

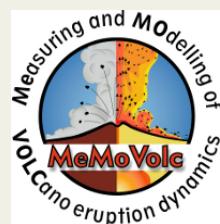
Dynamics of eruptive columns and their controls

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Dynamics of Explosive Eruptions,
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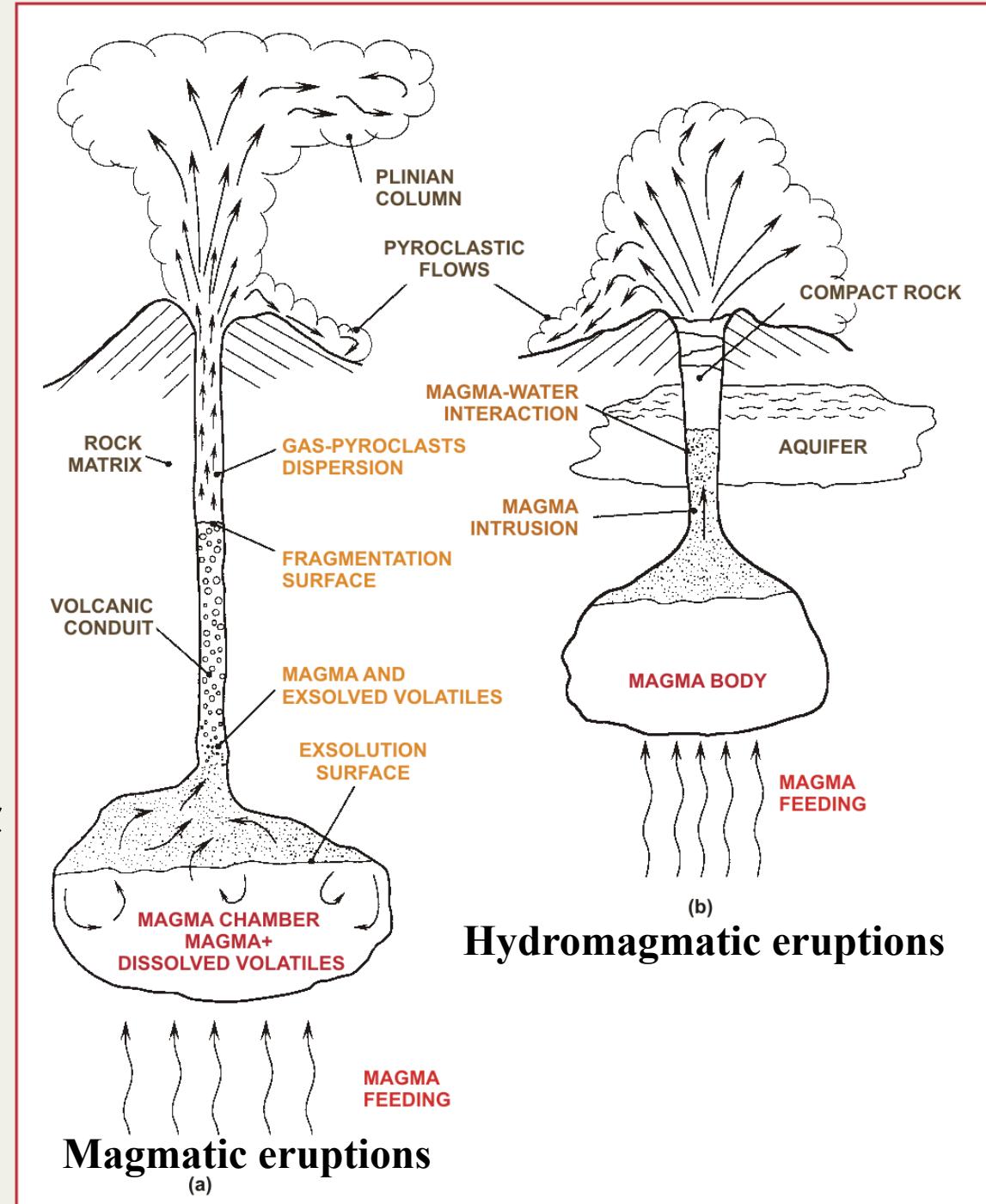
Outline of the talk

- Key processes of **explosive volcanism** and **eruptive column dynamics**
- **Main controls on column dynamics** (conduit-column systems)
- **Additional key processes and controls** on eruption dynamics and styles
- **Concluding remarks**

Causes of explosive volcanism

a) *Exsolution of volatiles dissolved in magma (magmatic eruptions)*

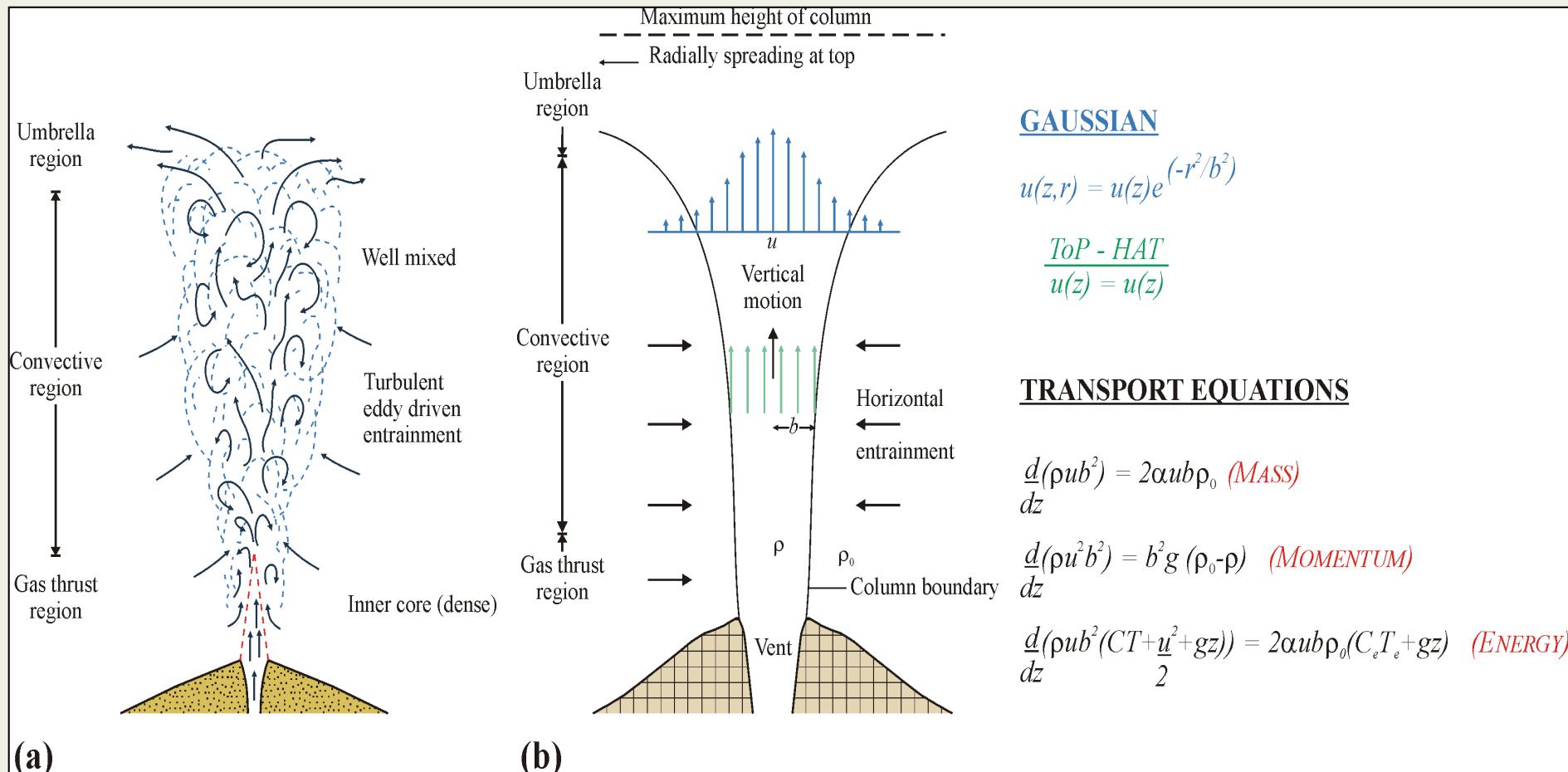
b) *Interaction of magma with external water (hydromagmatic eruptions)*



Evolution of numerical models of volcanic columns

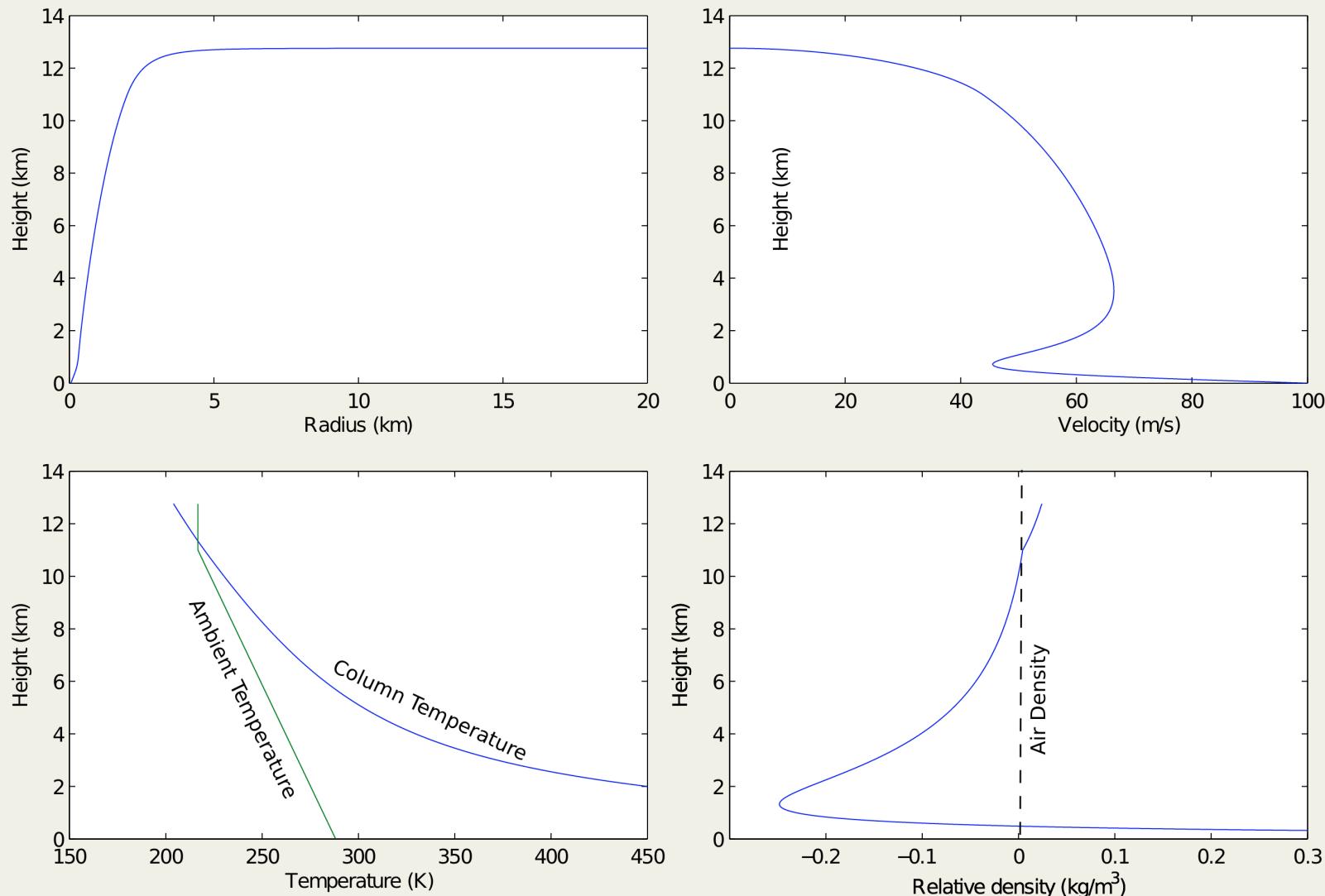
- First **1D steady-state homogeneous flow** models were developed to investigate the different eruptive mechanisms controlling volcanic columns (e.g. *Wilson 1976; Sparks and Wilson, 1978; Wilson et al., 1980; Suzuki, 1983; Carey and Sparks, 1986, Woods 1988, 1995; Bursik 2001, Carazzo et al., 2008, Koyaguchi et al., 2010*).
- Nowadays, the development of a variety of **transient, 2D/3D, multiphase flow models** of volcanic columns (e.g. *Valentine and Wohletz, 1989; Oberhuber et al., 1998; Darteville et al., 2004; Bonadonna et al., 2005; Macedonio et al., 2005; Costa et al., 2006; Dufek and Bergantz, 2007; Esposti Ongaro et al., 2007; Barsotti et al., 2008; Suzuki and Koyaguchi, 2009; Ogden et al., 2010; Carcano et al., 2013, etc.*) provides further insights into the dynamics of explosive eruptions and the assessment of volcanic hazards.

Schematic representation of the different regions of a volcanic column (*plume theory*)



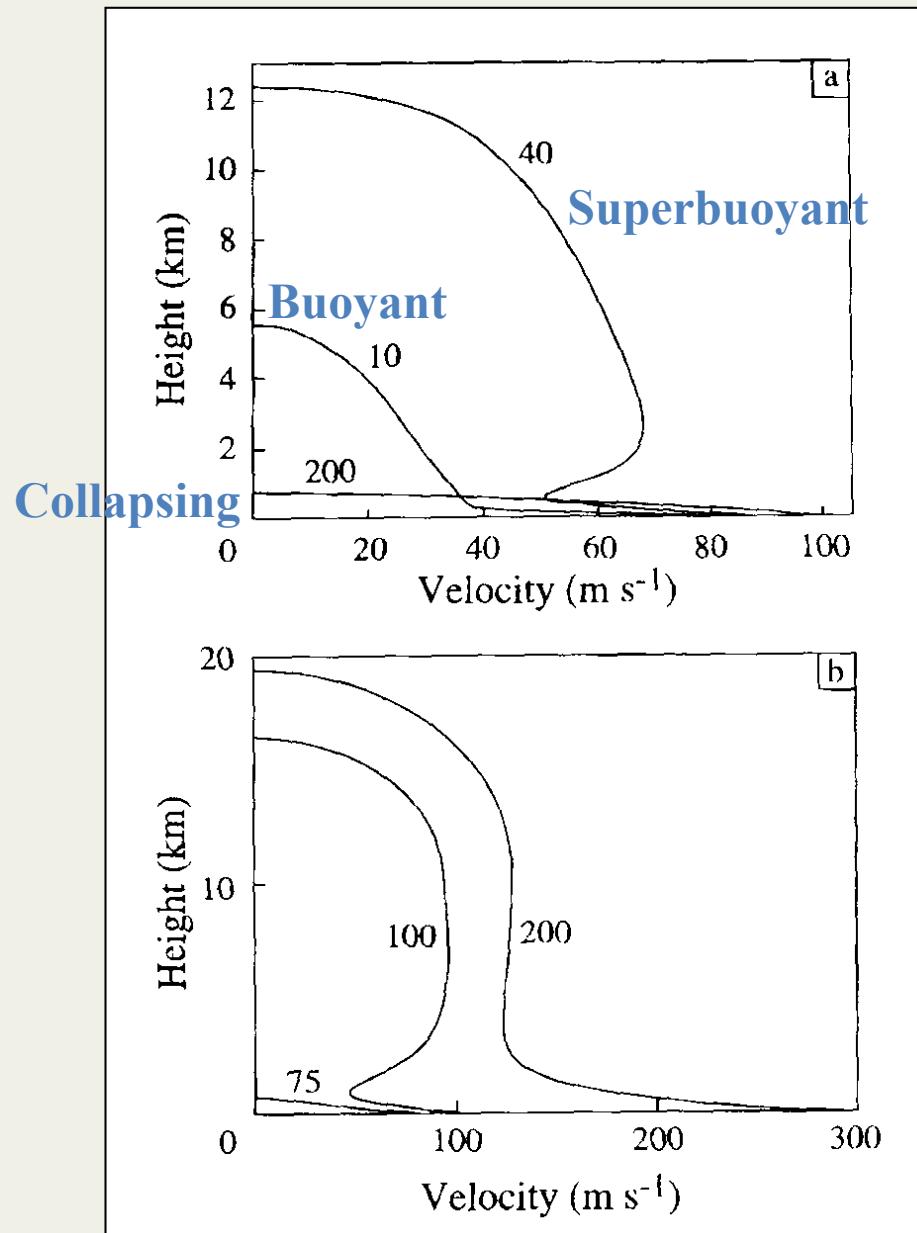
(Modified from Sparks et al. 1997)

Distribution of flow variables along the column (1)



Initial velocity is 100 m/s, vent radius is 50 m, flow temperature is 1000 K, and the water content is 3 wt%.

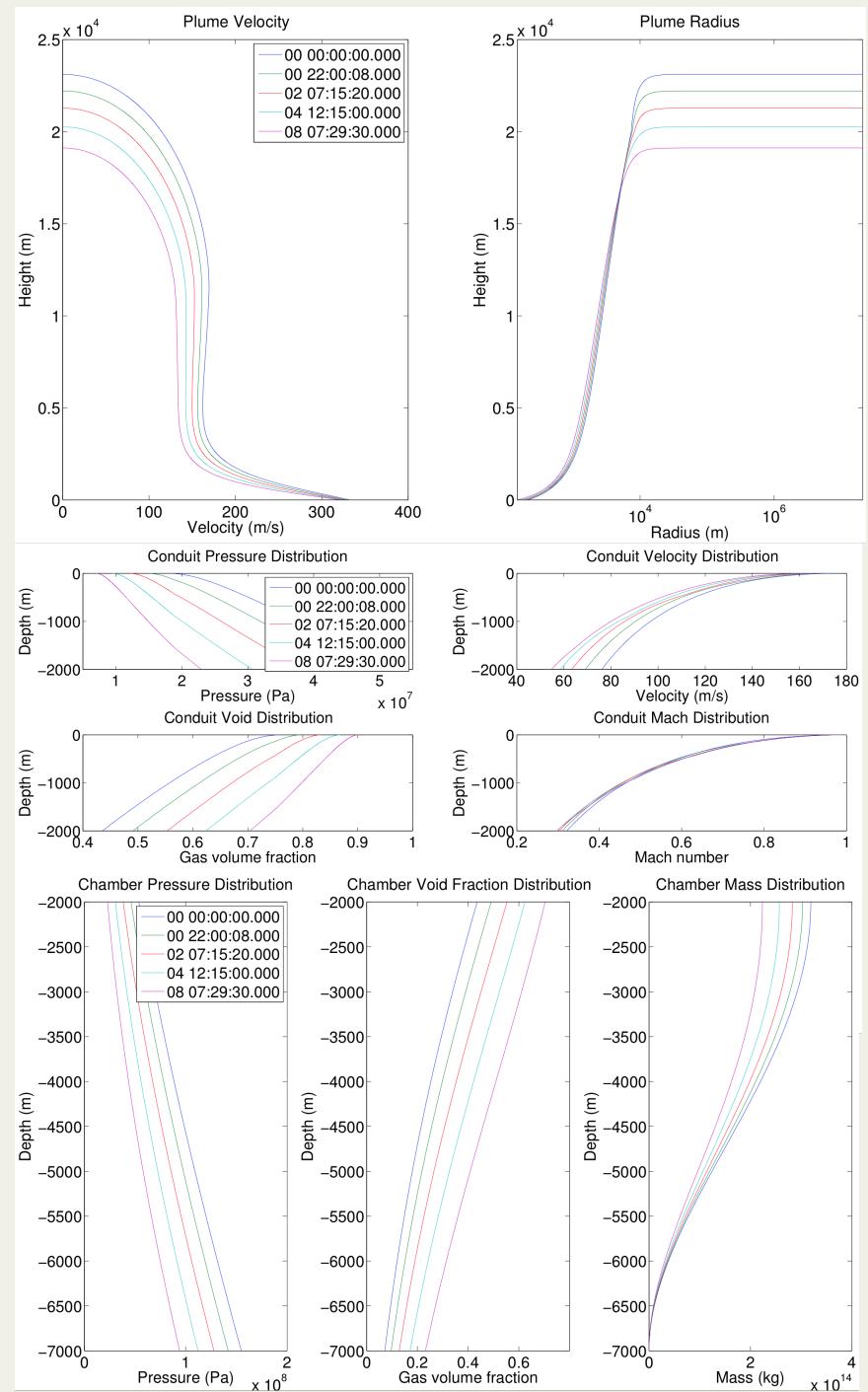
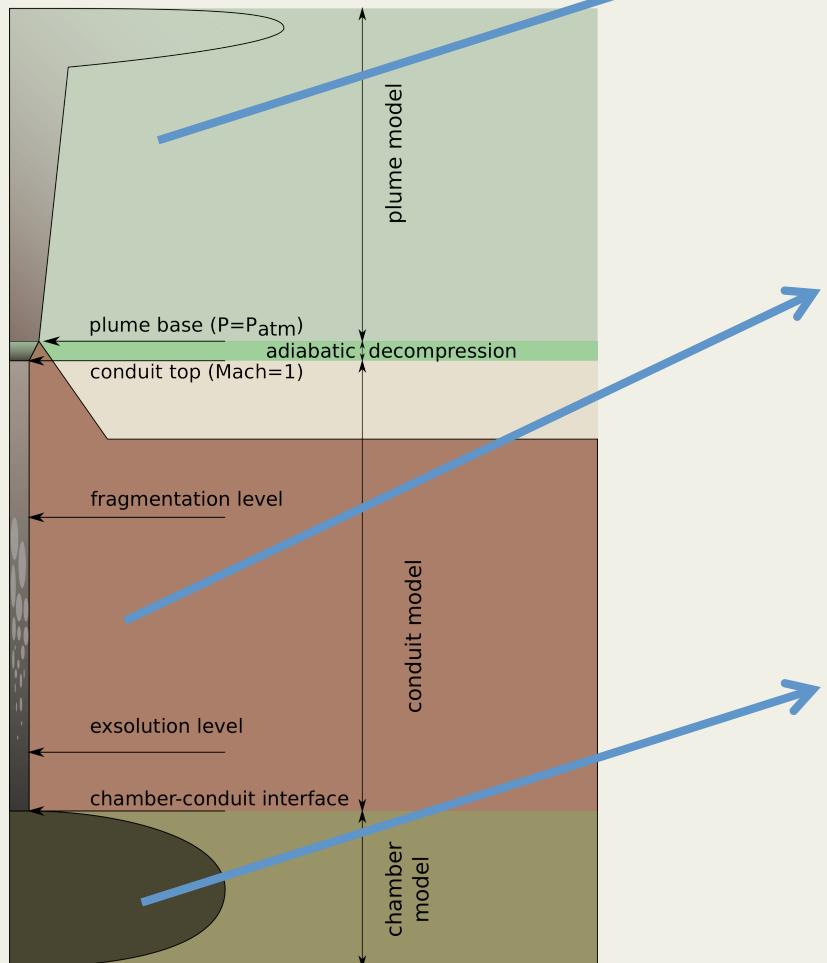
Distribution of flow variables along the column (2)



- (a) Curves are shown for vent radii of 10, 40, and 200 m with eruption velocity of 100 m/s.
- (b) Curves are shown for three velocities 300, 100 and 75 m/s at constant radius of 100 m. Water content is 3 wt% and flow temperature is 1000 K.

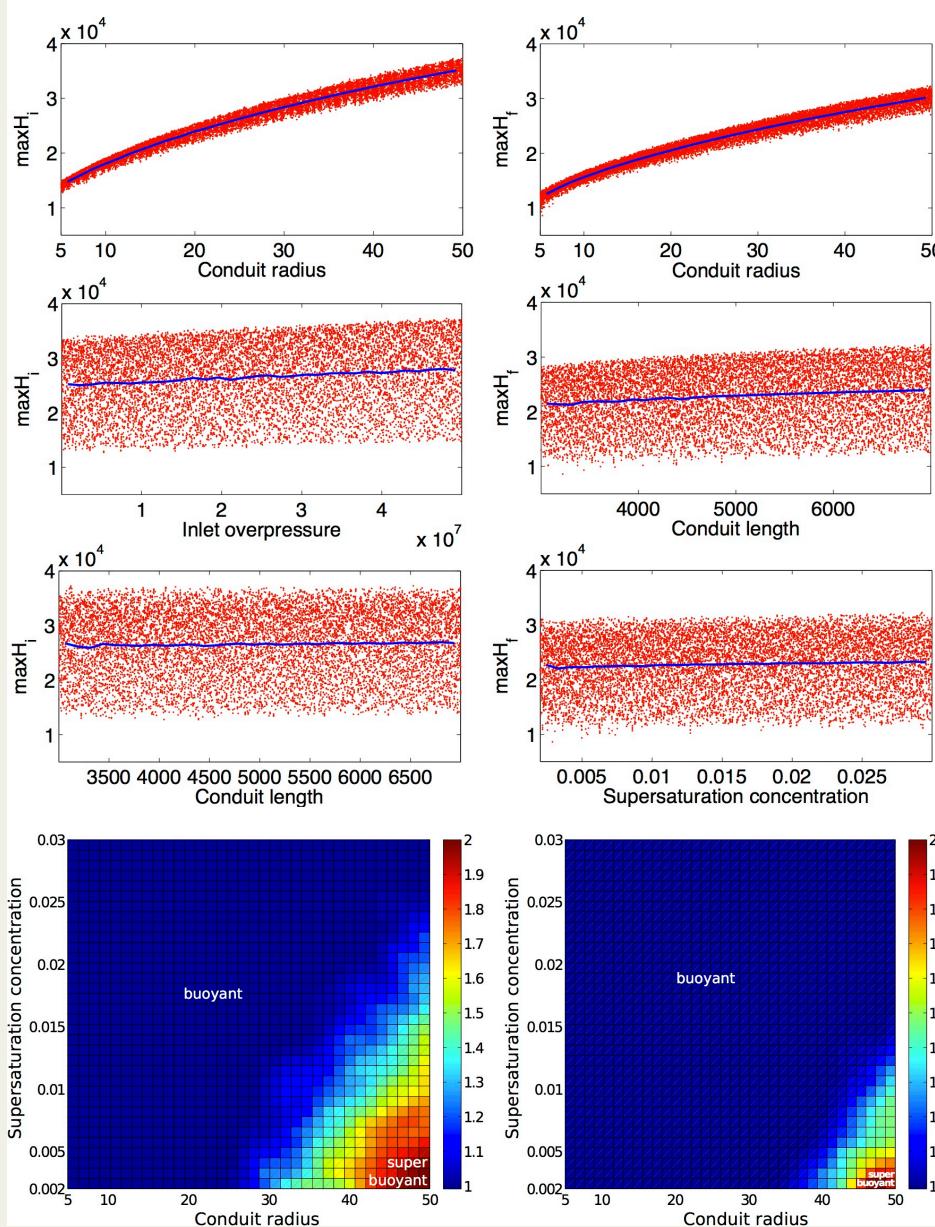
(From Sparks et al. 1997)

Integrated system: C-Cubed-chamber+conduit+column (de' Michieli Vitturi et al.)



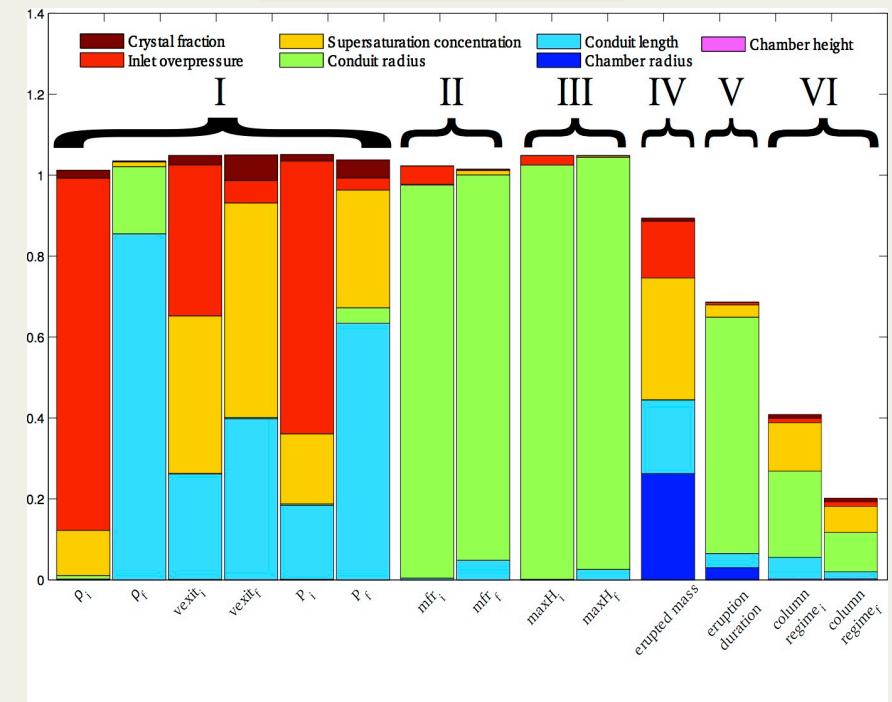
Integrated system (chamber+conduit+column)

Sensitivity analysis on system parameters



- We used a global sensitivity analysis technique that allows the simultaneous exploration of the input parameter space on the whole domain of uncertainty.

$$S_i = \frac{V[E(Y|x_i)]}{V(Y)}$$

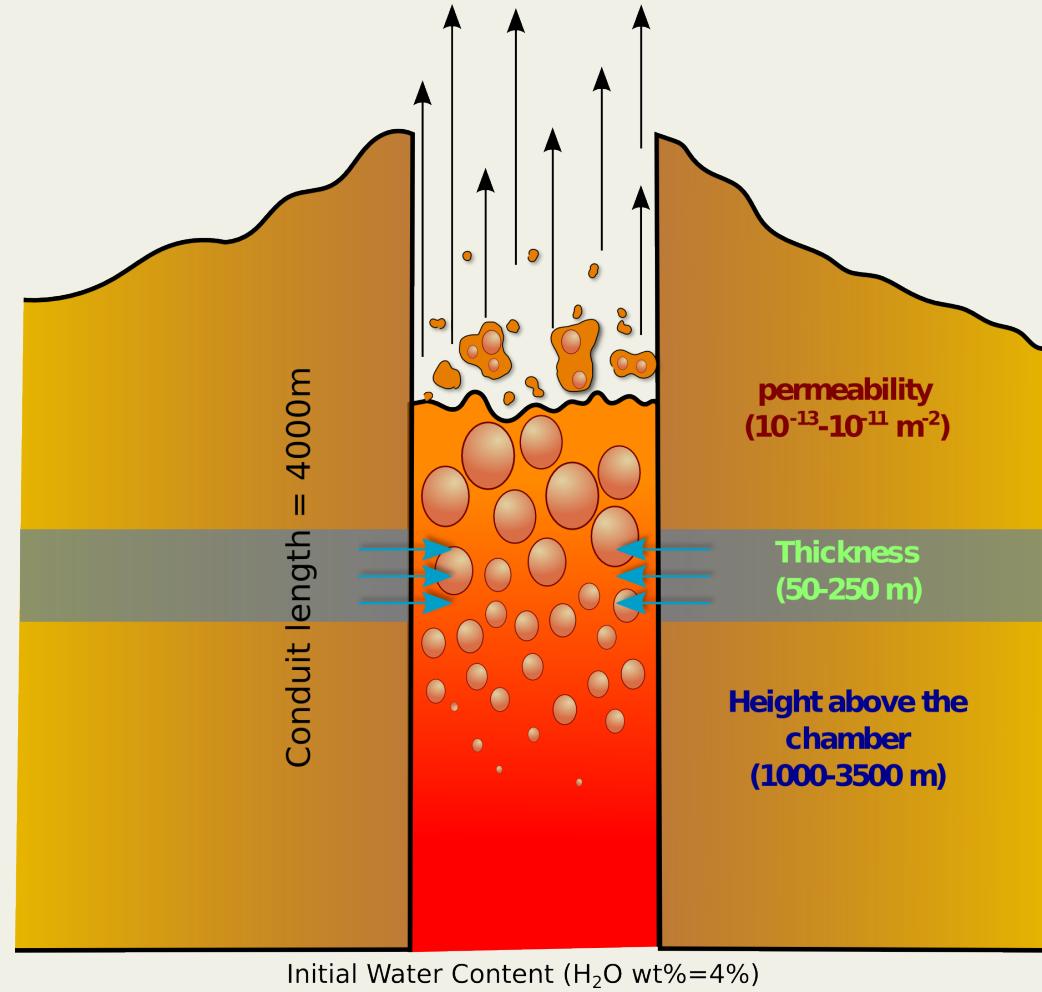


(From Colucci et al., submitted)

Effect of external water (preliminary insights)

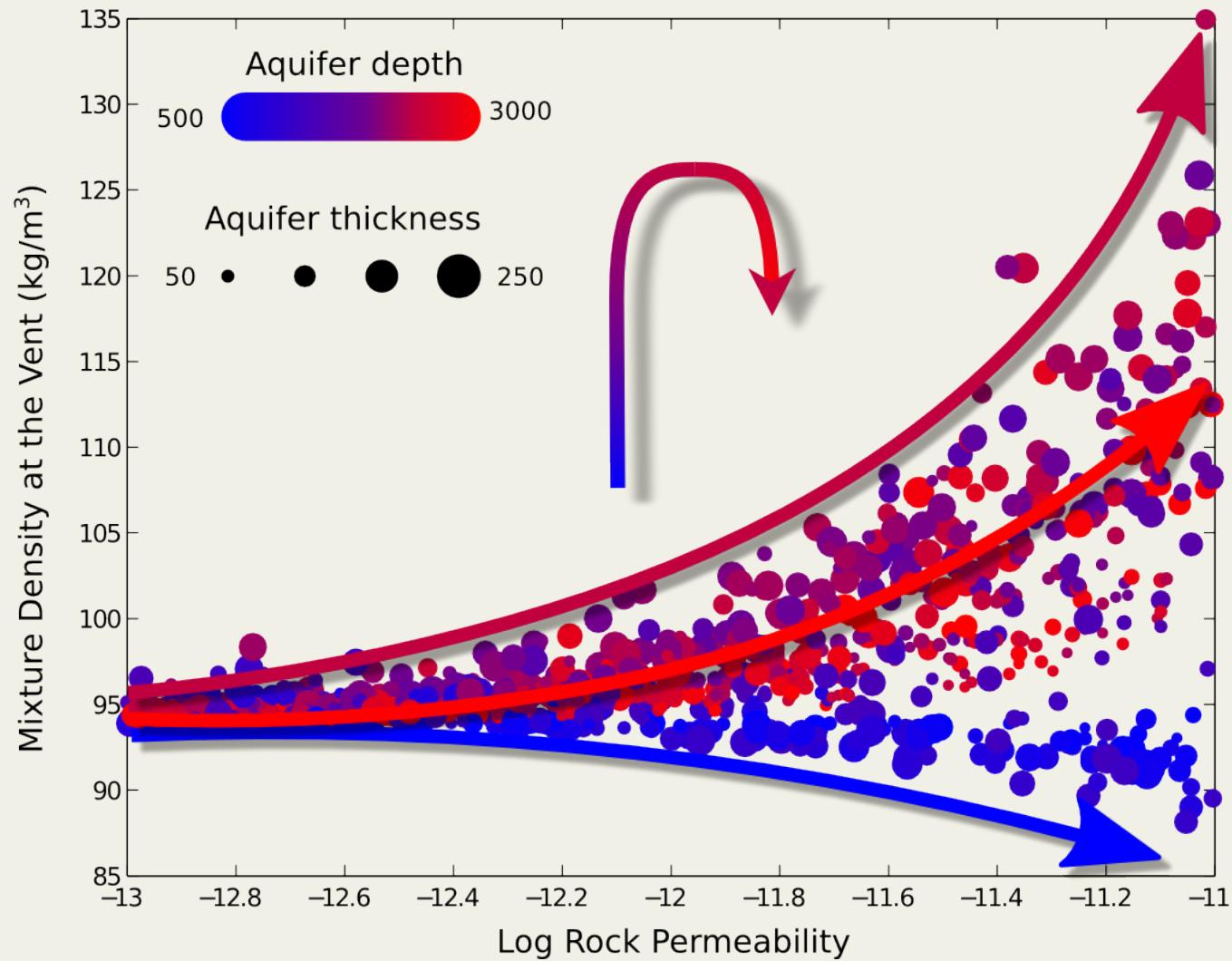
We developed a [new multiphase flow model](#) based on the theory of thermodynamically compatible systems (Romenski et al. 2010) capable of:

- 1) treating both dilute and dense flow regimes;
- 2) describing flow above and below the fragmentation level in a coupled and consistent way;
- 3) quantifying the interaction between the two phases forming the magmatic mixture (both in the bubbly-flow and gas-particle regimes) with [two distinct pressures and velocities](#);
- 4) accounting for [disequilibrium crystallization and degassing](#);
- 5) treating the dissolved water as a separate phase with its own equation of state;
- 6) allowing for [instantaneous or delayed vaporization](#) of the external water from an aquifer.

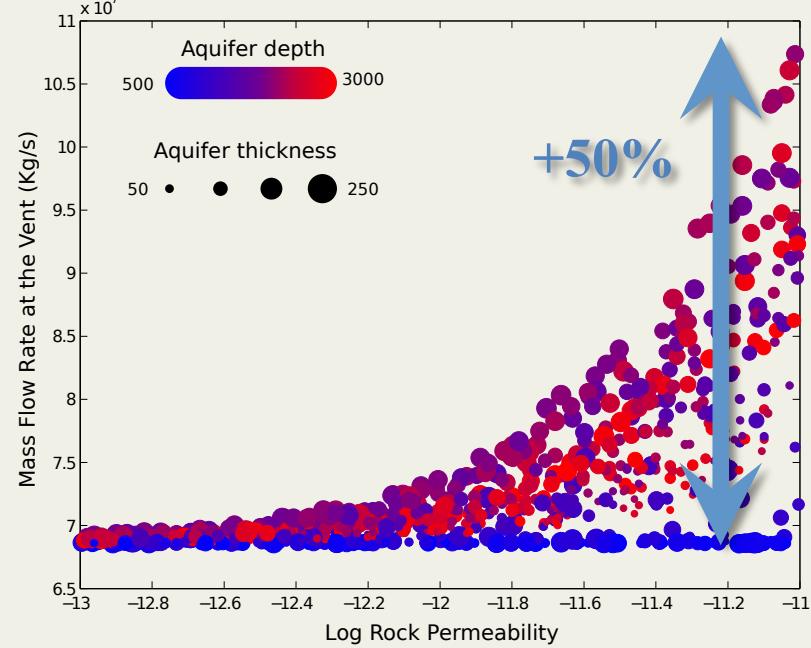
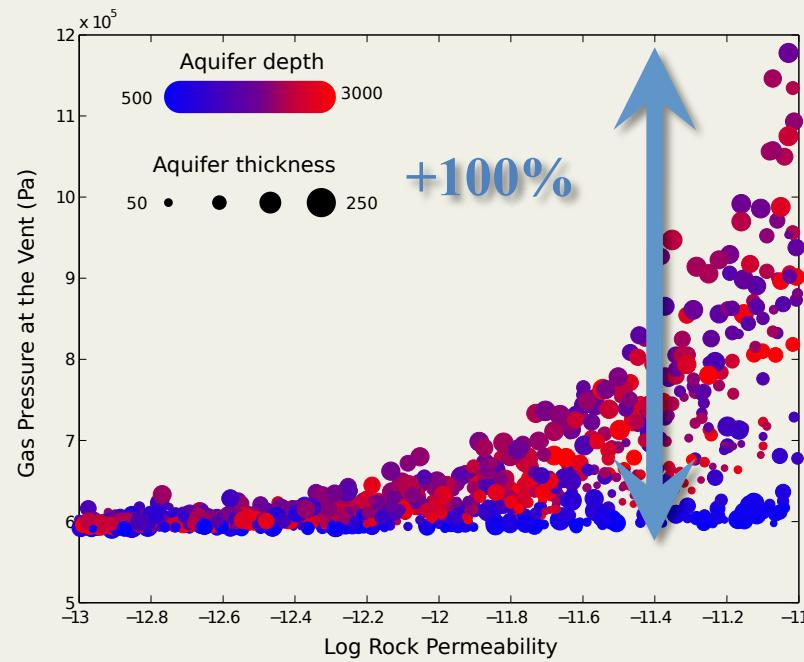


Vent conditions: density

- Density, in the most favorable conditions, can change up to 50%.
- For thin aquifers density changes little with depth and permeability.
- For thicker and shallow aquifers density decreases with increasing permeability.
- For thicker and deep aquifers density increases with increasing permeability.
- The change in density with increasing permeability is not monotonic.



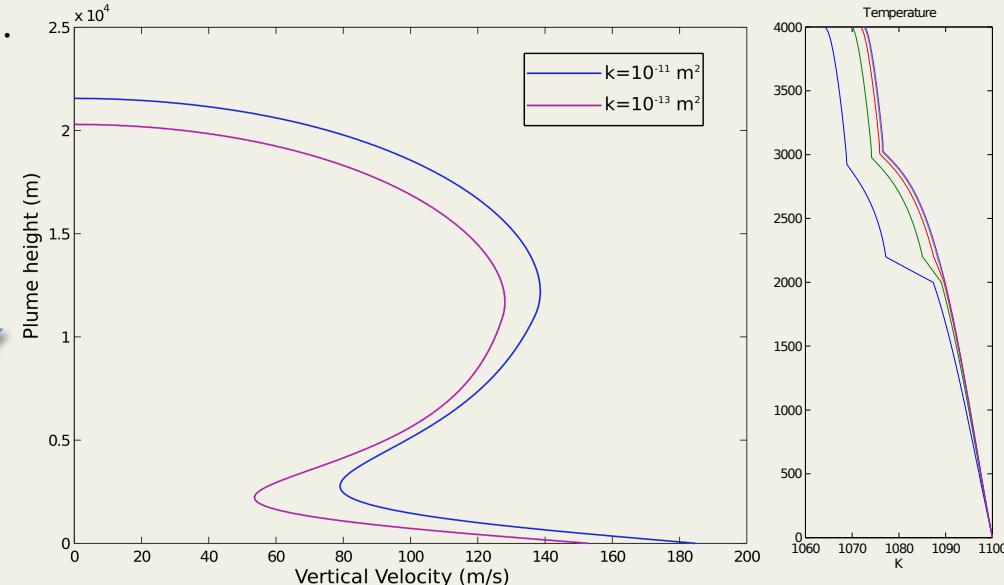
Vent conditions



Gas pressure at the vent can change up to 100%.

Mass flow rate at the vent can change up to 50%.

- Vent condition are used as input parameters for a plume model.
- Preliminary results on the effect of permeability on the volcanic column are shown.

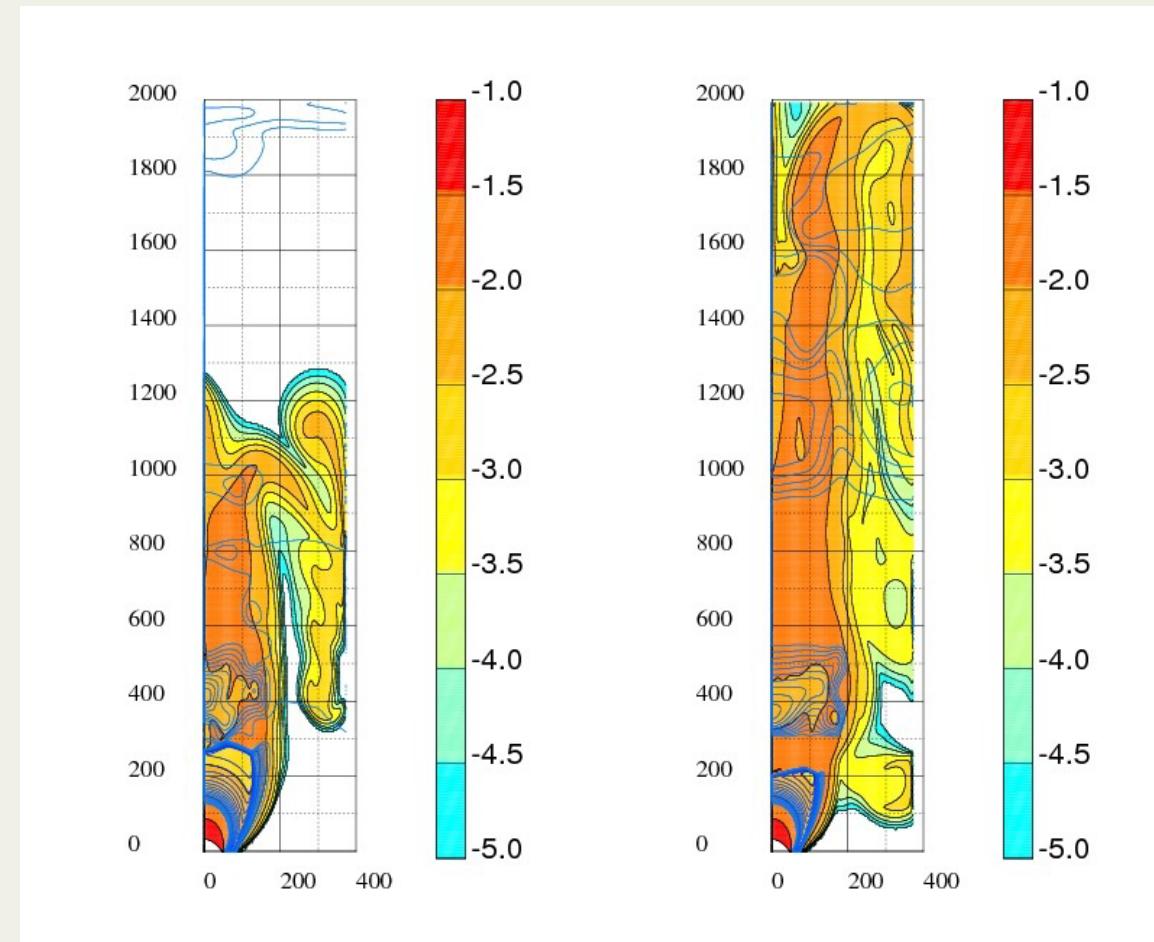


Volcanic jet dynamics

(PDAC code, Neri et al., 2003, Esposti Ongaro et al., 2007, 2008)

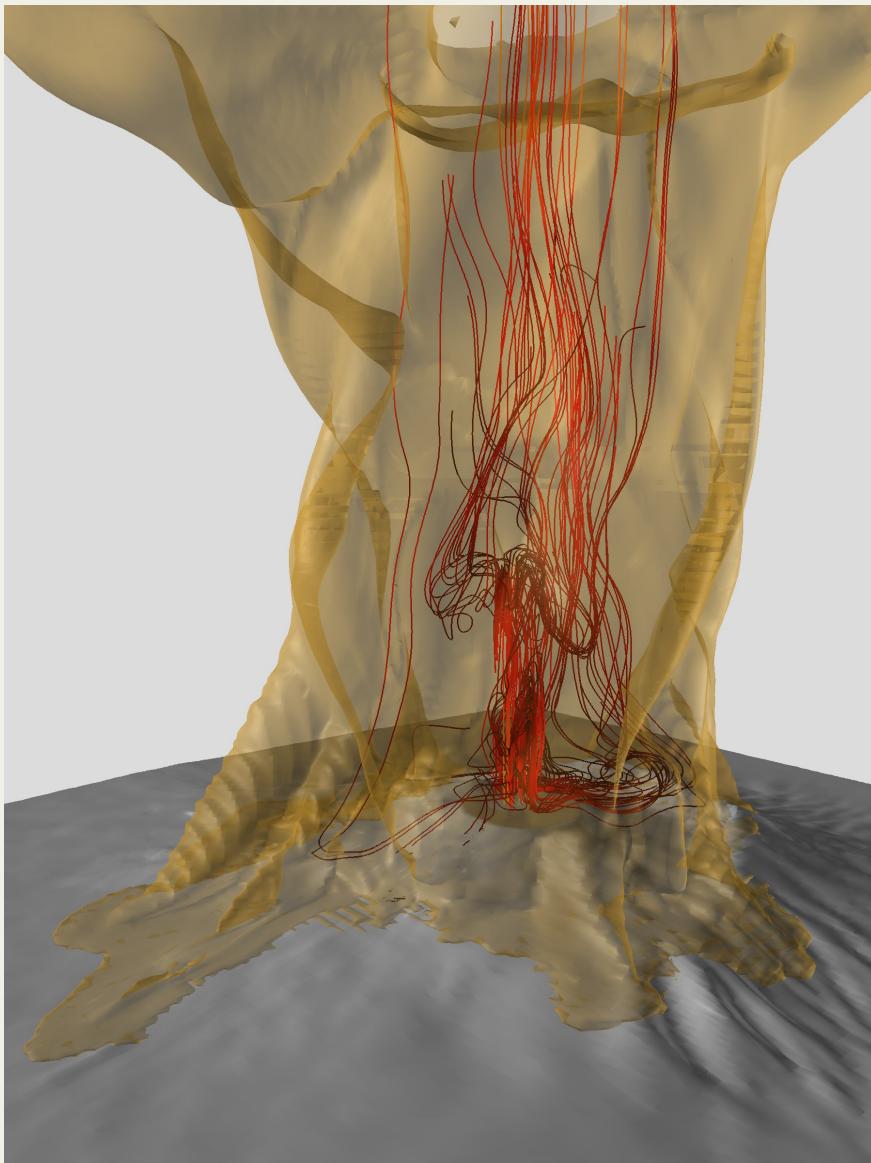
The model is able to illustrate the *complex pattern of volcanic jets*. The dynamics is characterized by a complex interplay between rarefaction and compression waves.

Distribution of particle volume fraction (Log10 colour contours) and pressure (isolines) in a sustained explosive eruption (10, 30s)



(From Esposti Ongaro et al. 2008)

Column collapse dynamics



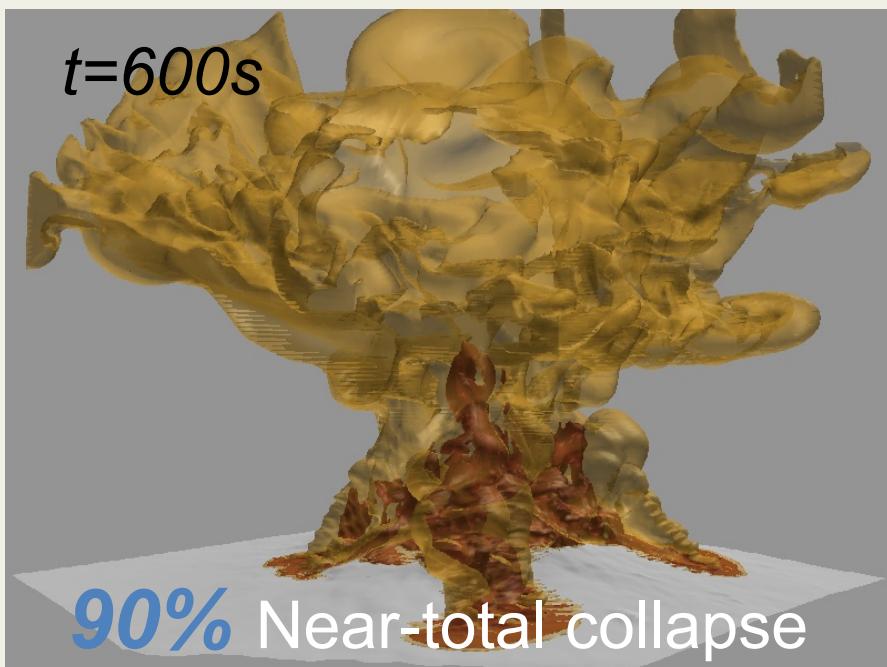
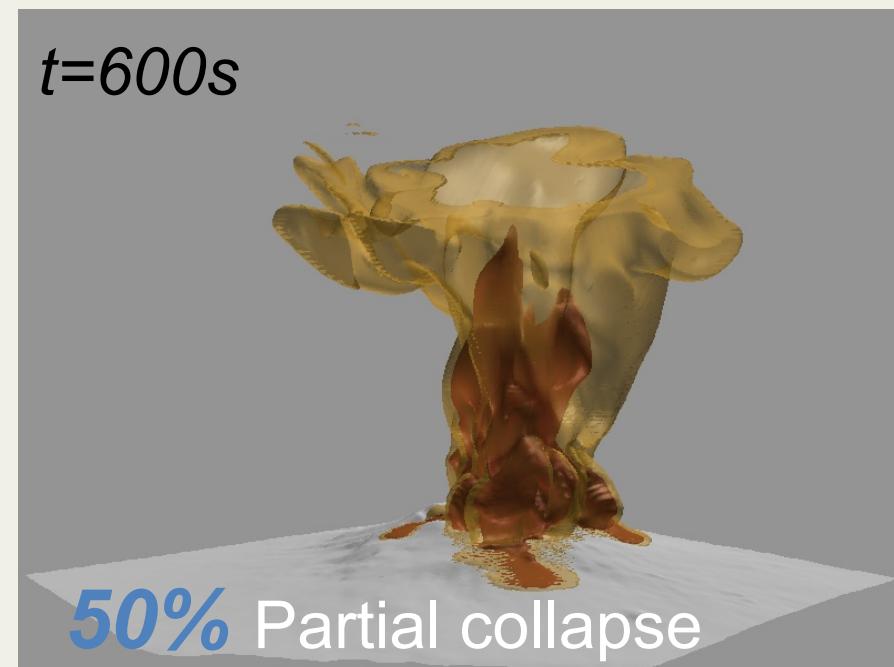
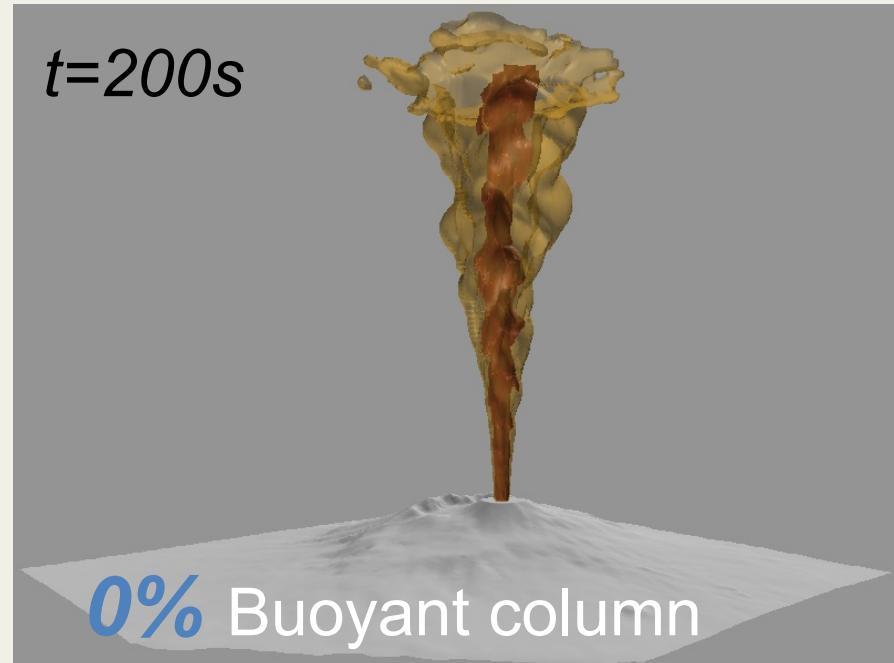
(modified from Esposti Ongaro et al., 2008)

The collapse of the column is characterized by a series of **asymmetric batches** of mass that **intermittently** leave the column.

On a **time-average basis**, the column collapse is **isotropic** (absence of wind).

The **collapse height oscillates** significantly (up to 50%).

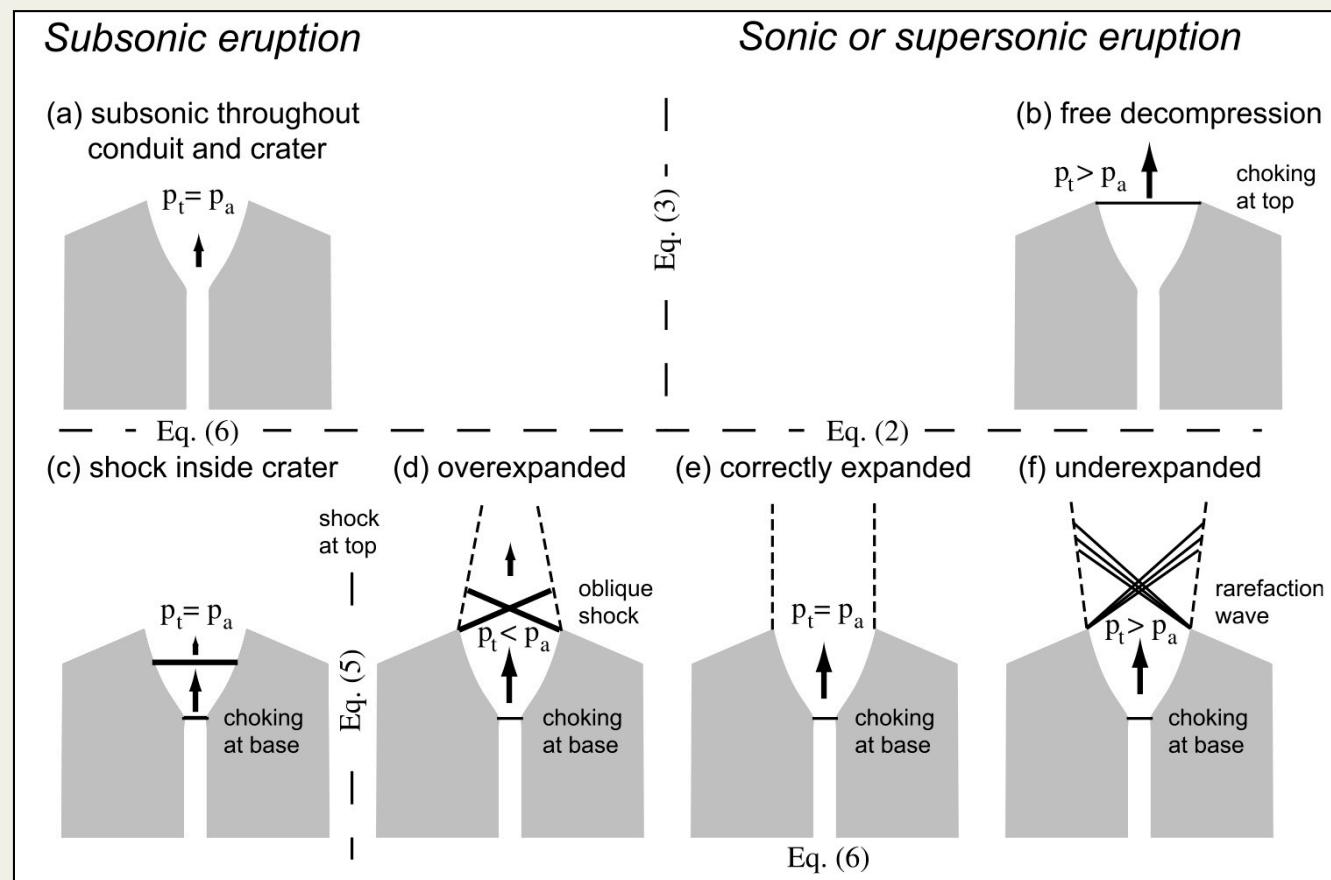
Vesuvius sub-Plinian event ($5 \times 10^7 \text{ kg/s}$): wt% of collapsed mass



Effect on the crater on eruption dynamics (Koyaguchi et al., 2010)

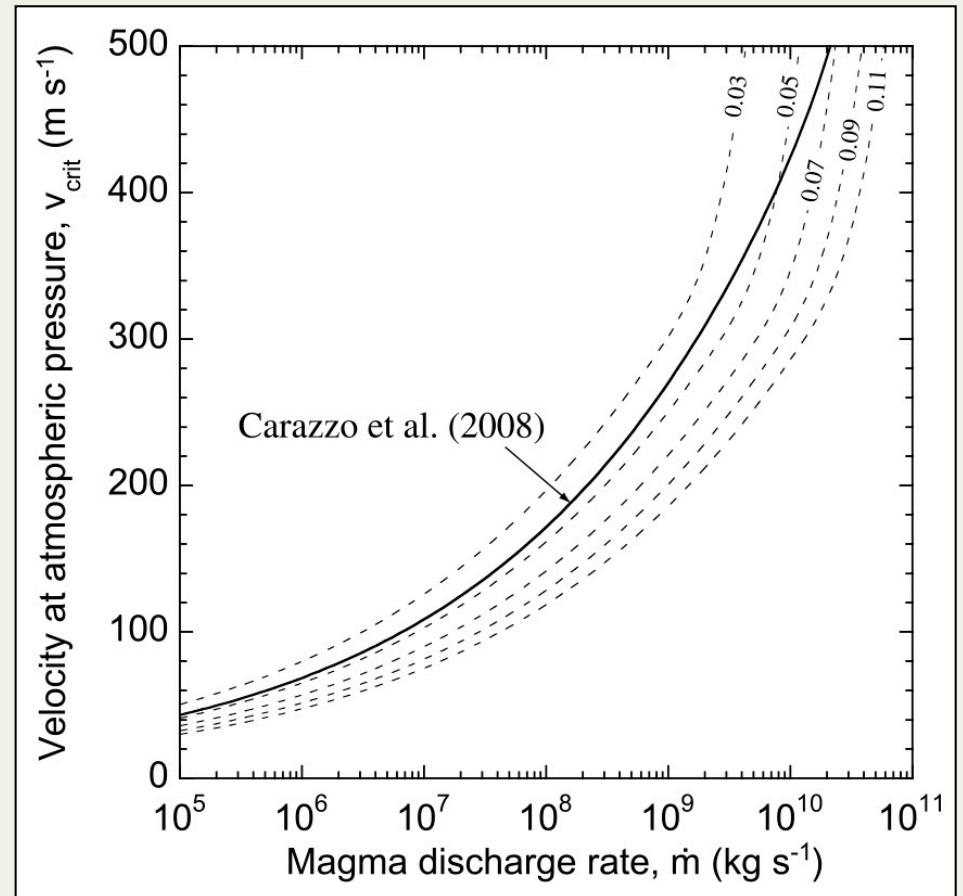
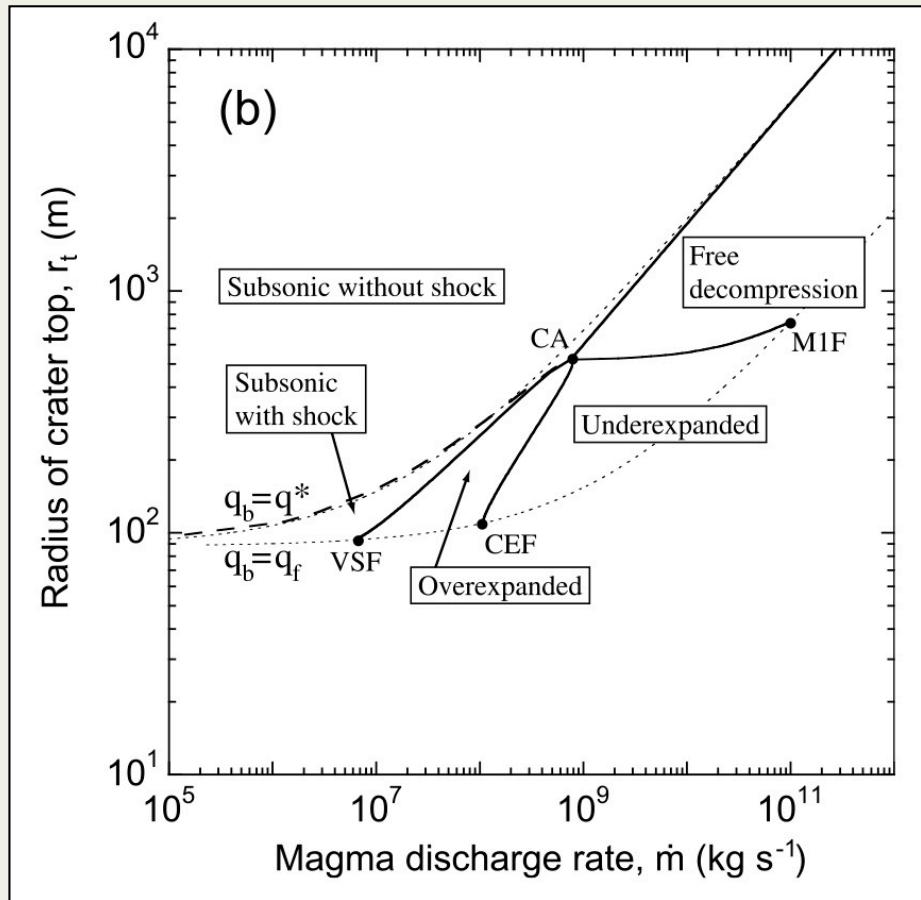
It is investigated how the condition that separate buoyant and collapsing columns depends on crater shape.

On the base of theoretical studies, it has generally accepted that a column collapse occurs over in the course of an explosive eruption as the magma discharge increases.



(From Koyaguchi et al., 2010)

Effect on the crater on eruption dynamics (Koyaguchi et al., 2010)



(From Koyaguchi et al., 2010)

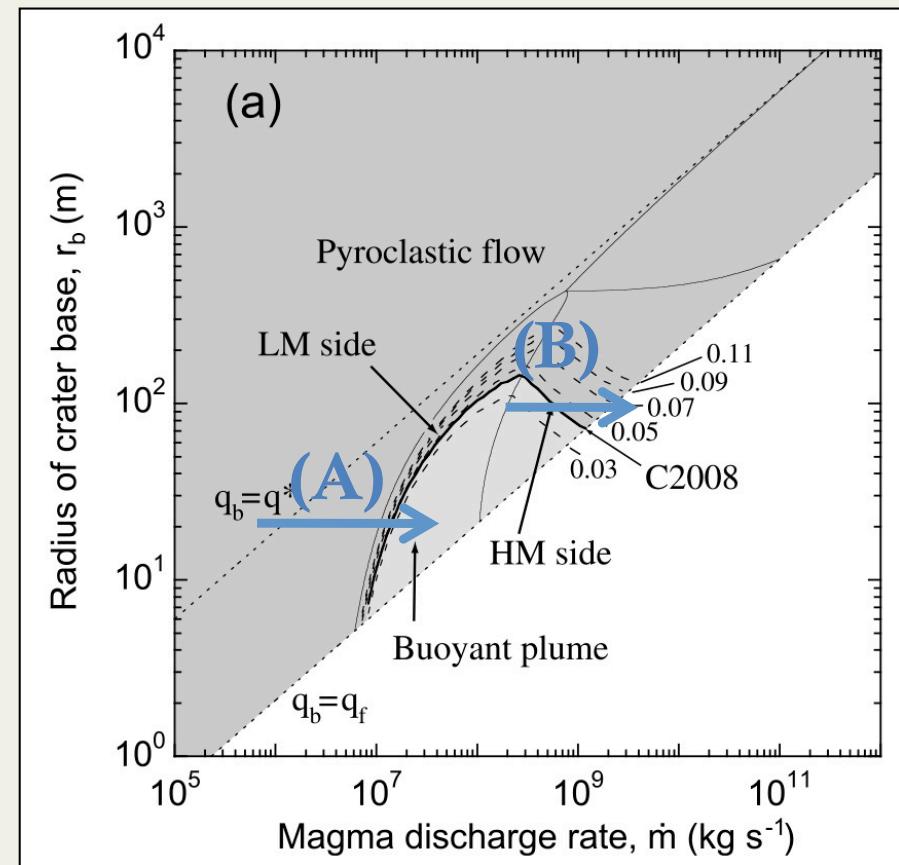
Left. Boundaries of the flow types inside the craters.

Right. Critical velocity for column collapse as a function of magma discharge rate.

Column collapse

When a crater is present, the decompression and/or compression of a gas-pyroclast mixture inside and just above the crater result in two distinct types of column collapse:

- (A) collapse with increasing discharge rate (caused by an increase in conduit radius during the waxing stage of an eruption)
- (B) collapse with decreasing discharge rate (associated with a decrease in magma chamber pressure during the waning stage).

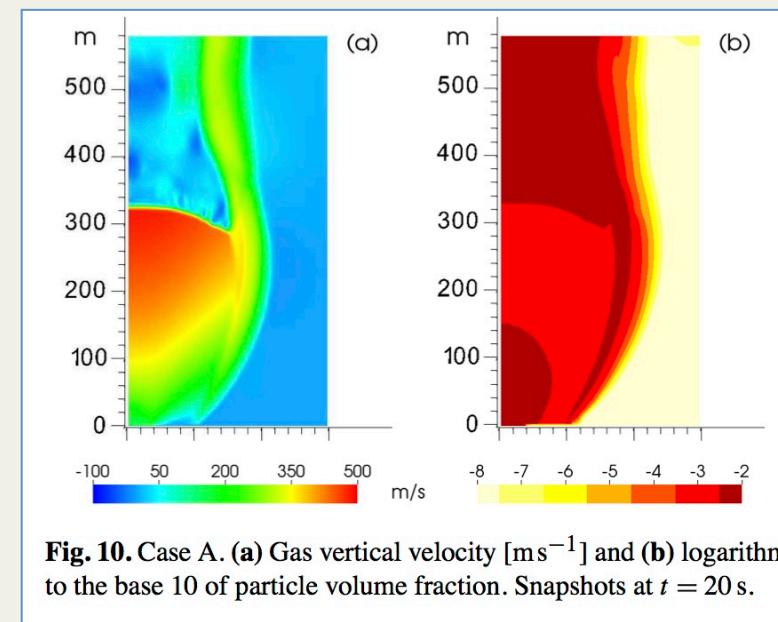
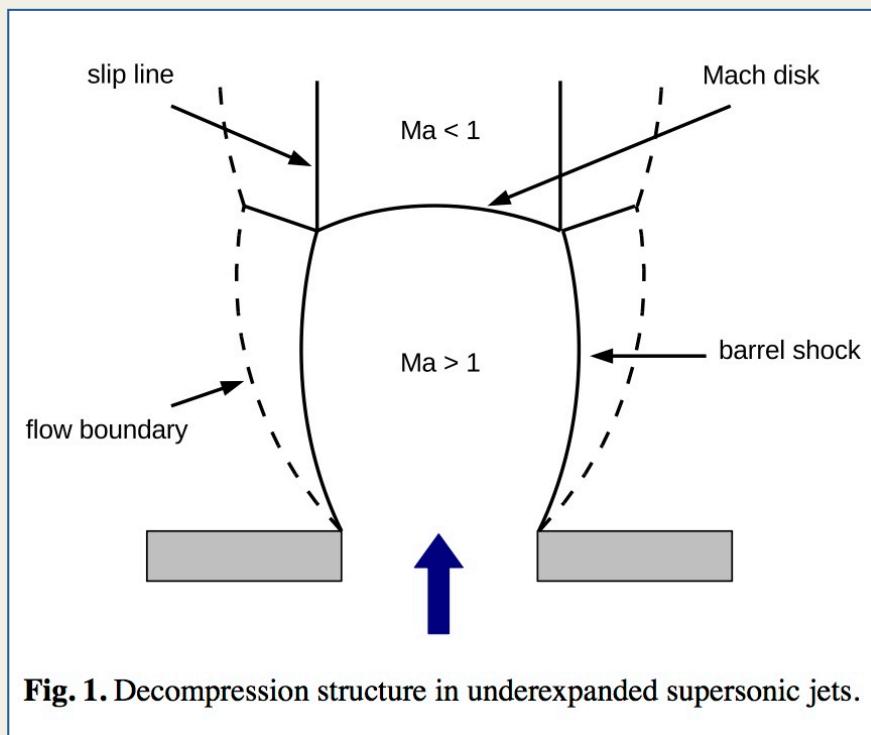


(From Koyaguchi et al., 2010)

Volcanic jet dynamics

(PDAC Code - Carcano et al., 2013)

The numerical algorithm has been recently modified in order to increase the accuracy in the simulation of **near-vent decompression dynamics** and the 3D dynamics of turbulent eddies than control, for example, the atmospheric air entrainment.

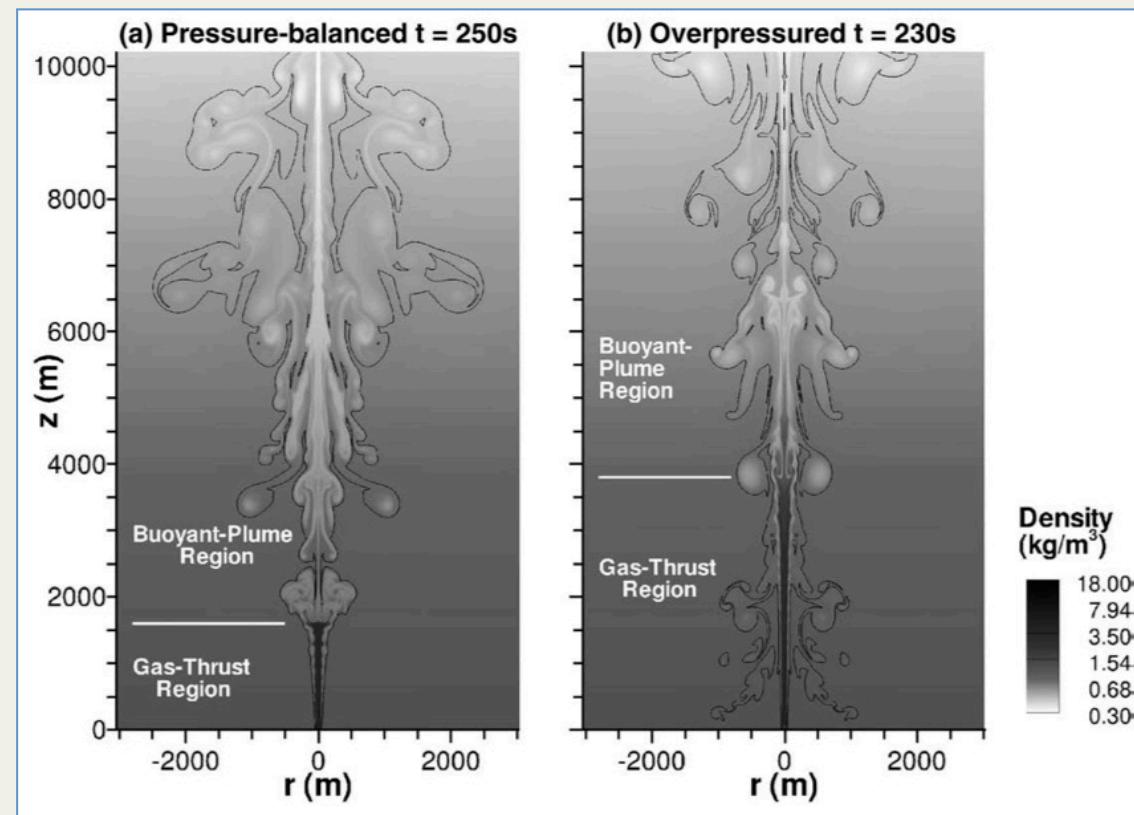


(From Carcano et al., 2013)

Effects of vent overpressure on buoyant eruption columns

(Ogden et al., 2008)

In comparison to pressure-balanced jets with the same vent heat flow, vent overpressure increases the maximum altitude of the transition from the inertia-dominated to buoyancy-dominated regime of the associated column.



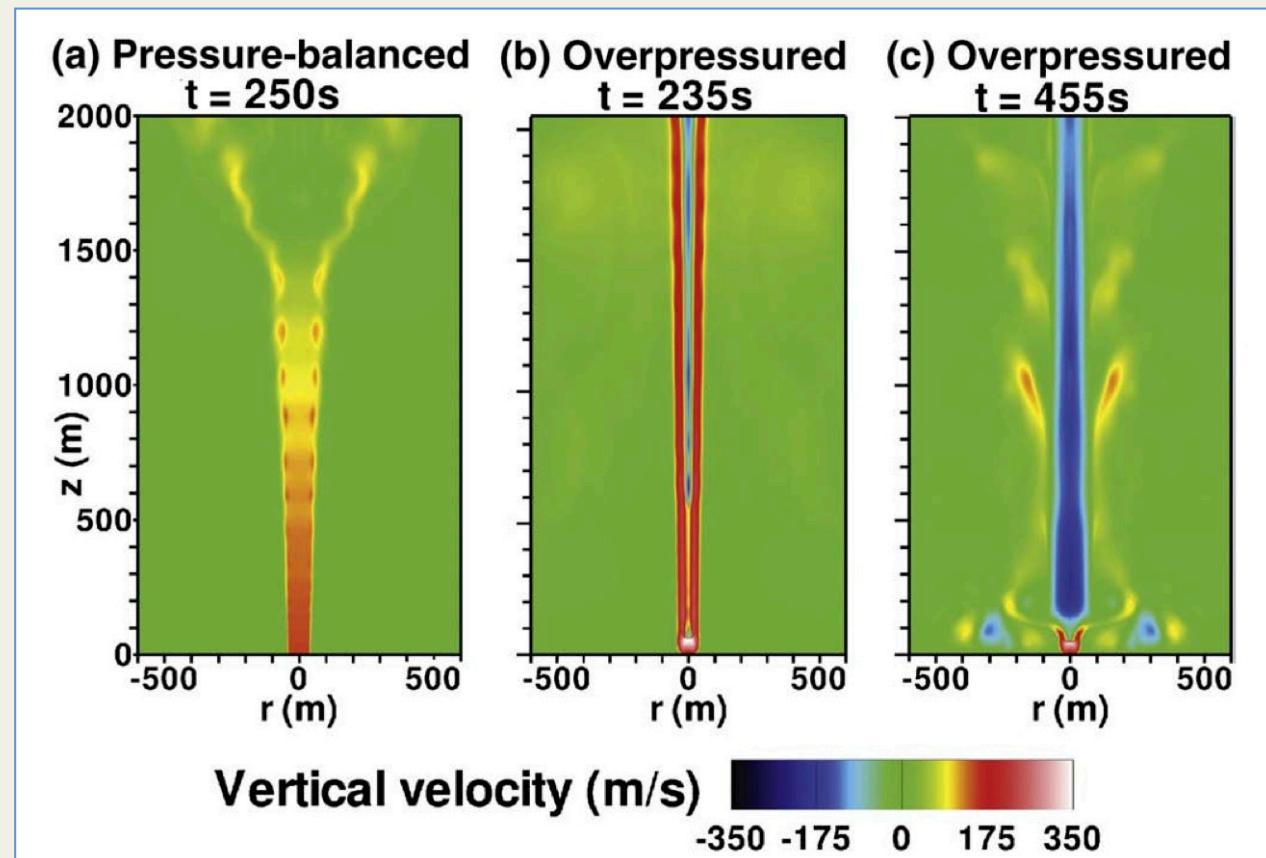
(From Ogden et al., 2008)

Implications for plume stability

(Ogden et al., 2008)



- Some overpressured vents may result in oscillations between buoyant and collapsing columns without any changes of source condition.



(From Ogden et al., 2008)

Column time-dependent behavior

- Most models of volcanic plumes include an assumption that volume fluxes remain constant over the eruption duration [e.g. Woods, 1988; Suzuki et al., 2005; Ogden et al. 2008; Kaminski et al., 2011].
- When the mass flux variations are on the order of $1/N$, where N is the atmospheric buoyancy frequency, these variations may lead to unsteady dynamic conditions in the plume.

Transient source conditions

(Scase, 2009)

- The classical steady state model is extended to allow the source condition at the volcanic vent to change in time.
- It is shown that when the source condition change rapidly the steady state model becomes inappropriate.

$$\frac{\partial}{\partial t} \left(\frac{Q^2}{M} \right) + \frac{\partial Q}{\partial z} = 2\varepsilon\alpha^{1/2}M^{1/2},$$

$$\frac{\partial Q}{\partial t} + \frac{\partial M}{\partial z} = g \frac{\alpha - \beta}{\beta} \frac{Q^2}{M},$$

$$\frac{\partial}{\partial t} \left(\frac{Q^2}{M} \Theta \right) + \frac{\partial}{\partial z} (Q\Theta) =$$

$$2 \left[C_a T_e + \frac{1}{2} \left(\frac{M}{Q} \right)^2 \right] \varepsilon \alpha^{1/2} M^{1/2} - \frac{\alpha}{\beta} g Q,$$

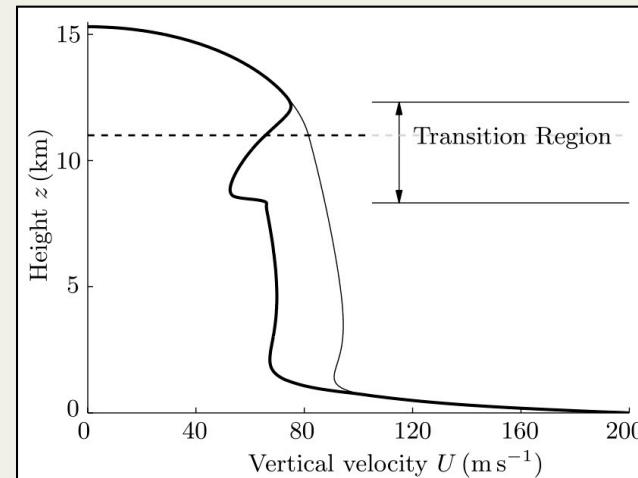
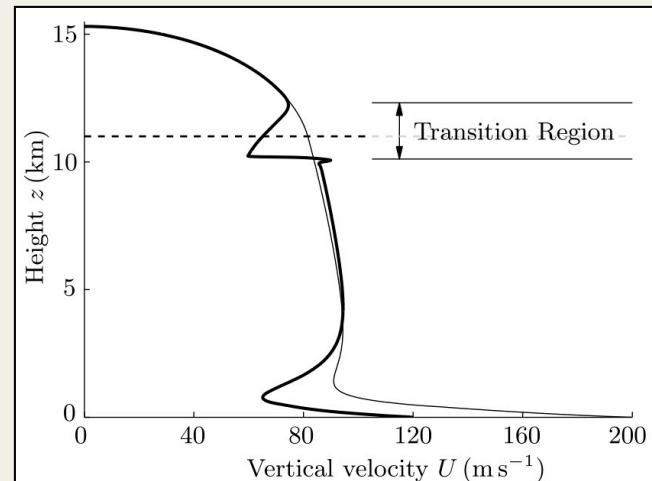
$$\frac{\partial}{\partial t} \left(\frac{Q}{M} Q_m \right) + \frac{\partial Q_m}{\partial z} = 0,$$

$$\frac{\partial}{\partial t} \left(\frac{Q}{M} Q_s \right) + \frac{\partial Q_s}{\partial z} = 0.$$

(From Scase, 1999)

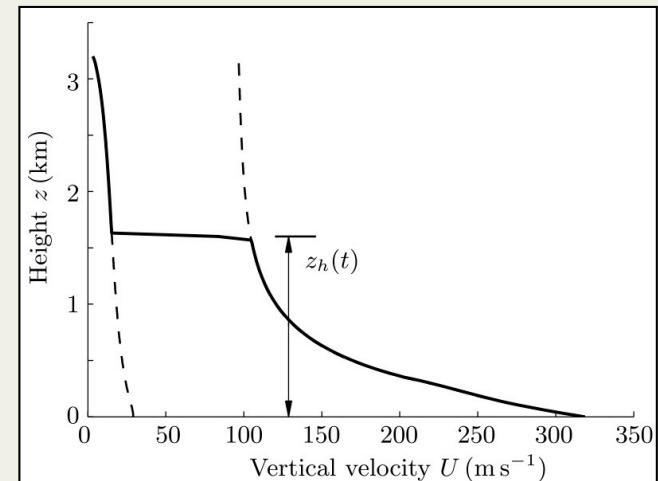
Transient source conditions

- When the source velocity or the source temperature are reduced, a transient region is formed, characterized by a narrowing of the eruption column radius.



(From Scase, 1999)

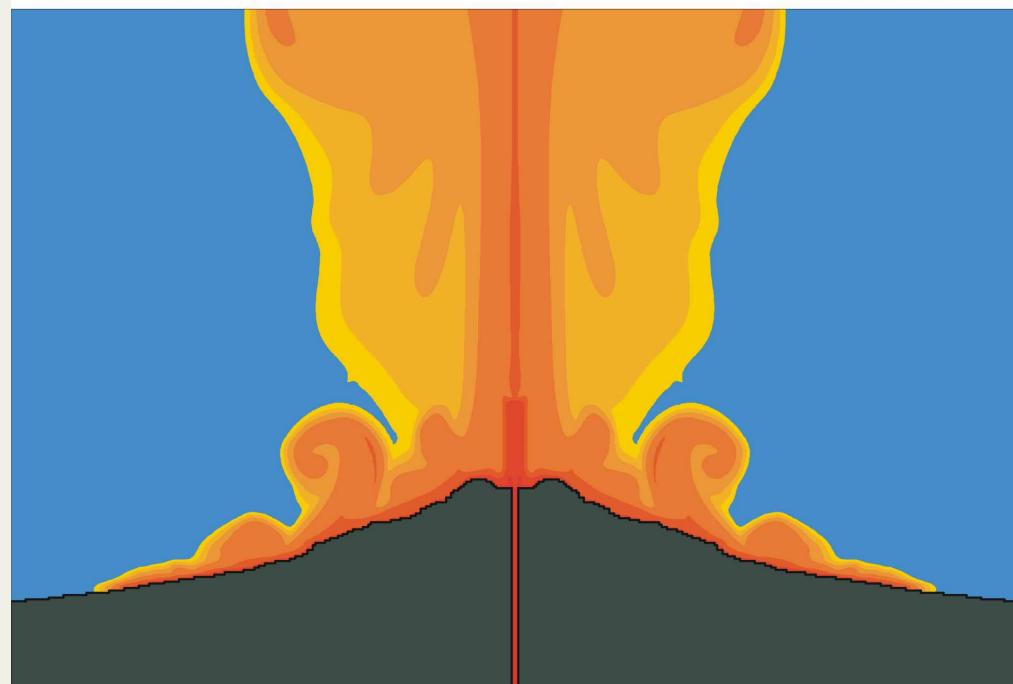
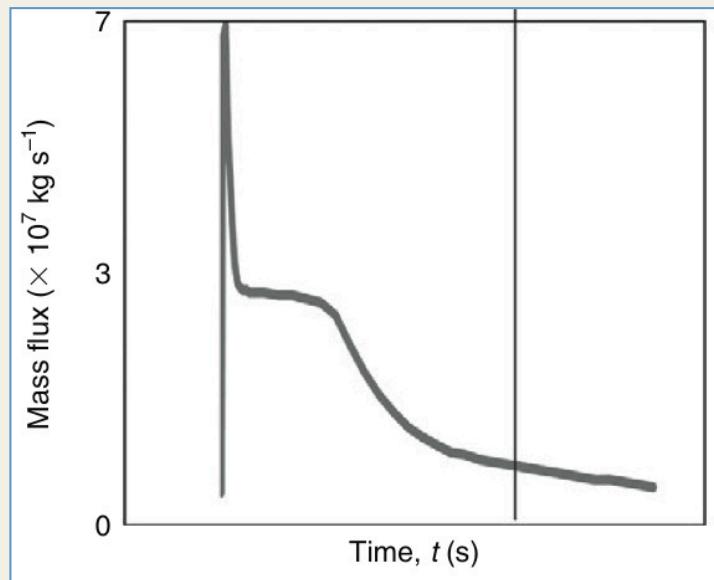
- When the source velocity increases, as time evolves, the eruption column adjusts to the new stronger source conditions. The front of the eruption column moved significantly more slowly than the mean velocity on the axis of a steady eruption column with identical source conditions.



Short-lived Vulcanian explosions

(Clarke et al., 2002)

Observation and simulation
after 90s from the beginning
of a Vulcanian explosion of
the Soufriere Hills volcano,
Montserrat (West Indies,
UK)

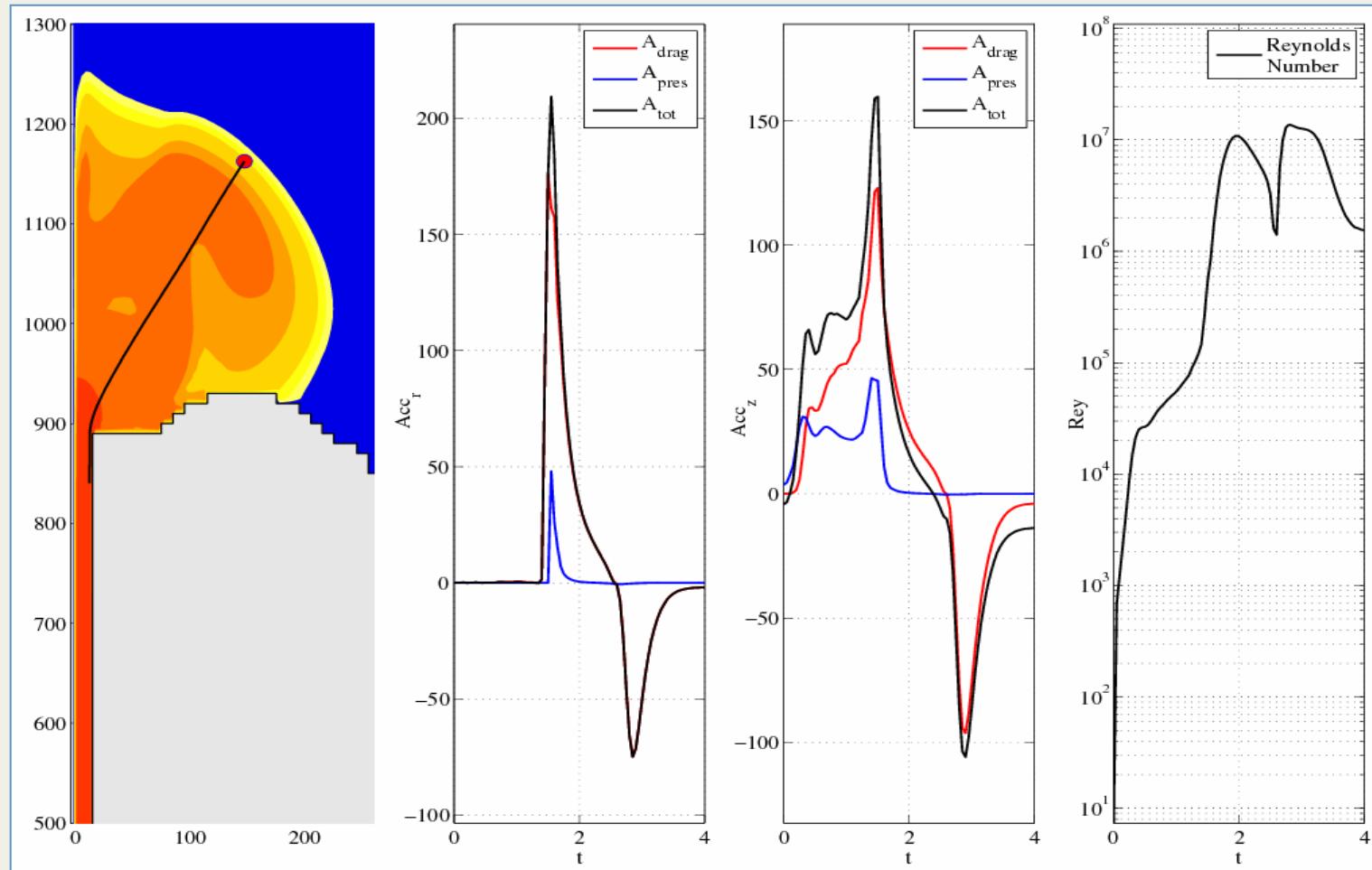


(From Clarke et al., 2002)

The dynamics of large particles

(LPAC code, de'Michieli Vitturi et al., 2010)

Results highlight the key role of the conduit-column background flow field as well as of pressure and drag forces on the large particle dynamics during Vulcanian explosions.



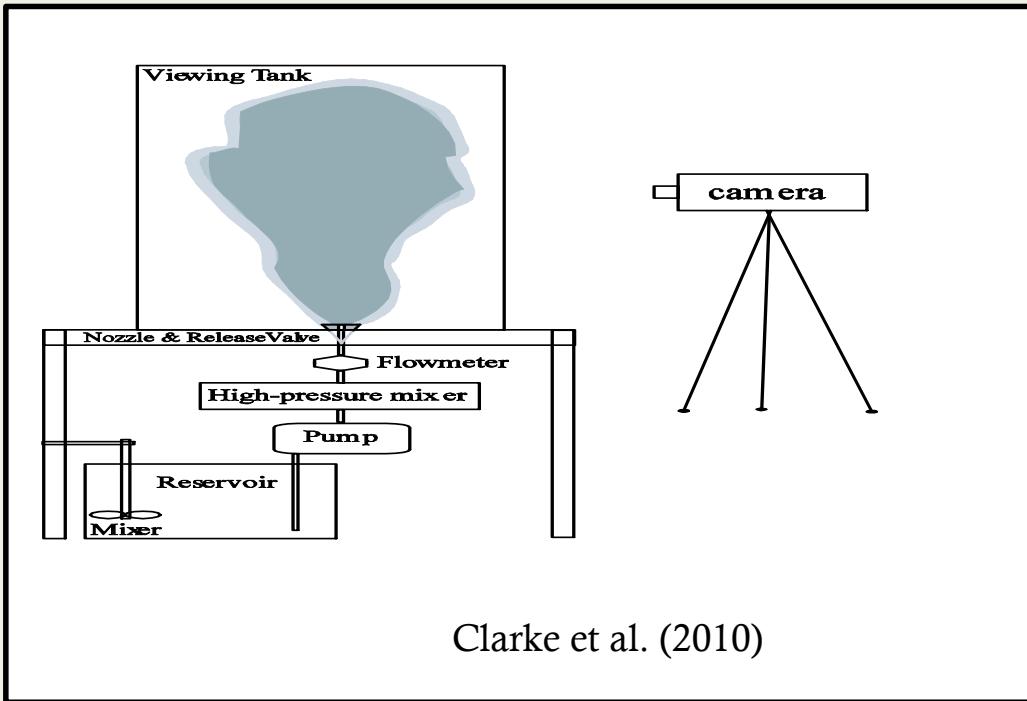
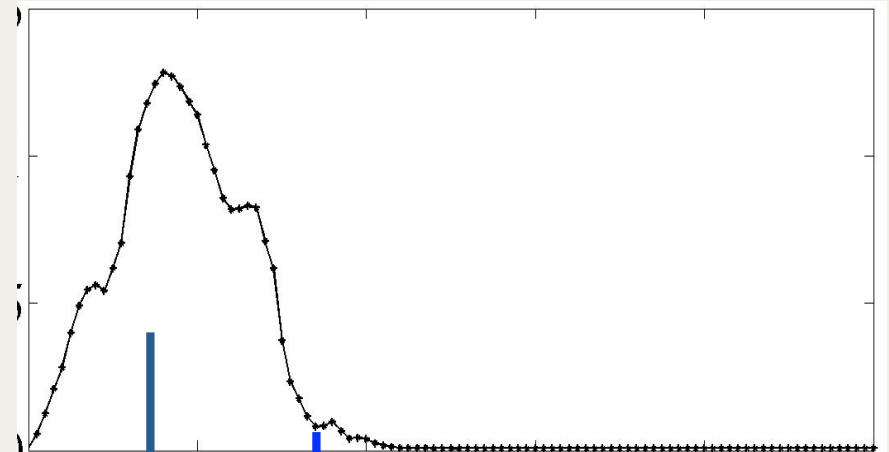
(From de' Michieli Vitturi et al., 2010)

Short-lived jets/plumes

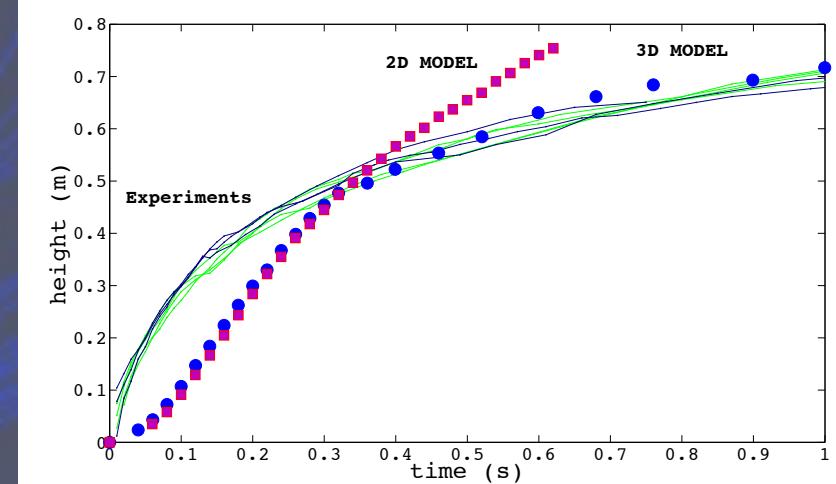
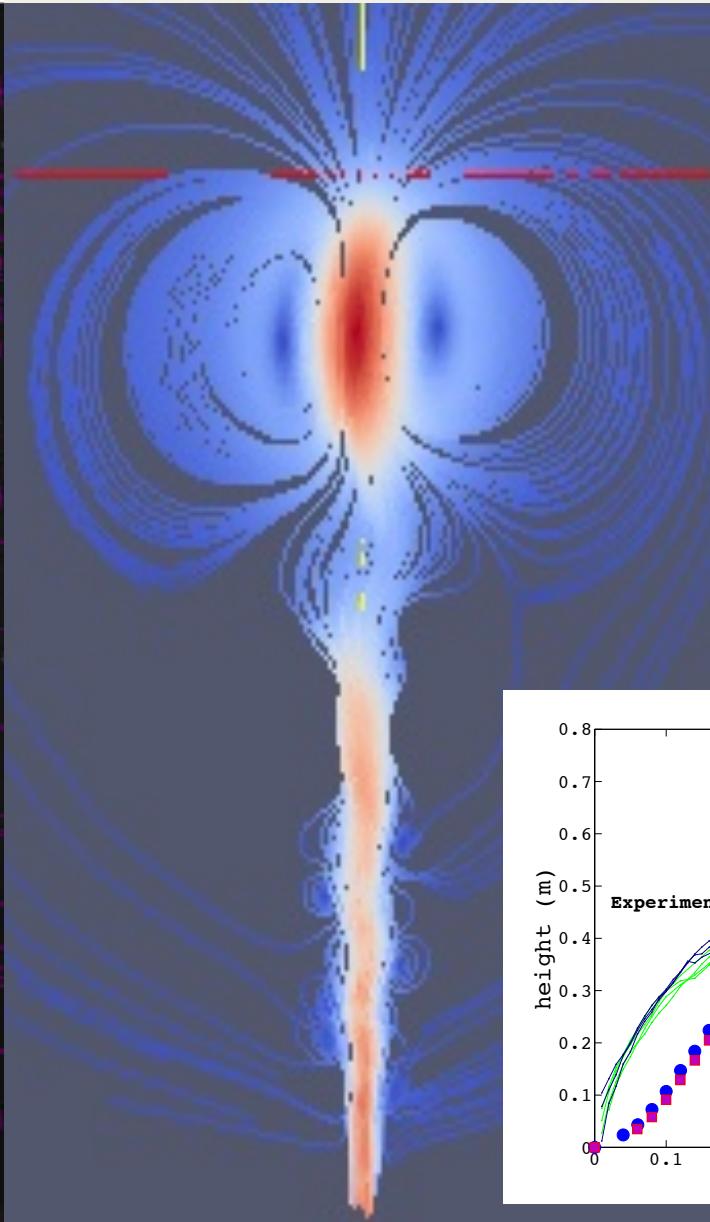
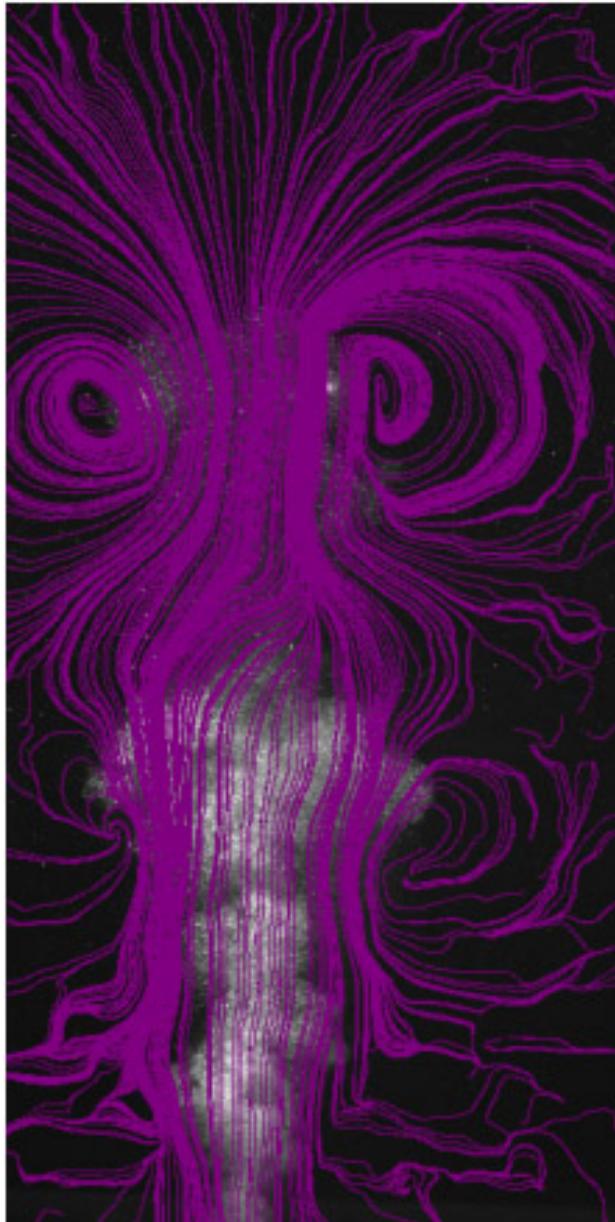
(Chojnicki and Clarke)

Focus on unsteady vent flux and overpressured source: thermal disequilibrium minimized

Vent Velocity



Comparison between experiments and models



Concluding remarks

- Vent conditions exert a major control on plume dynamics.
- Overpressure at the conduit exit and decompression inside the conduit can result in column collapse with both increasing and decreasing discharge rate.
- Decompression outside the crater can lead to oscillatory column behavior.
- Transient source conditions strongly affects column dynamics.