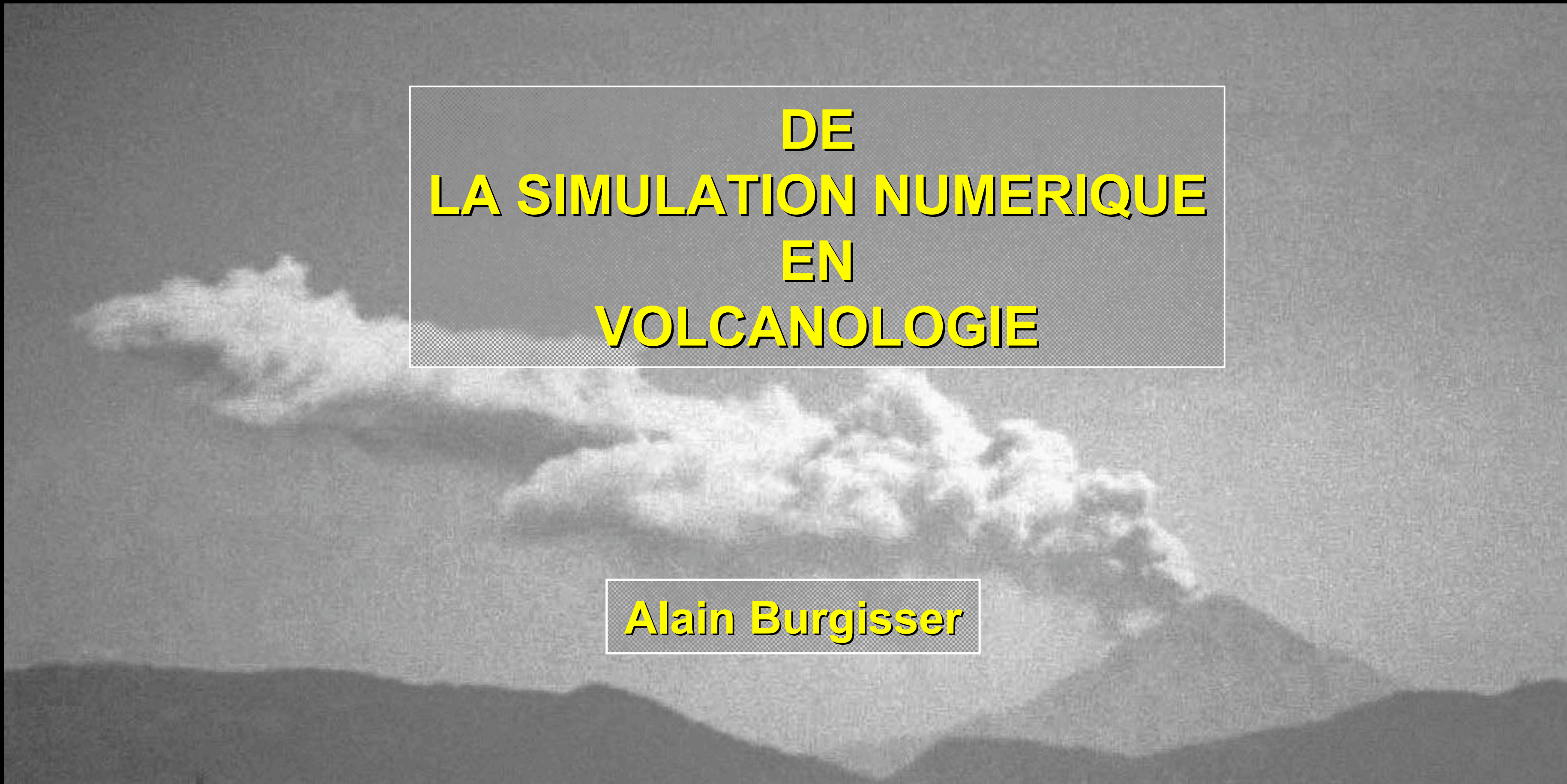
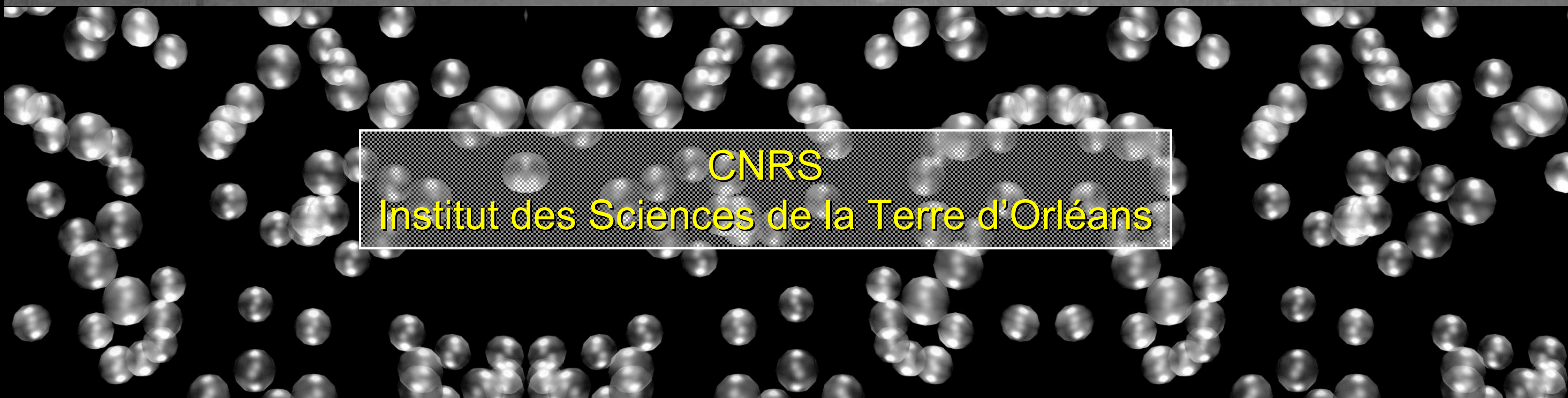


DE LA SIMULATION NUMERIQUE EN VOLCANOLOGIE

Alain Burgisser



CNRS
Institut des Sciences de la Terre d'Orléans

ECOULEMENT DE CONDUIT

PERMEABILITE DU MAGMA

MODELISER LA CHIMIE DU DEGAZAGE

CONVECTION MAGMATIQUE

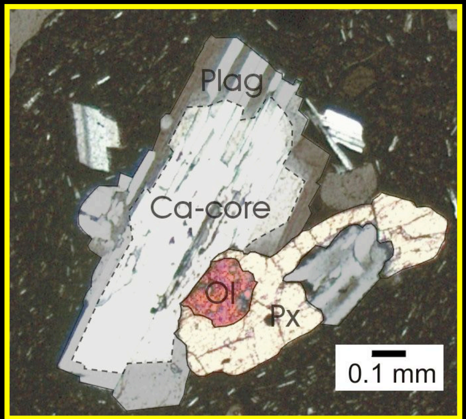
ECOULEMENT DE CONDUIT

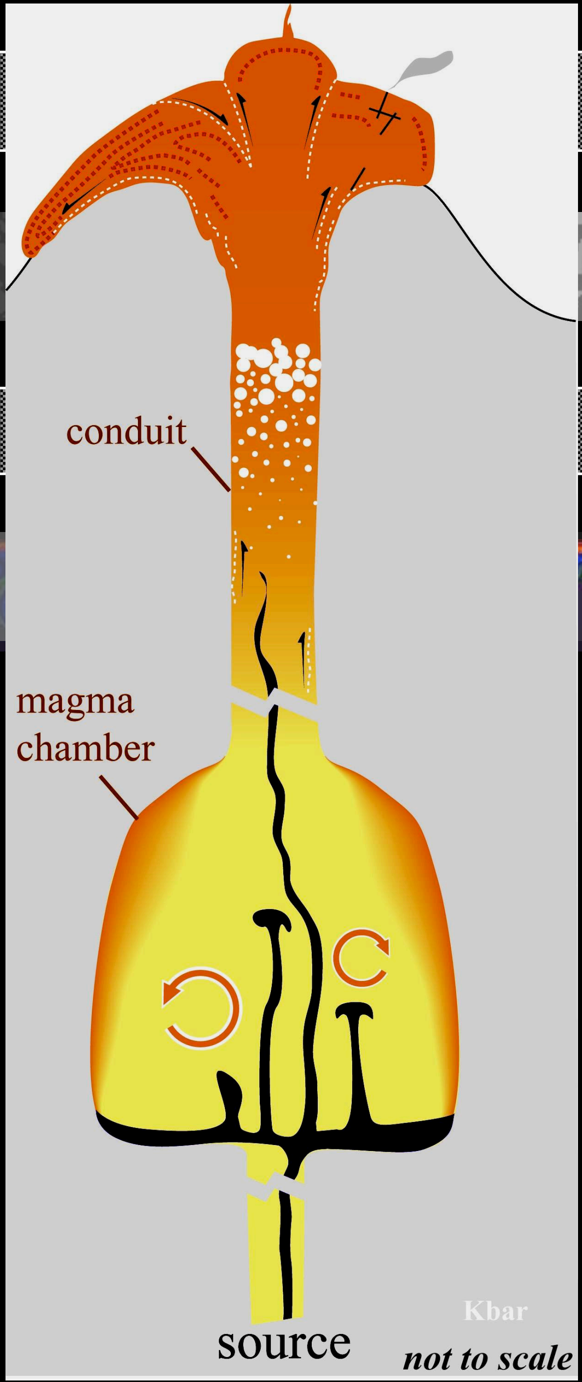
PERMEABILITE DU MAGMA

MODELISER LA CHIMIE DU DEGAZAGE

CONVECTION MAGMATIQUE

Magma = liquide + cristaux + bulles





ECOULEMENT DE CONDUIT

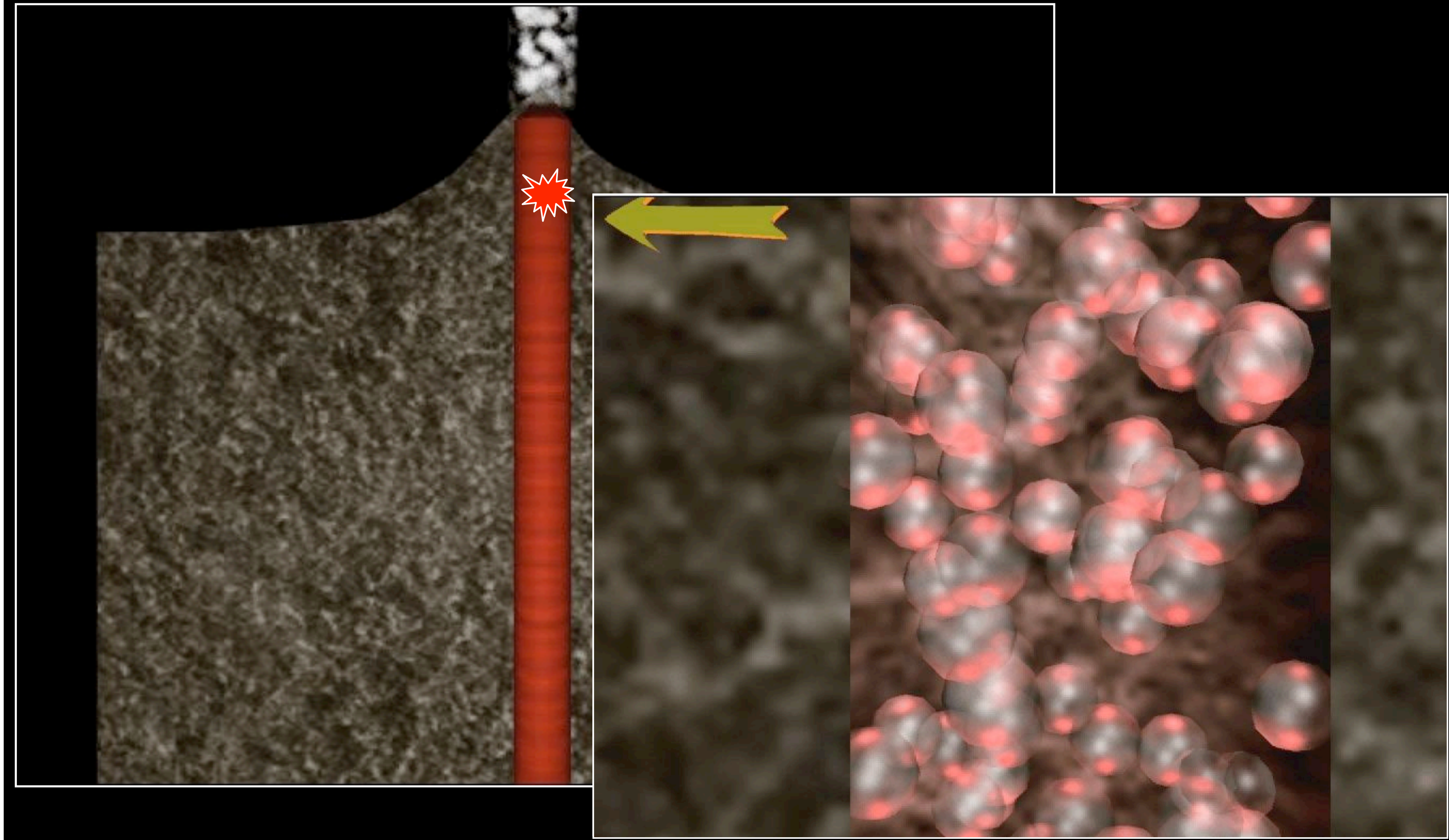
Magma visqueux = Bulles peu mobiles

Eruptions potentiellement (très) dangereuses

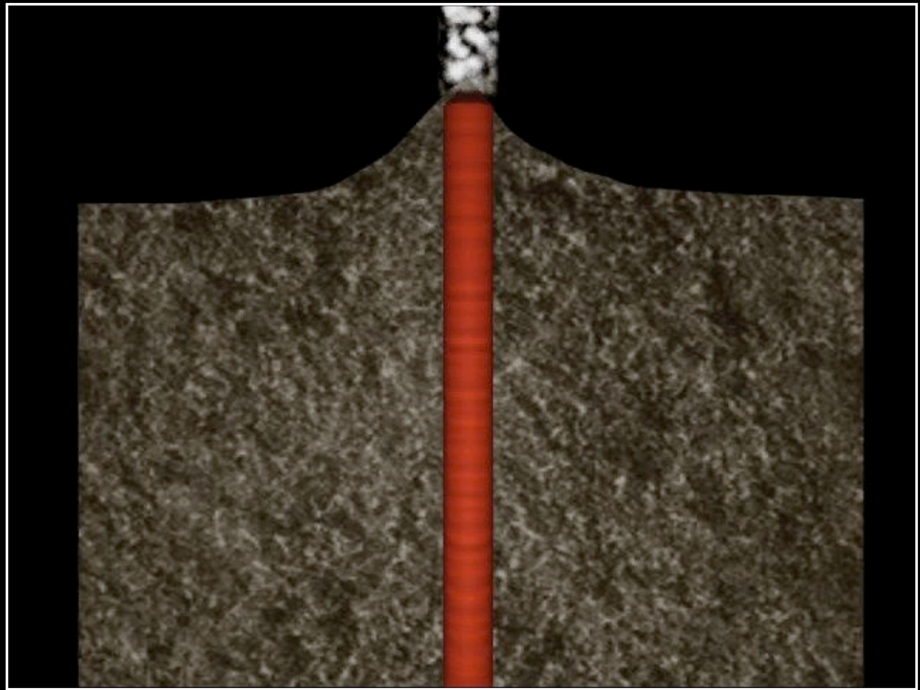
A. Burgisser

USGS

ECOULEMENT DE CONDUIT



ECOULEMENT DE CONDUIT



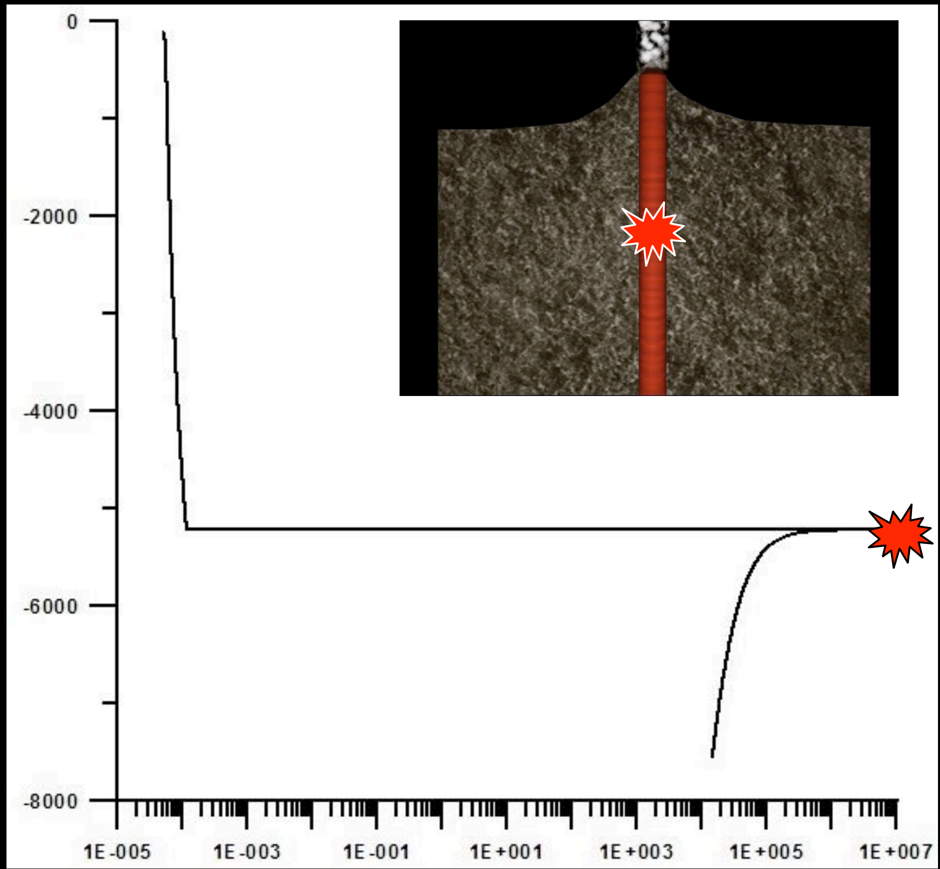
Cons. masse

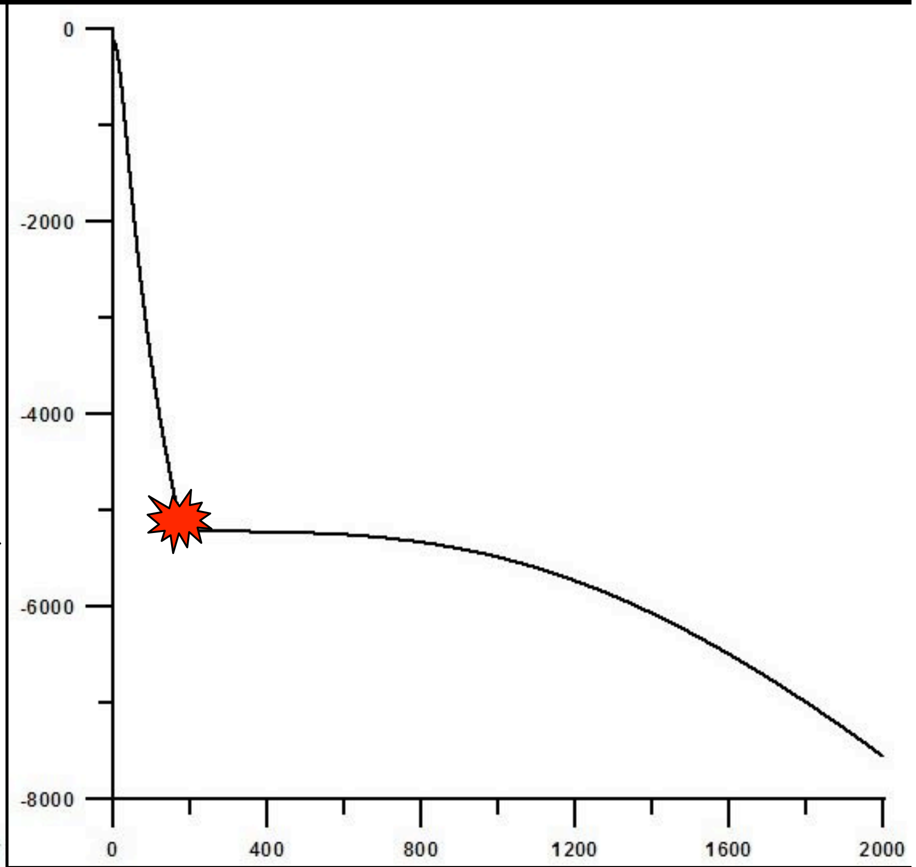
$$\frac{d(\rho v)}{dz} = 0$$

Cons. quantité mvt

$$\rho v \frac{dv}{dz} = -\frac{dP}{dz} - \rho g - \frac{8\mu v}{r^2} + 0.0025 \frac{\rho v^2}{r}$$

ECOULEMENT DE CONDUIT





$$\frac{d(\rho v)}{dz} = 0 \qquad \rho v \frac{dv}{dz} = -\frac{dP}{dz} - \rho g - \frac{8\mu v}{r^2} + 0.0025 \frac{\rho v^2}{r}$$

ECOULEMENT DE CONDUIT MULTIPHASE

Gas continuity: $$\frac{\partial}{\partial t}(\epsilon_g \rho_g) + \nabla\cdot(\epsilon_g \rho_g \vec{v}_g) = \sum_{n=1}^{N_g} R_{gn}$$

Solids continuity: $$\frac{\partial}{\partial t}(\epsilon_{sm} \rho_{sm}) + \nabla\cdot(\epsilon_{sm} \rho_{sm} \vec{v}_{sm}) = \sum_{n=1}^{N_{sm}} R_{smn}$$

Gas momentum balance:

$$\frac{\partial}{\partial t}(\epsilon_g \rho_g \vec{v}_g) + \nabla\cdot(\epsilon_g \rho_g \vec{v}_g \vec{v}_g) = -\epsilon_g \nabla P_g + \nabla\cdot \overline{\overline{\tau}}_g + \sum_{m=1}^{M} F_{gm}(\vec{v}_{sm} - \vec{v}_g) + \epsilon_g \rho_g \vec{g} - \sum_{m=1}^{M} R_{0m}\left[\xi_{0m}\vec{v}_{sm} + \bar{\xi}_{0m}\vec{v}_g\right]$$

Solids momentum balance:

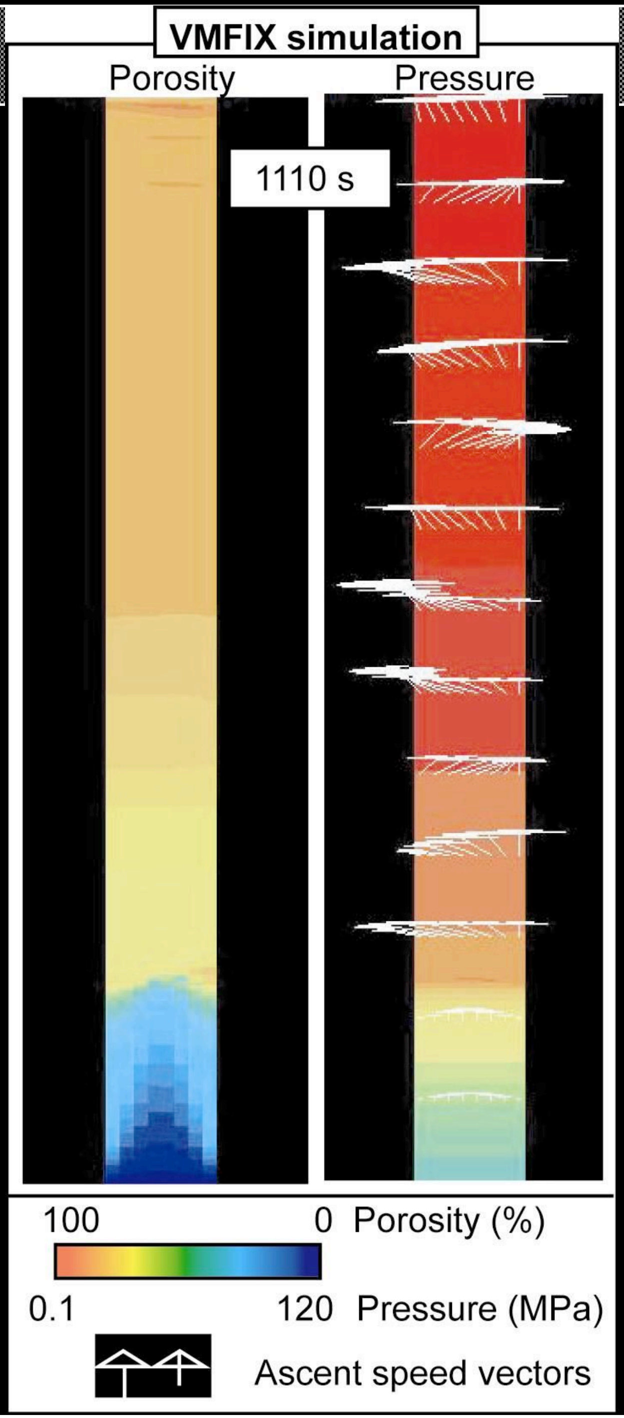
$$\frac{\partial}{\partial t}(\epsilon_{sm} \rho_{sm} \vec{v}_{sm}) + \nabla\cdot(\epsilon_{sm} \rho_{sm} \vec{v}_{sm} \vec{v}_{sm}) = -\epsilon_{sm} \nabla P_g + \nabla\cdot \overline{\overline{S}}_{sm} - F_{gm}(\vec{v}_{sm} - \vec{v}_g) + \sum_{l=1}^{M} F_{slm}(\vec{v}_{sl} - \vec{v}_{sm})$$
$$+ \epsilon_{sm} \rho_{sm} \vec{g} - \sum_{l=0}^{M} R_{ml}\left[\xi_{ml}\vec{v}_{sl} + \bar{\xi}_{ml}\vec{v}_{sm}\right]$$

ECOULEMENT DE CONDUIT

- Croissance des bulles
  à taux contrôlé expérimentalement
  -> Dégazage

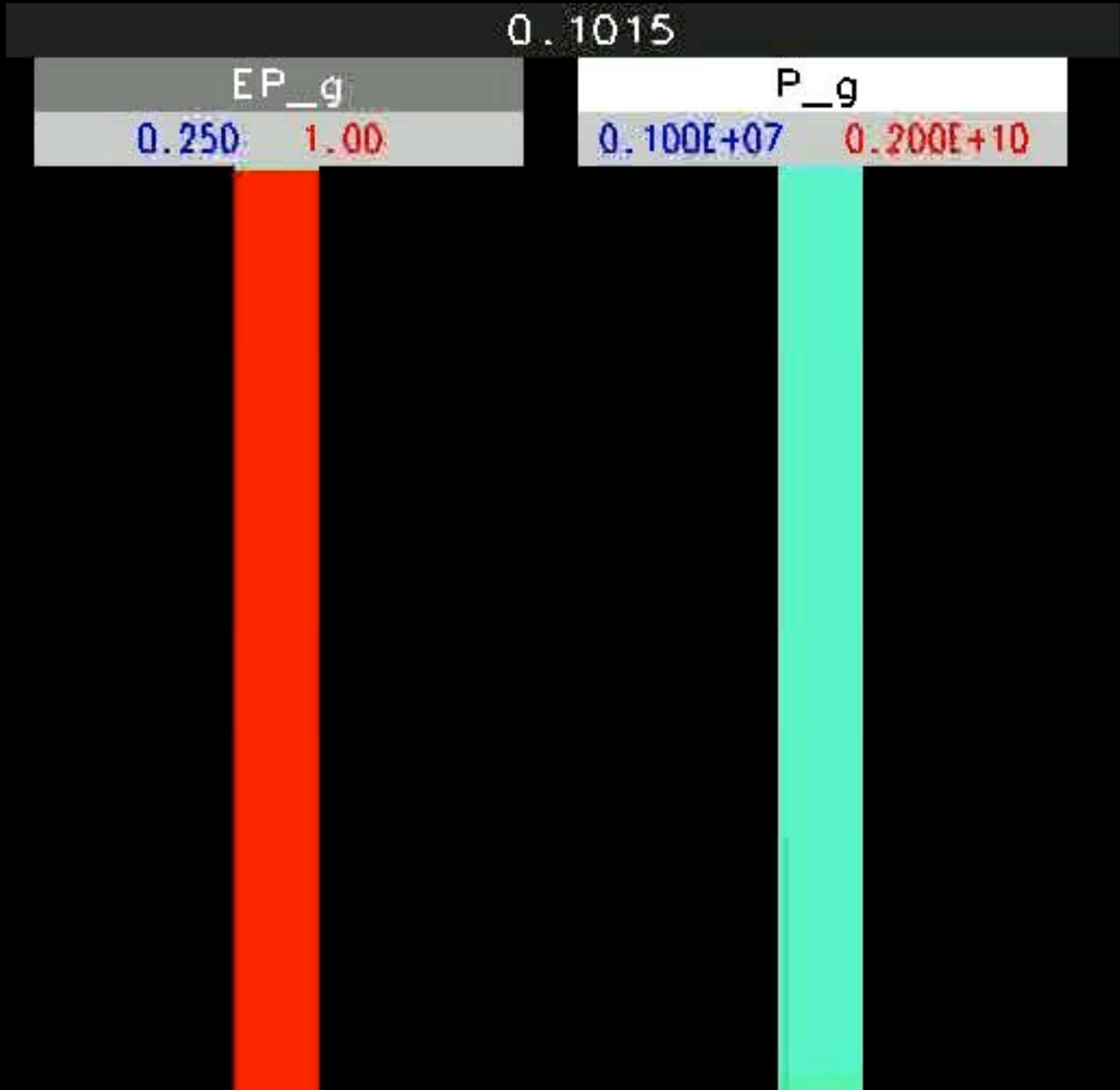
- Nombre variable de bulles
  par cellule
  -> Coalescence

- Entrainement variable
  bulles/liquide
  -> Perméabilité



ECOULEMENT DE CONDUIT

Porosité Pression



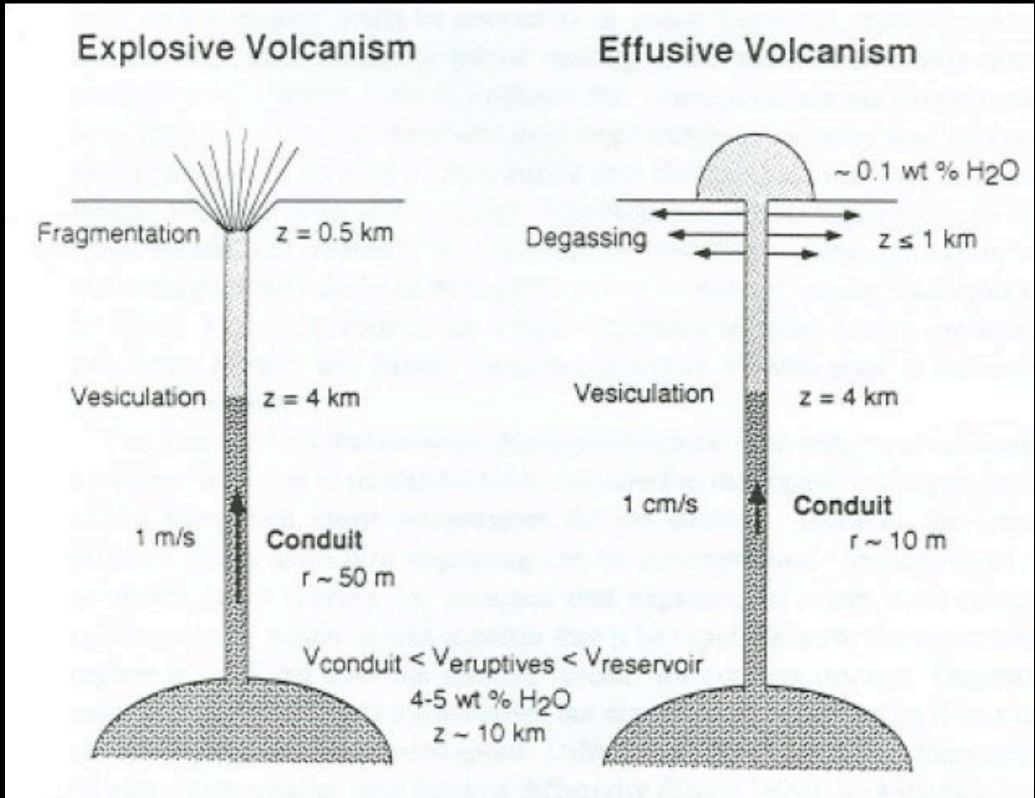
ECOULEMENT DE CONDUIT : LES PROBLEMES

- Taux de décompression irréalistes

- Sous relaxation

PERMEABILITE DU MAGMA

Comment le gaz sort-il des bulles ?



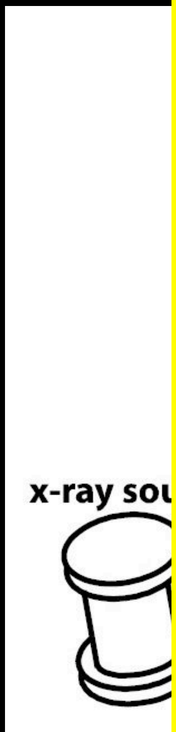
Eichelberger, 1995

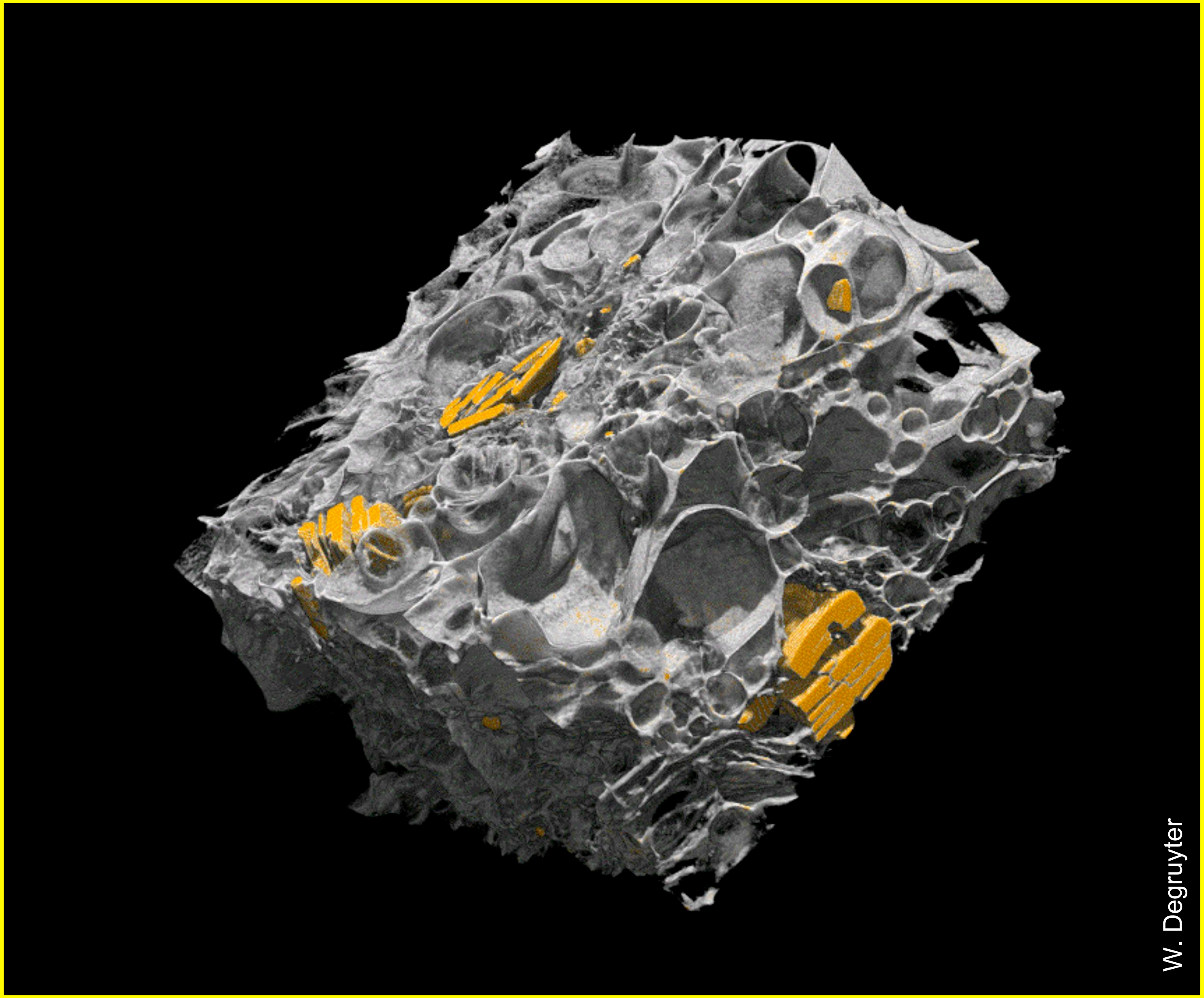
MICROTOMOGRAPHY
METHOD

Acquis

ability
ation

X-ra





voxel

x 1000

800

200

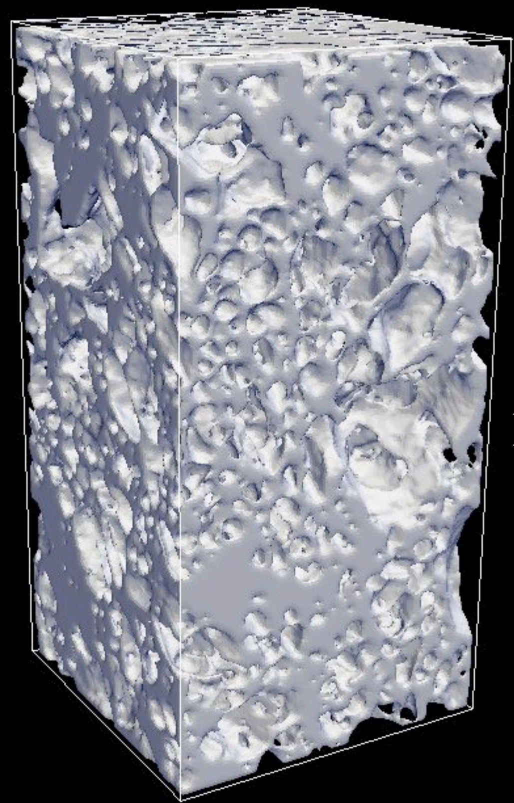
MICROTOMOGRAPHY
THE SAMPLES

Acquisition → Thresholding → Numerical simulation fluid flow ↔ Permeability calculation

Tricks to obtain a good thresholding of a connected network:

1. Use 3D filters to preserve seamless volumes
2. Start by underestimate bubble size, so that walls are preserved
3. Then expand the selection while preserving these walls

Tube Pumice
(4.8 mm high)



Frothy Pumice
(14.4 mm high)

MICROTOMOGRAPHY
THE APPARATUS

Acquisition → Thresholding → Numerical simulation fluid flow ↔ Permeability calculation

1. Seal the four sides
2. Fill the volume with low-viscosity liquid
3. Apply pressure
3. Solve

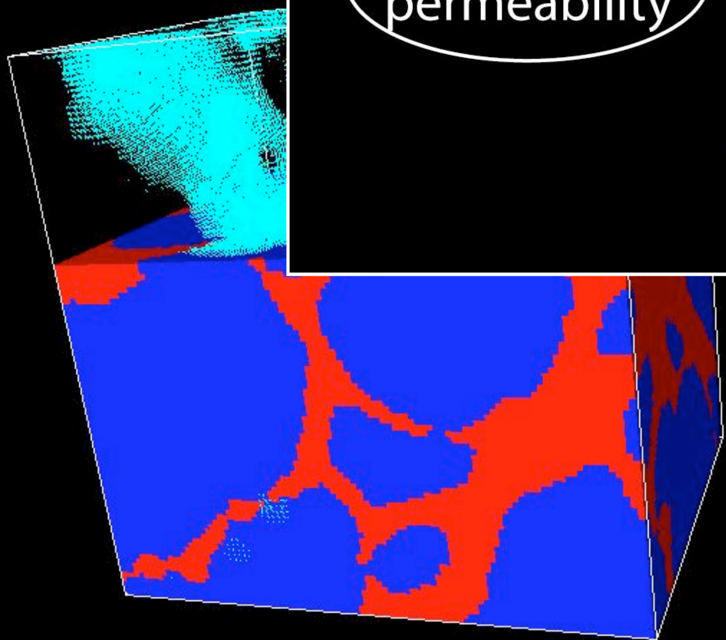
Issues:
Precision of the solution
flow laminar

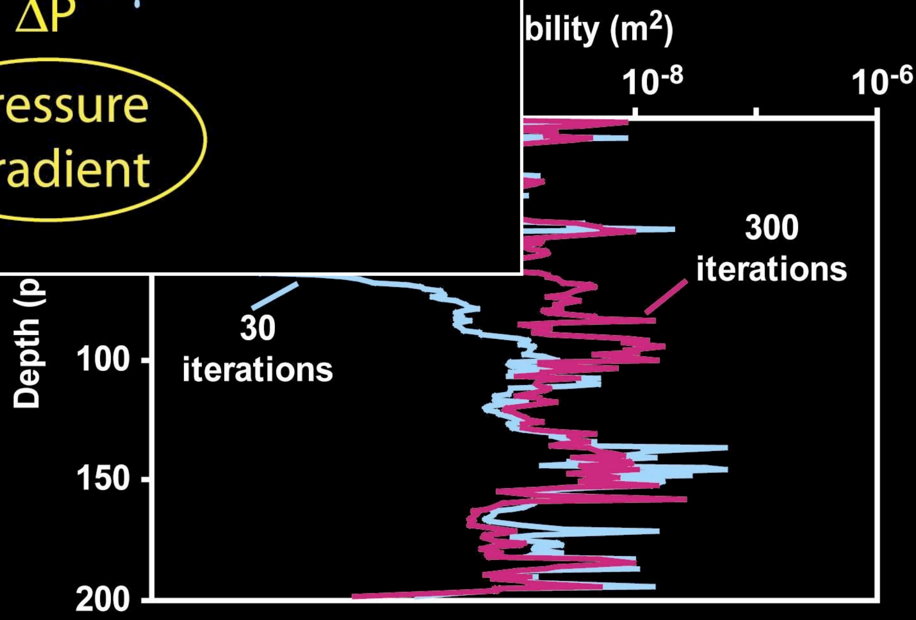
Darcy's permeability

$$k_D = \frac{L}{\Delta P} v \mu$$

Fluid viscosity density

Pressure gradient

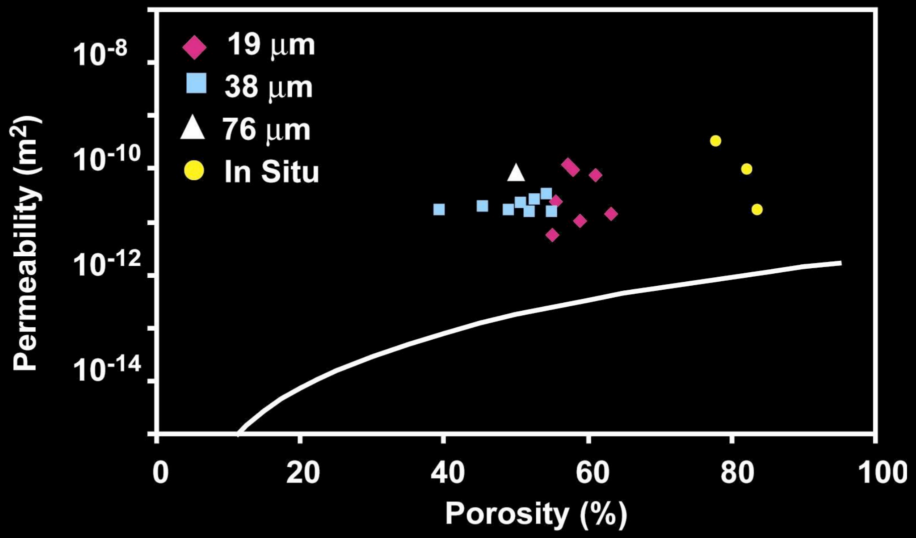




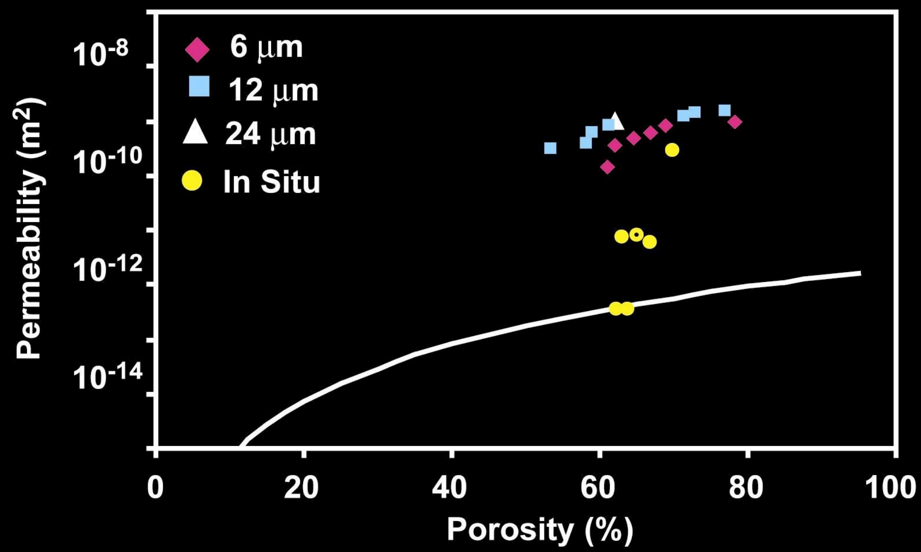
MICROTOMOGRAPHY
RESULTS

Acquisition → Thresholding → Numerical simulation fluid flow ↔ Permeability calculation

Frothy Pumice



Tube Pumice



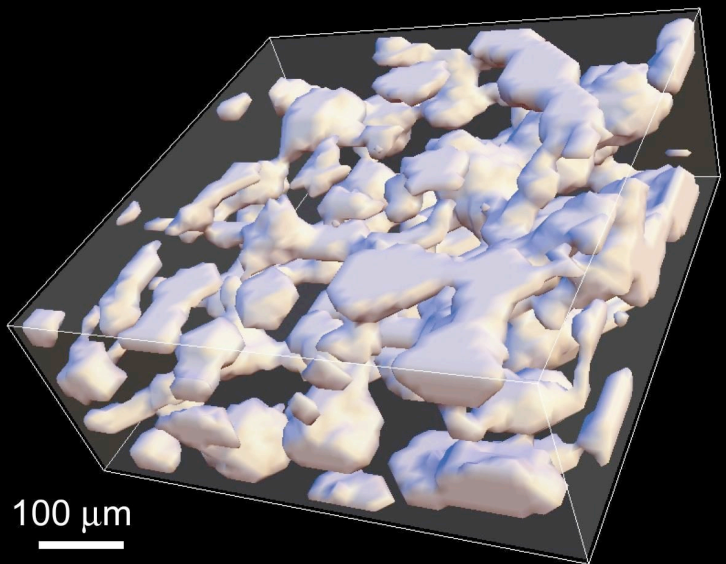
CONCLUSIONS ON TOMOGRAPHY

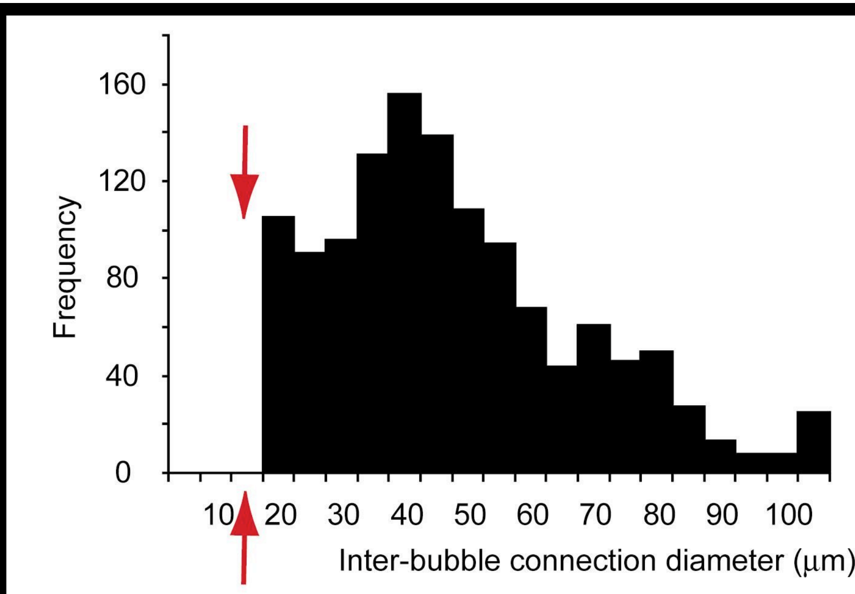
	Strength	Weakness
In situ	Large samples High precision (2%)	Small samples
Tomography	Small samples	Resolution of connections

Complementarity

Use in-situ to calibrate thresholding,
use resulting volume for 3D morphology measurements

Use tomography for small samples (experimental products)





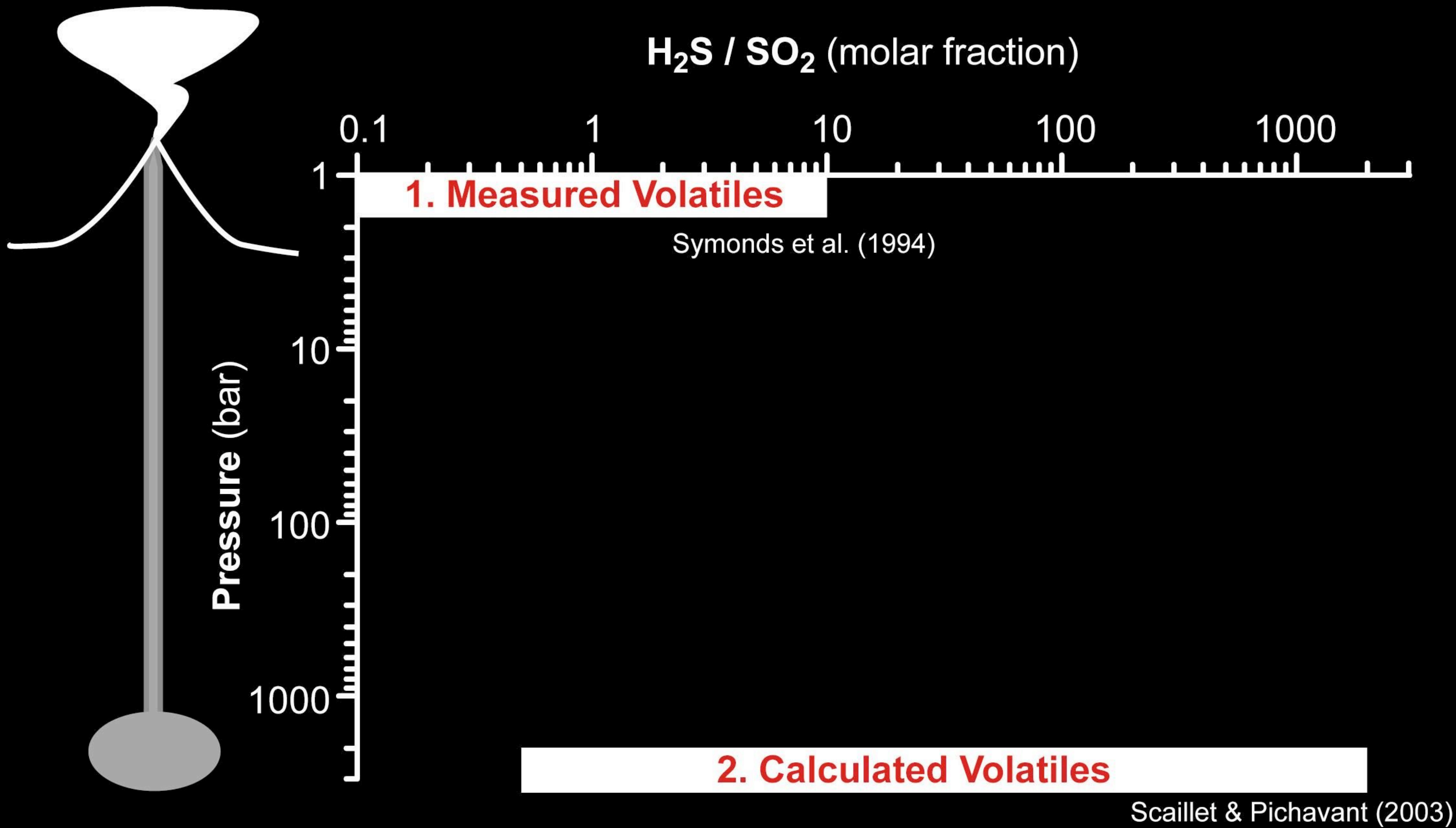
MODELISER LA CHIMIE DU DEGAZAGE

La chimie des gaz change durant une éruption

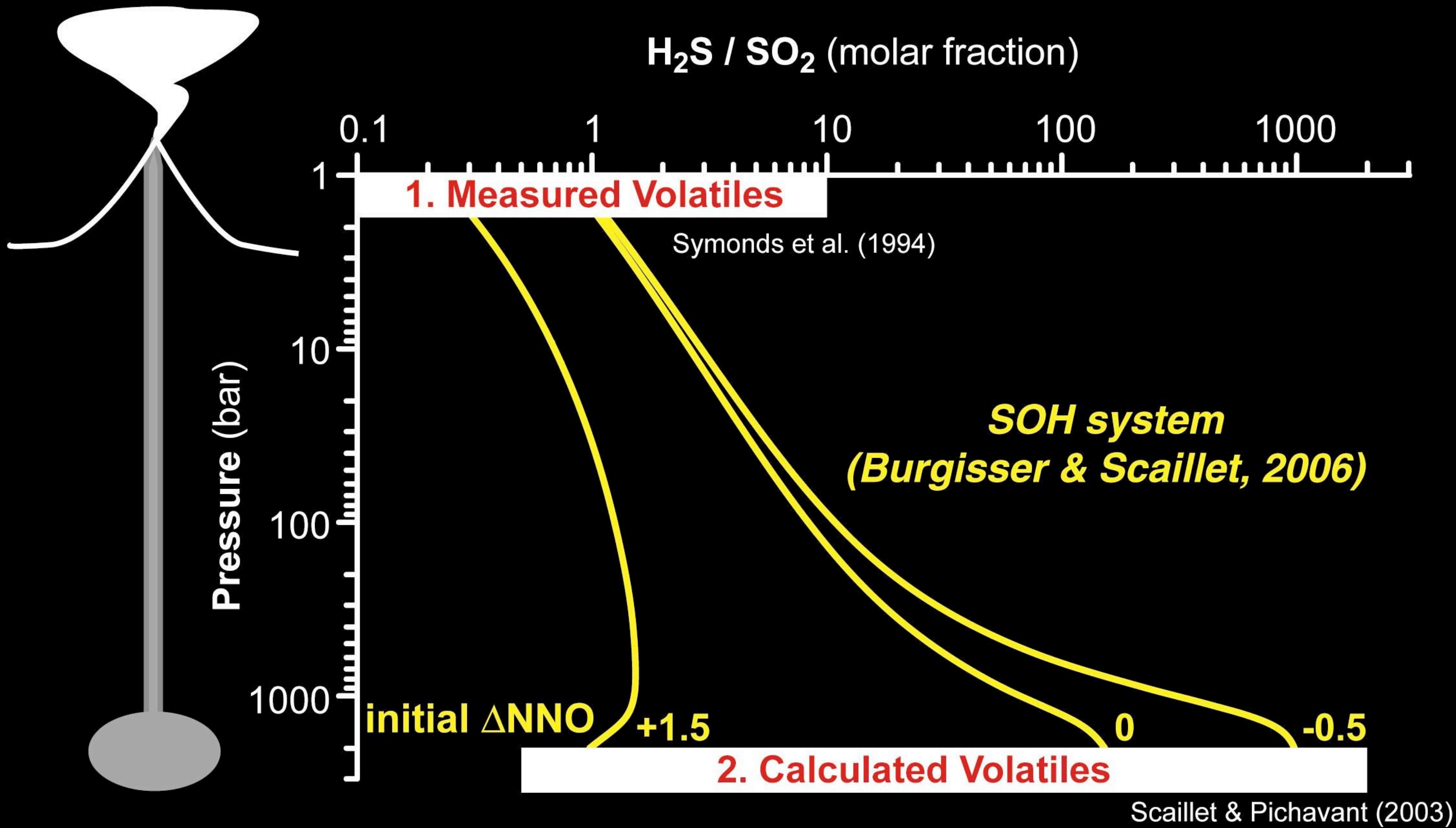
M. Coombs

Que signifient ces changements ?

LINK BETWEEN DEPTH AND SURFACE



LINK BETWEEN DEPTH AND SURFACE



MODELLING THE C-O-H-S SYSTEM

Chemical equi
balance in the g

PHYSICAL MODEL

The conduit flow model is homogenous and 1D. From mass and momentum conservation, the pressure evolution with depth is given by:

$$dP/dz = v^2 \, d\rho/dz - \rho g - f(\mu)$$

$$\mu = \text{fct}(f\, H_2O)$$

$$\rho = \text{fct}(H_2O, H_2, O_2, S_2, SO_2, H_2S, CO, CO_2, CH_4)$$

v : magma velocity
ρ : magma density
g : gravity
f (μ) : friction factor = $8\mu/r^2 + 0.0025\, \rho v^2/r$
r : conduit radius
μ : viscosity magma, melt (Hess & Dingwell, 1996)
bubbles (Dobran, 1992)
viscosity dusty gas (Dobran, 1992)
(above fragmentation, porosity>75%)

$+ a_i(\gamma_i m_i P)^{b_i}$

Mass balance

$$\frac{W_{TH}}{2M_H} = \frac{W_{TH_2O}}{M_{H_2O}} + \frac{W_{TH_2S}}{M_{H_2S}} + \frac{W_{TH_2}}{M_{H_2}} + 2\frac{W_{TCH_4}}{M_{CH_4}}$$

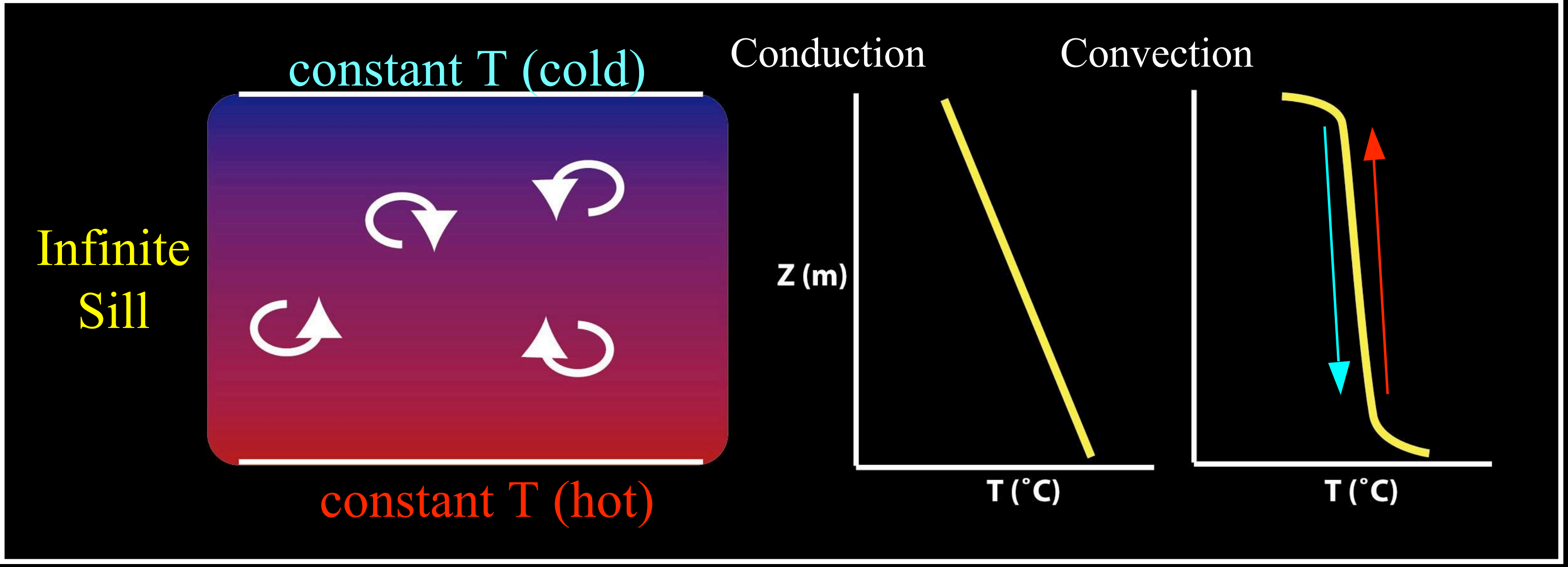
CHIMIE DU DEGAZAGE : LE PROBLEME

- Chiffres significatifs

CONVECTION OF FLUID + PARTICLES

A S S U M P T I O N S

Modeling of independent motions of fluid and crystals
Changes in temperature influence *only* the fluid density



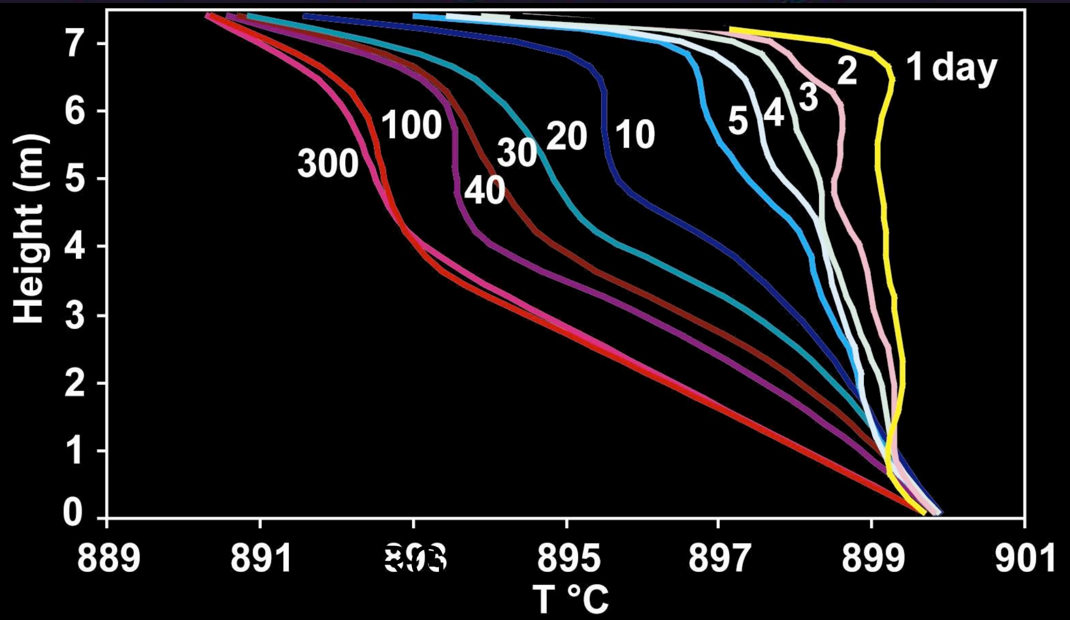
A S S E S S E M E N T

Heating vs. Cooling
Heat transfer conduction vs. Heat tranfer convection
Convection cells

SILL COOLED FROM ABOVE

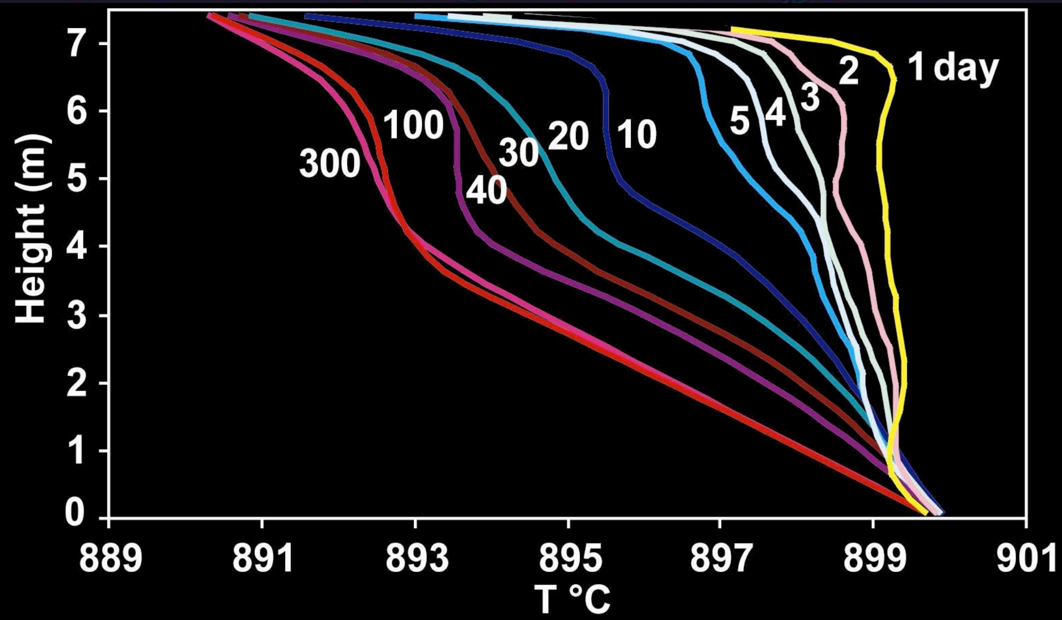
30 vol.% crystal

Temperature distribution

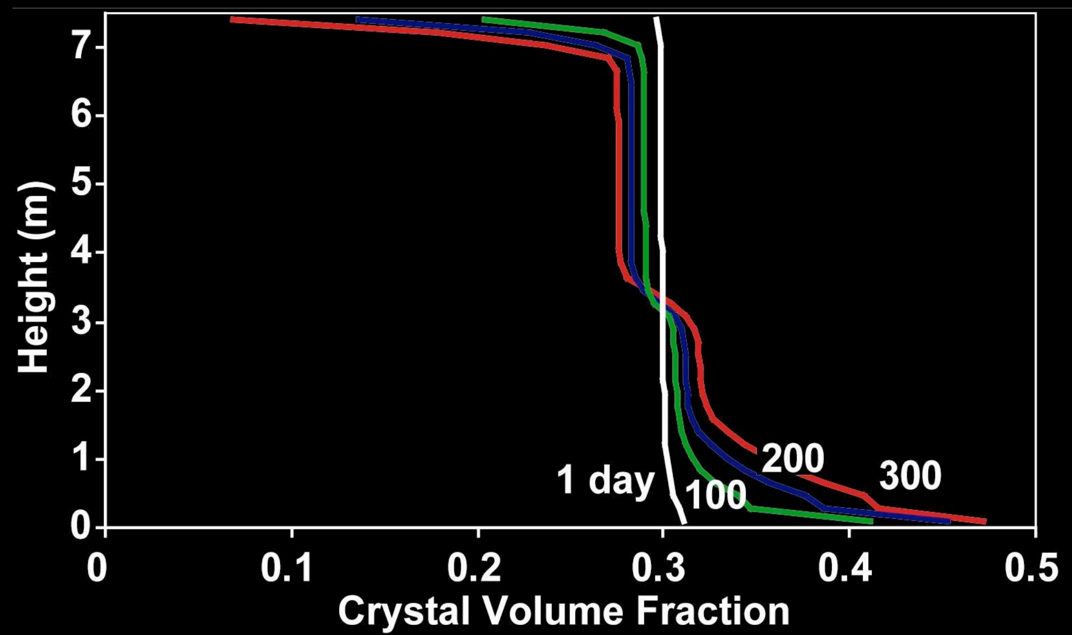


SILL COOLED FROM ABOVE

Temperature distribution



Crystal distribution



INITIATION OF CONVECTION

1. Sill cooled from above

Days

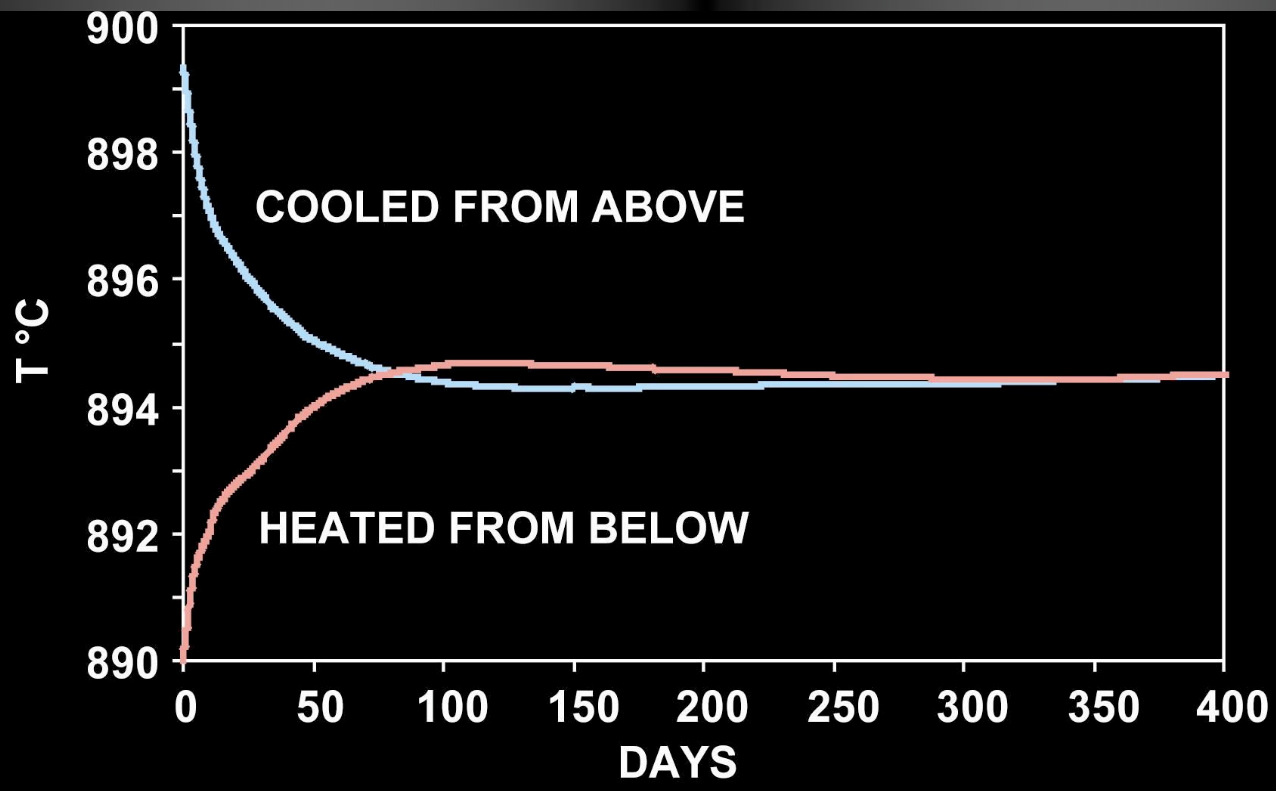
Temperature

Liquid volume fraction

7.5 m height
Liquid viscosity 144 Pa s
30 vol.% crystals

T_{top} = 890 °C
T_{base} = 900 °C

CONVECTION WITH CRYSTALS : ALMOST SYMMETRIC



Steady state: 100 days

Characteristic Times — Crystal gradient: 200-300 days

Plume travel: 2 days

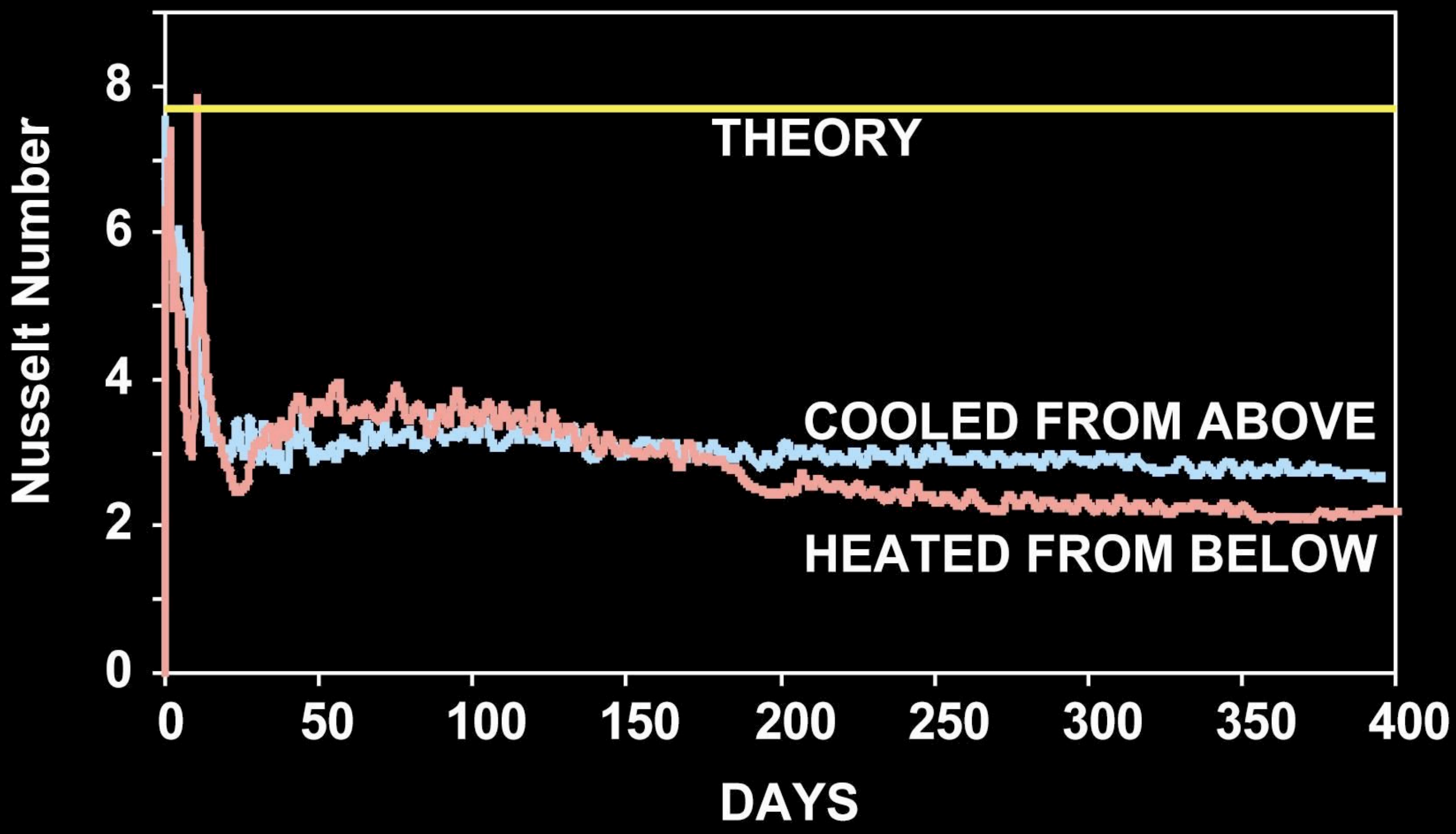
HEAT TRANSFER

$Q_{conduction}$ $(W/m^2) = k\ \Delta T/\Delta x$

$Q_{convection}$ $(W/m^2) = H\ \Delta T$

Nusselt number

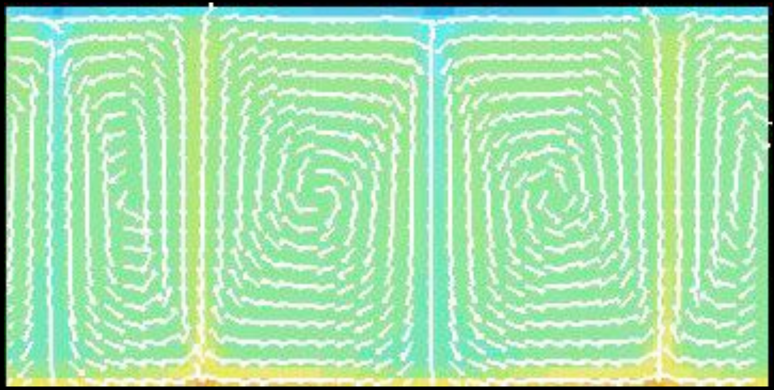
$$Nu = \frac{\text{heat flux convection}}{\text{heat flux conduction}}$$



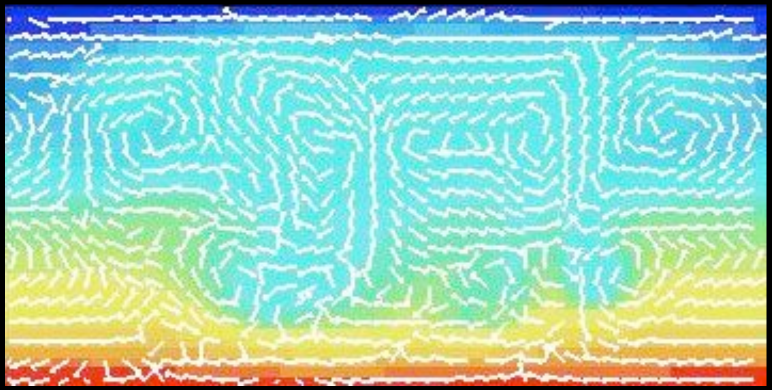
CONVECTION CELLS

ΔT = 10 °C, H = 7.5 m

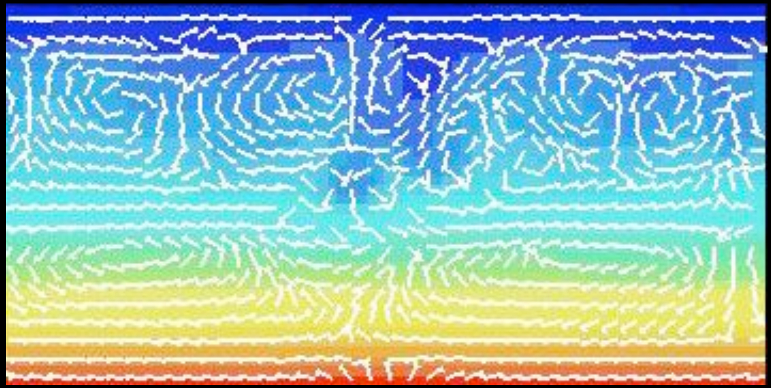
5 vol.% crystals



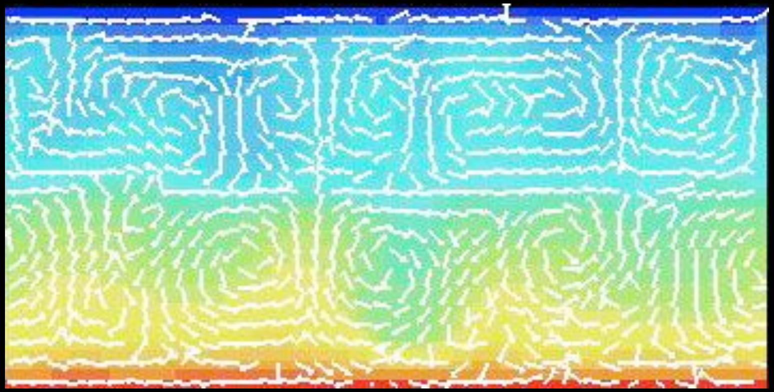
10 vol.% crystals



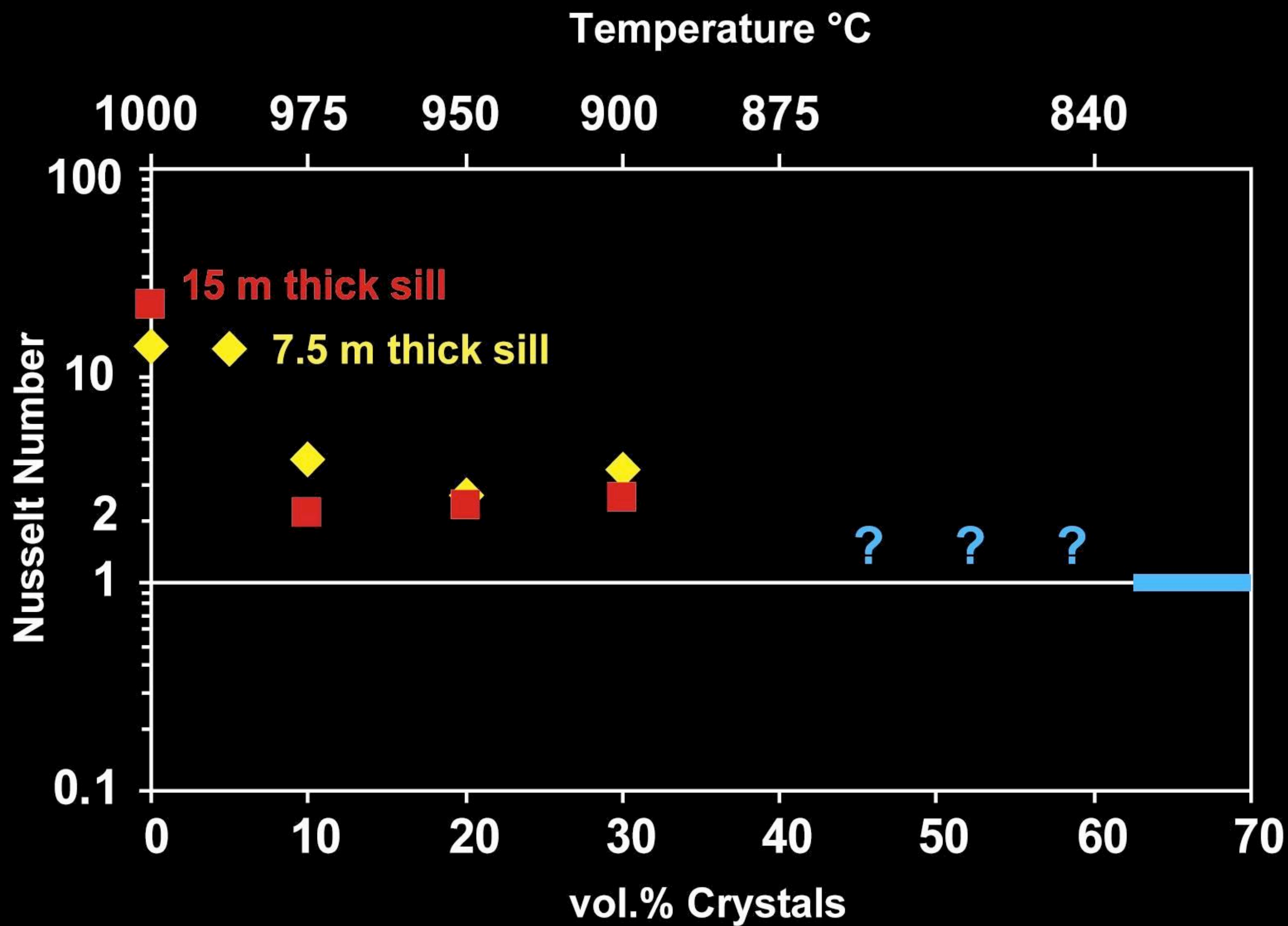
20 vol.% crystals



30 vol.% crystals



HEAT TRANSFER



CONVECTION MAGMATIQUE : LES PROBLEMES

1. Taille de cellule ~30 cm

2. Pas de temps : 1 semaine sans cristaux
   1 minute avec cristaux

3. >45% cristaux : blocage général

CONVECTION MAGMATIQUE : LE MODELE

Gas continuity:

$$\frac{\partial}{\partial t}(\epsilon_g \rho_g) + \nabla \cdot (\epsilon_g \rho_g \vec{v}_g) = \sum_{n=1}^{N_g} R_{gn}$$

Solids continuity:

$$\frac{\partial}{\partial t}(\epsilon_{sm} \rho_{sm}) + \nabla \cdot (\epsilon_{sm} \rho_{sm} \vec{v}_{sm}) = \sum_{n=1}^{N_{sm}} R_{smn}$$

Gas momentum balance:

$$\frac{\partial}{\partial t}(\epsilon_g \rho_g \vec{v}_g) + \nabla \cdot (\epsilon_g \rho_g \vec{v}_g \vec{v}_g) = -\epsilon_g \nabla P_g + \nabla \cdot \overline{\overline{\tau}}_g + \sum_{m=1}^{M} F_{gm}(\vec{v}_{sm} - \vec{v}_g) + \epsilon_g \rho_g \vec{g} - \sum_{m=1}^{M} R_{0m}\left[\xi_{0m}\vec{v}_{sm} + \overline{\xi}_{0m}\vec{v}_g\right]$$

Solids momentum balance:

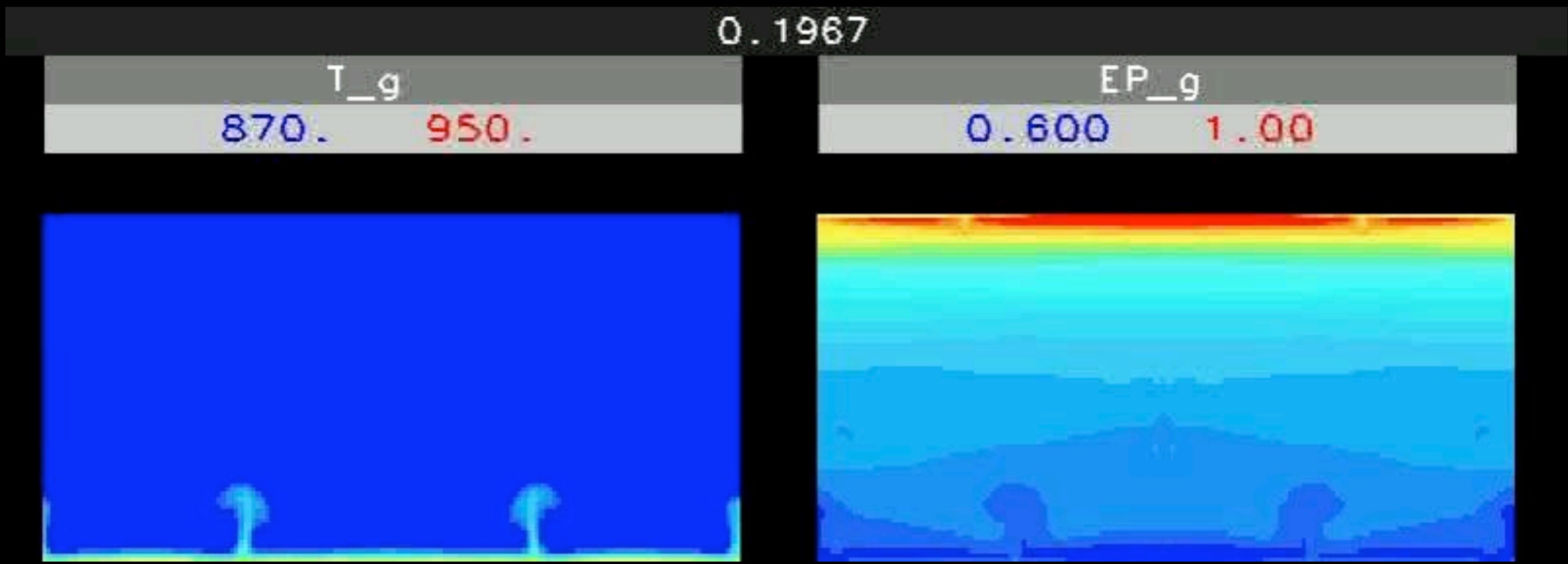
$$\frac{\partial}{\partial t}(\epsilon_{sm} \rho_{sm} \vec{v}_{sm}) + \nabla \cdot (\epsilon_{sm} \rho_{sm} \vec{v}_{sm} \vec{v}_{sm}) = -\epsilon_{sm} \nabla P_g + \nabla \cdot \overline{\overline{S}}_{sm} - F_{gm}(\vec{v}_{sm} - \vec{v}_g) + \sum_{l=1}^{M} F_{slm}(\vec{v}_{sl} - \vec{v}_{sm})$$

$$+ \epsilon_{sm} \rho_{sm} \vec{g} - \sum_{l=0}^{M} R_{ml}\left[\xi_{ml}\vec{v}_{sl} + \overline{\xi}_{ml}\vec{v}_{sm}\right]$$

CONVECTION CELLS

Convection can appear in the most crystalline part...

Days



Temperature

Liquid volume fraction

7.5 m height
Liquid viscosity 144 Pa s
Crystal concentration gradient

T_{top} = 870 °C
T_{base} = 950 °C
Heated from below

CONVECTION MAGMATIQUE : PERSPECTIVES

1. S'approcher du seuil rhéologique

2. Etablir une carte des comportements convectifs

3. Etablir les temps caractéristiques
   – pour atteindre l'état d'équilibre
   – pour le transport de cristaux par des instabilités

CONCLUSION : CE N’EST PAS DE LA SIMULATION !

A. Burgisser