ESF - Short Visit Grant - Scientific Report

Title of the proposed research project: *Influence of the fragmentation process on explosive eruptions: comparison between laboratory and numerical modelling results*

Reference Number: *4839*

Applicant's Name: *Dr. Mattia de' Michieli Vitturi, Pisa, Italy*

The proposed visit aimed at promoting the collaboration and knowledge transfer between the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Pisa (Italy) and the Department of Earth and Environmental Sciences at the Ludwig-Maximilians-University (LMU) in Munich (Germany).
During the first two days of the visit the applicant had the possibility to visit the laboratories of LMU and to present the numerical code implemented for magma ascent, in order to define with the researcher of LMU several test cases for the comparison between the laboratory experiments and the numerical results of the model.

The code presented considers a multi-phase multi-component mixture assuming that the mixture is a continuum and the state of each of the two phases, denoted by the subscripts i=1,2, is characterized by its volume fraction α_i, mass density ρ_i, velocity u_i, and specific entropy s_i. Below the fragmentation level the first phase represents the mixture of liquid phase, dissolved gases and crystals (carrier phase), while the second phase represents the bubbles of exsolved gases (dispersed phase). Above the fragmentation level the first phase represents the dispersed fragments of magma, still carrying crystals and dissolved gases and the second phase is the mixture of exsolved gases (carrier phase). The first eight equations of this system are, in order below, conservation laws of total mass, liquid phase volume fraction, liquid phase mass fraction, total momentum, relative velocity, total energy, crystals mass fraction and dissolved gas mass fraction.

$$\frac{\partial}{\partial t}\rho + \frac{\partial}{\partial z}(\rho u) = -S_2$$

$$\frac{\partial}{\partial t}(\rho\alpha_1) + \frac{\partial}{\partial z}(\rho u\alpha_1) = -\frac{1}{\tau^{(p)}}(p_2 - p_1)$$

$$\frac{\partial}{\partial t}(\alpha_1\rho_1) + \frac{\partial}{\partial z}(\alpha_1\rho_1 u_1) = \frac{1}{\tau^{(d)}}\left(x_d - x_d^{eq}\right)\alpha_1(\rho_1 - \beta\rho_c)$$

$$\frac{\partial}{\partial t}(\alpha_1\rho_1 u_1 + \alpha_2\rho_2 u_2) + \frac{\partial}{\partial z}\left(\alpha_1\rho_1 u_1^2 + \alpha_2\rho_2 u_2^2 + \alpha_1 p_1 + \alpha_2 p_2\right) = -\rho g - \frac{8\mu_{mix}u}{R^2} - S_2\alpha_2 u_2$$

$$\frac{\partial}{\partial t}(u_1 - u_2) + \frac{\partial}{\partial z}\left(\frac{u_1^2}{2} - \frac{u_2^2}{2} + e_1 + \frac{p_1}{\rho_1} - e_2 - \frac{p_2}{\rho_2} - (s_1 - s_2)T\right) = -\rho g - \chi_f\frac{8\mu_{mix}u}{\alpha_f\rho_f R^2} - \frac{\rho}{\alpha_1\rho_1\alpha_2\rho_2}\delta(u_1 - u_2)$$

$$\frac{\partial}{\partial t}\left[\alpha_1\rho_1\left(e_1 + \frac{u_1^2}{2}\right) + \alpha_2\rho_2\left(e_2 + \frac{u_2^2}{2}\right)\right] + \frac{\partial}{\partial z}\left[\alpha_1\rho_1 u_1\left(e_1 + \frac{p_1}{\rho_1} + \frac{u_1^2}{2}\right) + \alpha_2\rho_2 u_2\left(e_2 + \frac{p_2}{\rho_2} + \frac{u_2^2}{2}\right) - \rho x_1 x_2(u_1 - u_2)(s_1 - s_2)T\right] =$$
$$- \rho g u - \frac{4\mu_{mix}u^2}{R^2} - S_2\alpha_2\left(e_2 + \frac{u_2^2}{2}\right)$$

$$\frac{\partial}{\partial t}(\rho_c\alpha_1\beta) + \frac{\partial}{\partial z}(\rho_c\alpha_1\beta u_1) = \frac{1}{\tau^{(c)}}\alpha_1\rho_c\left(\beta - \beta^{eq}\right)$$

$$\frac{\partial}{\partial t}\left[x_d\alpha_1(\rho_1 - \beta\rho_c)\right] + \frac{\partial}{\partial z}\left[x_d\alpha_1(\rho_1 - \beta\rho_c)u_1\right] = \frac{1}{\tau^{(d)}}\left(x_d - x_d^{eq}\right)\alpha_1(\rho_1 - \beta\rho_c)$$

$$\frac{\partial}{\partial t}(\rho_1\alpha_1\gamma_f) + \frac{\partial}{\partial z}(\rho_1\alpha_1 u_1\gamma_f) = \frac{1}{\tau^{(d)}}\left(x_d - x_d^{eq}\right)\alpha_1(\rho_1 - \beta\rho_c) + \frac{1}{\tau^{(f)}}\alpha_1\rho_1(1 - \gamma_f)$$

The last equation has been added to the system during the visit at LMU, in order:

1) to introduce in the system a parameter γ_f able to track the degree of fragmentation of the magma inside the conduit;

2) to implement more easily different fragmentation criteria in the model.

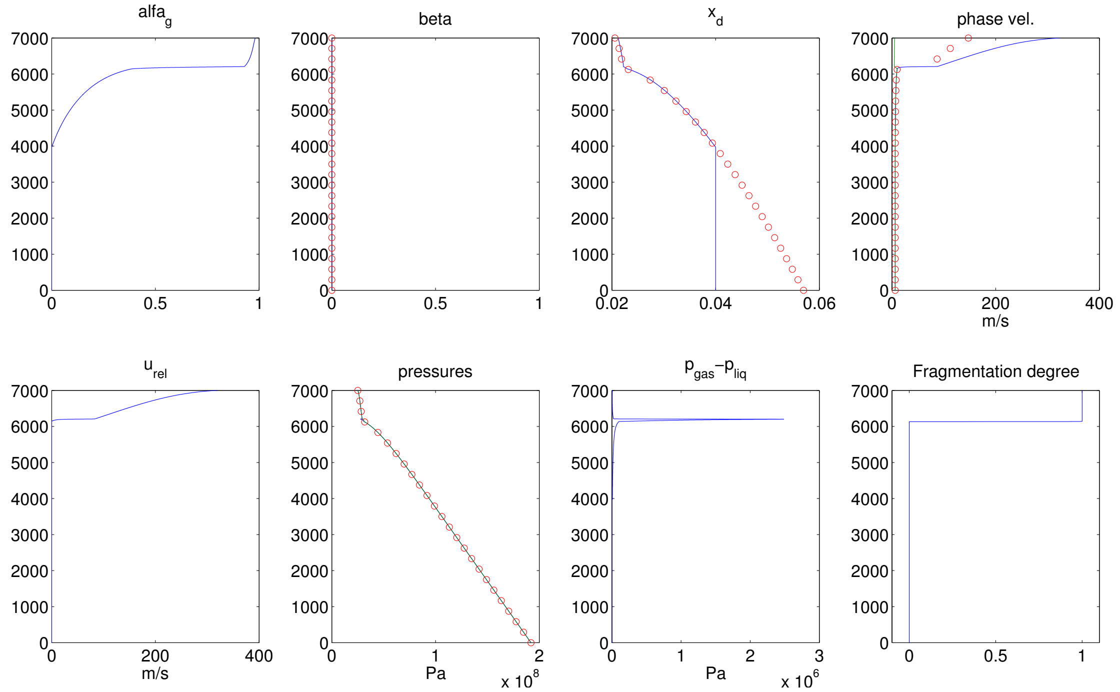

Figure 1. Plots of several variables for an explosive run. In particular the right-bottom subplot presents the fragmentation degree, as introduced in the model during the short visit at LMU.

Figure 2. Image of the fragmentation bomb (from Spieler et al. 2004).

To date, the influence of the fragmentation process on the dynamics of the gas-particle regime has been largely neglected. An output of the code showing the fragmentation degree is presented in Figure 1.

In order to validate the code, the fragmentation criterion for highly viscous bubbly magmas estimated from shock tube experiments at LMU (Koyaguchi et al. 2008) has been implemented in the code and the results will be compared with the large data set derived from experiments on 2-80 % vesicularity samples of rhyolitic to basaltic composition at experimental conditions of 25-850 °C and 0,1-50 MPa gas pressure (see Figure 2). In addition to the experiment with natural volcanic samples, additional decompression tests will be performed with silicone oil samples containing micron-sized spherical particles and a known content of dissolved water. This allows having a better characterization of the suspension rheology and to investigate and constrain the role of the degassing in the fragmentation process.

A decompression experiment with silicone oil is shown in Figure 3 for an experiment without solid particles and an initial pressure difference across the diaphragm of 10.4 MPa.

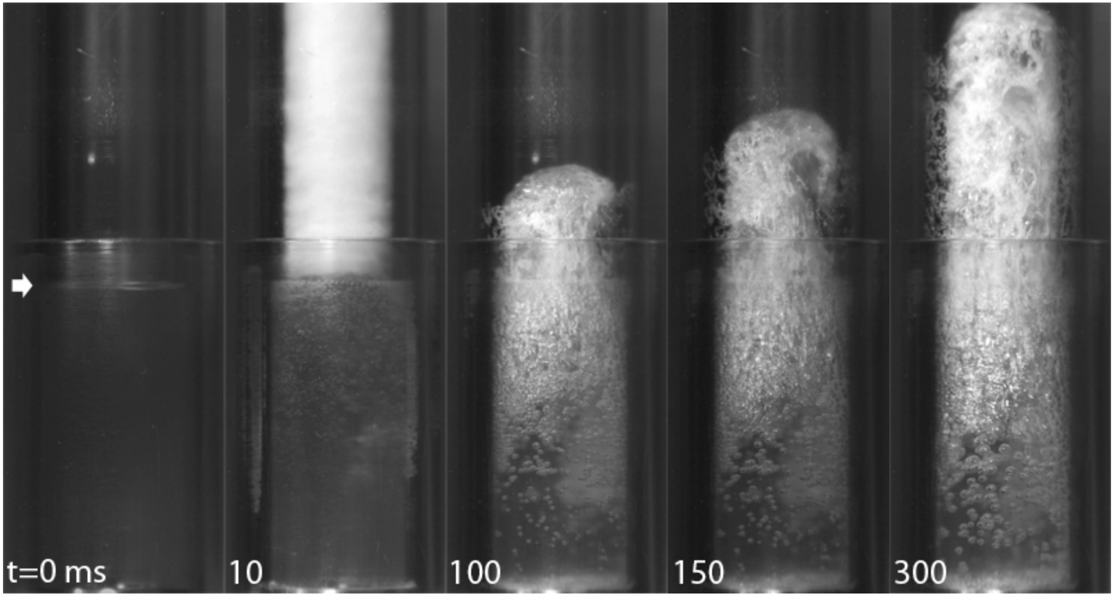

Figure 3. Decompression experiment with magma analog (from Cimarelli et al., AGU 2011 Fall Meeting poster).

The visit at LMU has also suggested another analysis to perform with both numerical and laboratory experiments to investigate the role of porosity on the fragmentation process consequent to a rarefaction wave traveling down into the conduit, as due for example to the rapid decompression after a dome collapse. In particular, an additional set of 2D or 3D numerical experiments has been defined in order to study the effect of bubbles of different size and/or different density on the rarefaction wave, to see if it is possible to observe critical sizes or distance that can affect the rarefaction wave and enhance or inhibit the fragmentation. In order to better understand the dynamic of this process only, the laboratory experiment will be performed again with silicone oil, while a simplified version of the numerical model implemented in the OpenFoam framework will be used (see Figure 4).

To conclude, the short-visit of the applicant has demonstrated the great potential of a collaborative research between the two host institutes, and we envisage that this visit has been only a first step of a longer collaboration of the applicant and the researchers at LMU. This will enforce both the applicability of the numerical models and the interpretation of the laboratory experiments to assess the influence of the fragmentation process on the dynamics of the gas-particle regime.

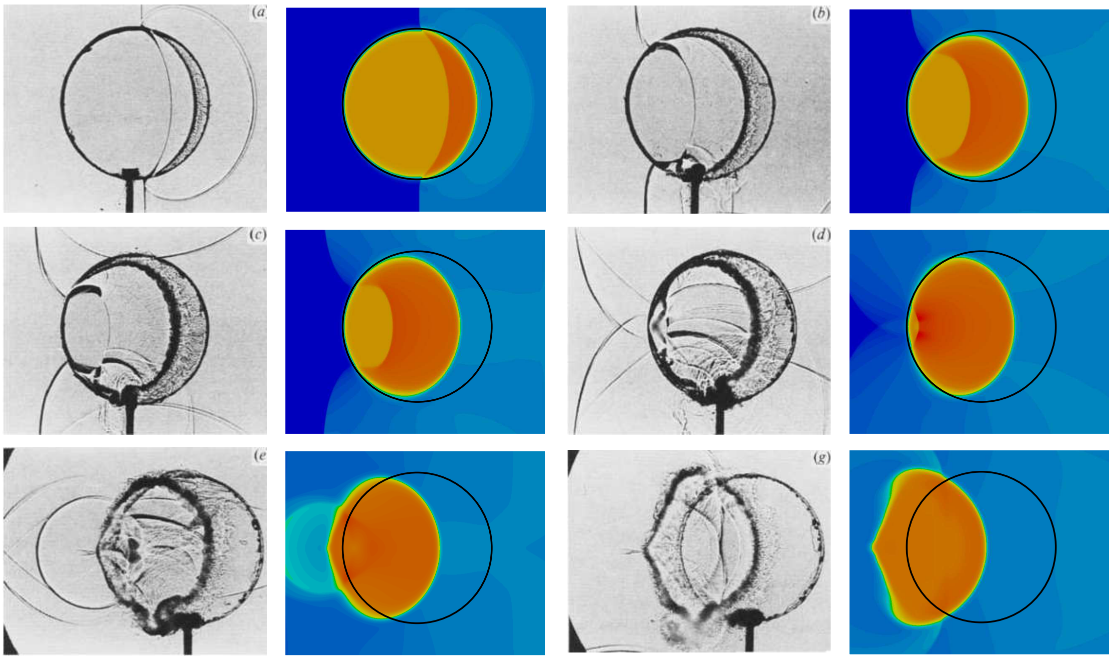

Figure 4. Interaction of a pressure wave with a bubble. Comparison between laboratory experiments and numerical results (from La Spina and de' Michieli Vitturi 2012, in revision).