is also the subject of discussion. The model of the Rayleigh-Taylor instability was used with tested variation of rheological, geometric and thermal properties. The model simulates the evolution of a large-scale lithosphere segment, related to late orogeny which is characterized by a massively thickened crustal domain, during the post-collision stage. Analysis of the selected simulations showed that the crustal-scale diapirism is typical for collisional and post-collisonal systems, that are characterized by a distinctly weak and hot lower felsic crust with developed density perturbations at the border with the overlying mafic crust. The rate of diapiric exhumation depends on the convergence rate of the indenter as well as on the amplitude/wavelength of the density perturbation and specially on the density contrast of the crustal material. The rheological parameters are controlled by time-variations of the heat redistribution from the mantle into the crust and by thermal productivity of the felsic lower crust. Diapirism and folding are involved in dependence on the slowing of the convergence and on distance of the perturbation from the indenter.

The last part of the thesis presents physical modeling of the mudflows propagating in atmospheric conditions at the surface of Mars. The series of more than sixty experiments was designed to study mudflow on both cold and hot surfaces made of granular unconsolidated material (sand) or solid consolidated material (plastic plate). The effect of the subsoil inclination on the distribution and shape of mudflows was also tested.

Experiments, conducted on pre-cooled sand, revealed significant geomorphological similarity between mudflows produced at reduced atmospheric pressure and Pahoehoe lava flows at the Earth’s surface atmospheric pressure. The emergence of mudflows reflects several development stages, including initial surface flow, mud degassing / freezing, and flow in closed channels with a progressive propagation at the head of the stream. The mud propagation through an enclosed channel and progressive development of the lobes in the stream foreland is similar to the development of pillow lavas on Earth.

Experiments conducted on a warm sand substrate revealed a different process of transporting mud material that combines 'classical flows' and 'levitation' of mud above a warm surface, depending on the distance from the source area.

Keywords: Analogue modelling, Numerical modelling, Orocline, Detachment folding, PIV analysis, DEM models, Diapirism, Mudflows, Mars