Experimental approach to constrain phreatic eruption processes on White Island, New Zealand

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Introduction

White Island is New Zealand's most active volcano and primarily characterised by phreatic and phreatomagmatic eruptions. A phreatic eruption on August 2nd, 2012 ended an eleven year quiescence. More than 100 years of intense hydrothermal activity from magmatic fluids and groundwater has created a weak and unstable volcanic edifice highly susceptible to sector collapses and landslides. This study is an experimental approach to constrain phreatic eruption processes under various conditions. Furthermore, we analyze rock mechanical properties of a set of samples subjected to an active hydrothermal system and link these properties to the fragmentation behaviour.

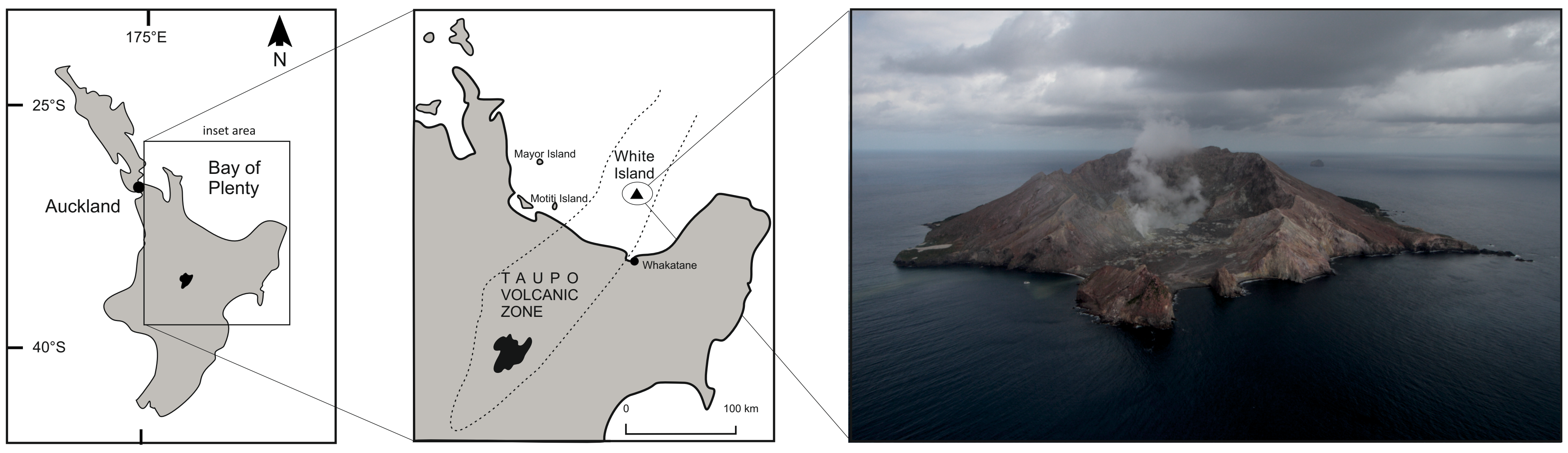


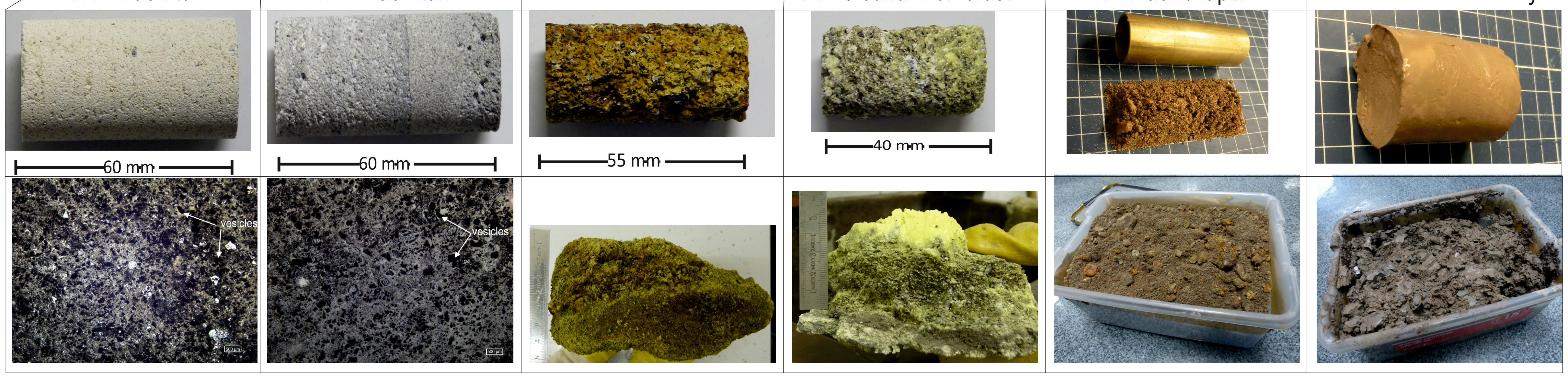
Fig. 1: Location map showing White Island approx. 50 km offshore in the Bay of Plenty, New Zealand. (Photo taken by B. Scheu 2010)

Sample characterisation

Two ash tuffs with different grades of alteration, sulfur-rich and iron-rich crusts from the surface of a fumarole field and a stream bed channel, as well as ash/lapilli from the crater floor and clay from the Donald Duck explosion crater were sampled and investigated to constrain the conditions for phreatic eruptions.

The geochemical analysis (XRF and XRD) showed, that the ash tuffs do not preserve any primary minerals or glass but are entirely altered. They contain high proportions of amorphous silica, alunite, kaolinite and other minerals, typical for hydrothermal alteration as well as high sulfur contents.
In addition some rock mechanical parameters have been determined at EOST (University of Strasbourg). By using an uniaxial compression apparatus, stress, axial strain, and the output of acoustic emission energy during experimentation could be measured under a variety of loading and under dry and wet environmental conditions.
The altered and heterogeneous ash tuffs are less permeable, slightly stronger, even though more porous than the crusts. Ash/lapilli and the volcanic clay have the highest, respectively lowest permeabilty of all investigated samples.

Density [g/cm³]	2.31	2.18	2.71	1.97	2.50	2.68
Porosity (open) [%]	31.86	46.78	22.19	28.19	34.86	26.13
Permeability [m²]	2.76×10^{-15}	3.14×10^{-14}	2.84×10^{-12}	1.05×10^{-12}	3.36×10^{-12}	8.71×10^{-20}
UCS [MPa]	11.04	5.97	6.50	1.93	n.m.	n.m.
	WI 21 ash tuff	WI 22 ash tuff	WI 25 iron-rich crust	WI 26 sulfur-rich crust	WI 27 ash / lapilli	WI 27 volcanic clay



Phreatic eruptions experiments

Methods

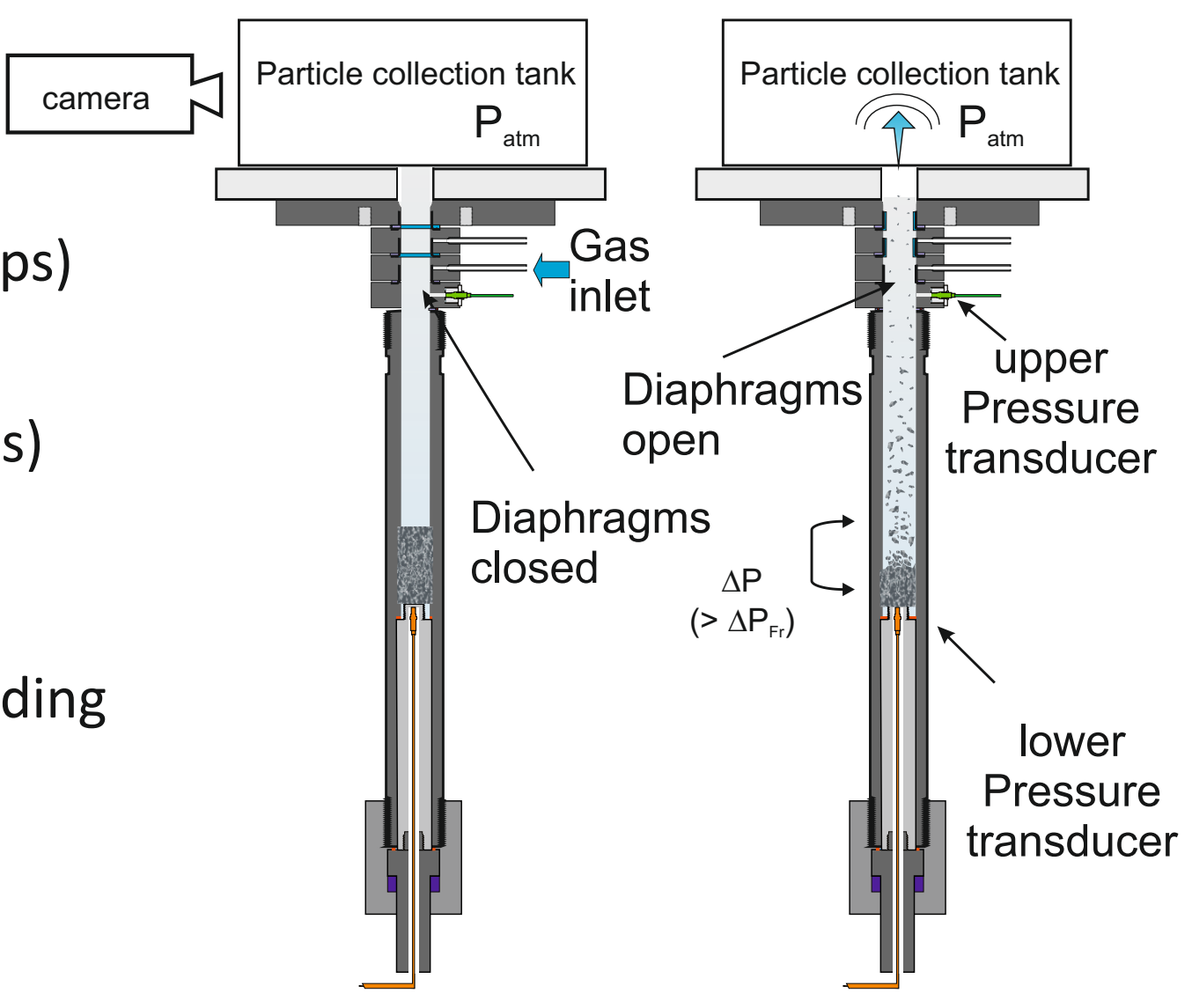
Fragmentation experiments performed in a shock tube apparatus (fragmentation bomb):

(1) large ambient pressure steel tank with plexiglass extension for filming
→ enables collection of fragmented samples

(2) system of two diaphragms
→ allows precise decompression of autoclave

(3) Nimonic pressure vessel (autoclave)
→ possible pressure range: 1 - 50 MPa

(4) external furnace around autoclave
→ heating of the system up to 900°C



Sensors and monitoring:

- high speed camera recording (10000 fps) of particle ejection
- dynamic pressure recording (10000 fps) above and below sample during fragmentation
- static pressure and temperature recording during entire experiment

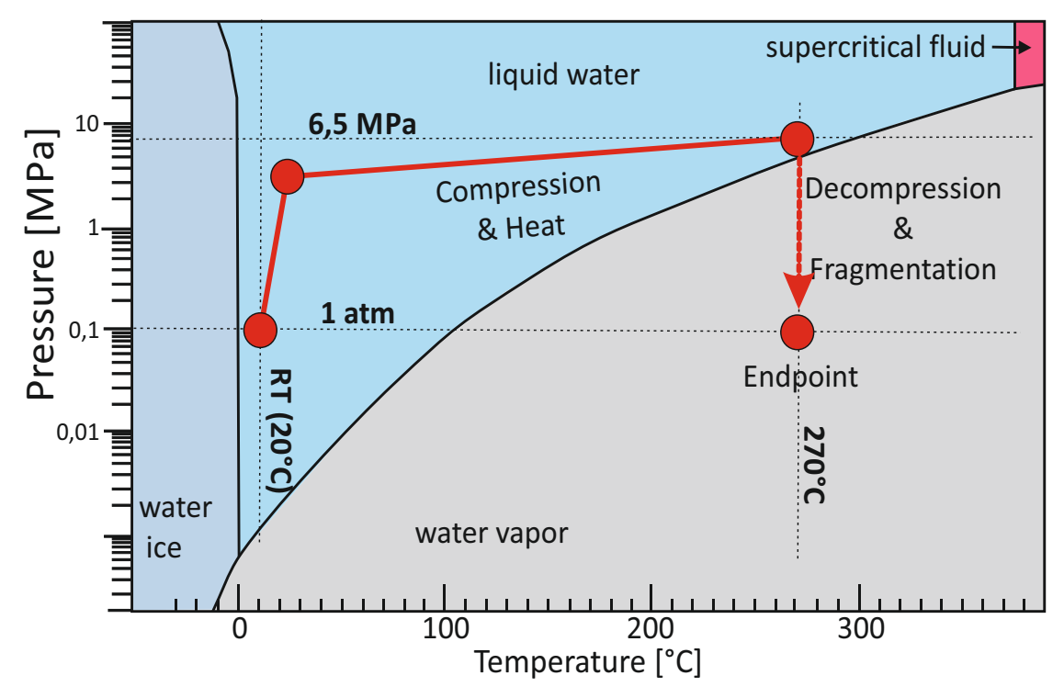
Experimental sequence:

→ diaphragm failure initiates rapid decompression

→ shock wave traveling upwards into the ambient pressure tank and rarefaction wave propagating downwards to the sample

→ crossing of the phase transition from superheated liquid water to water vapor in water saturated sample

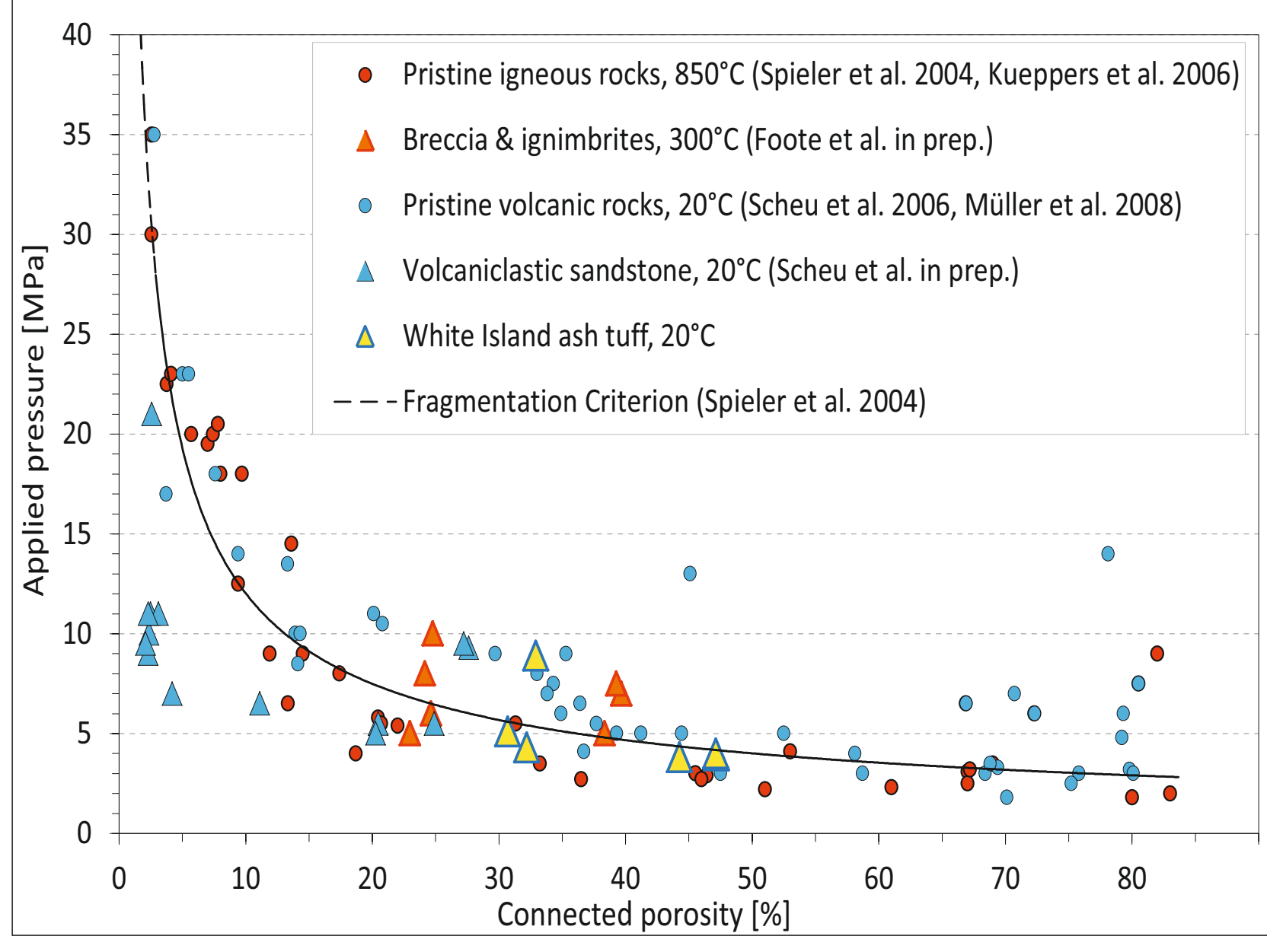
→ brittle fragmentation of sample in a layer-by-layer fashion



Experimental P-T path for both dry and water saturated (sat) samples

Fragmentation threshold

The fragmentation threshold is the minimum pressure difference leading to complete fragmentation of the pressurized porous rock.



Results of fragmentation threshold experiments with dry ash tuffs at 20°C

- Fragmentation threshold highly dependent on porosity
- White Island ash tuff follow the common trend of igneous and sedimentary rocks
- scattering due to sample heterogenity and permeability effects

Fragmentation speed

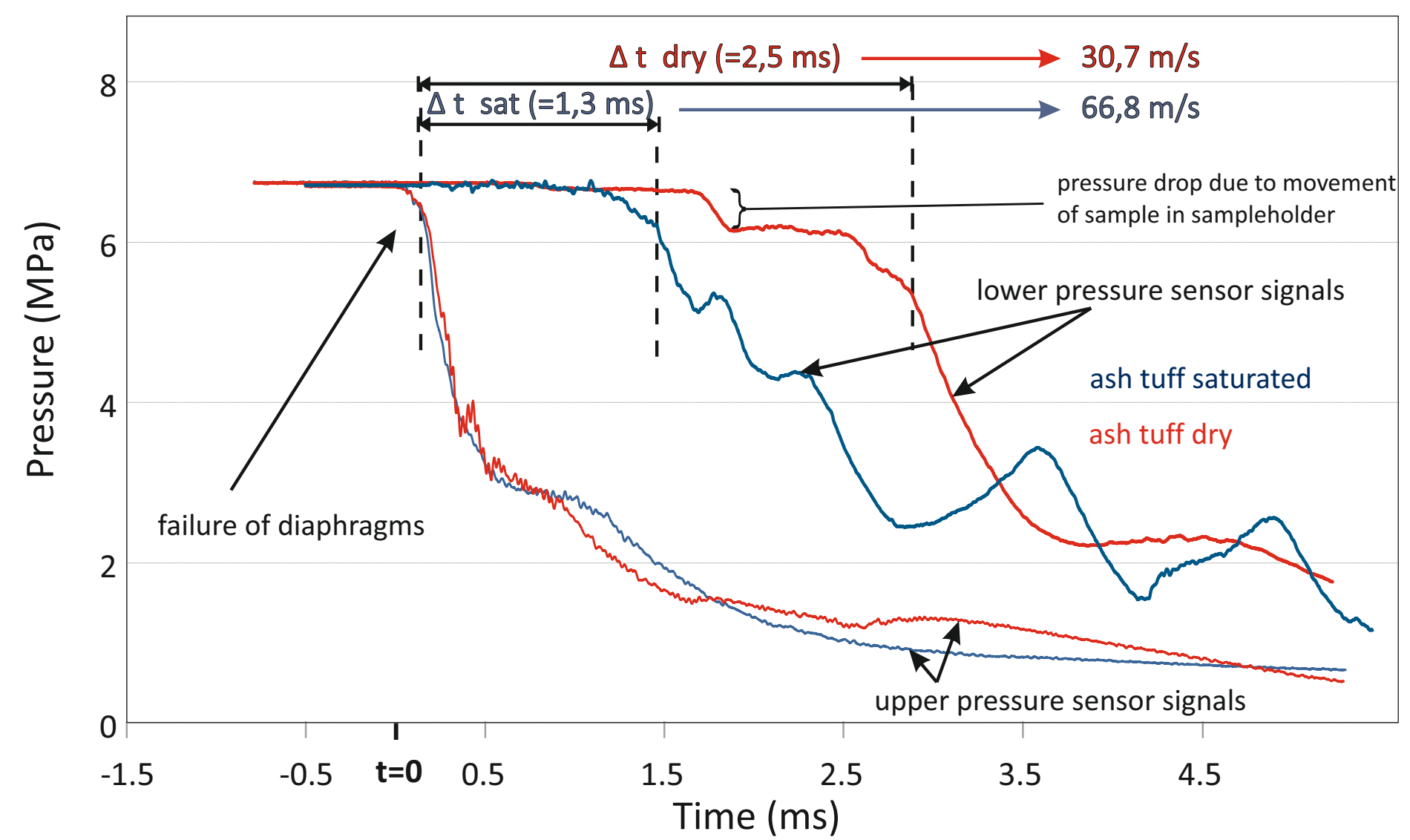
- speed of fragmentation front propagating through the sample

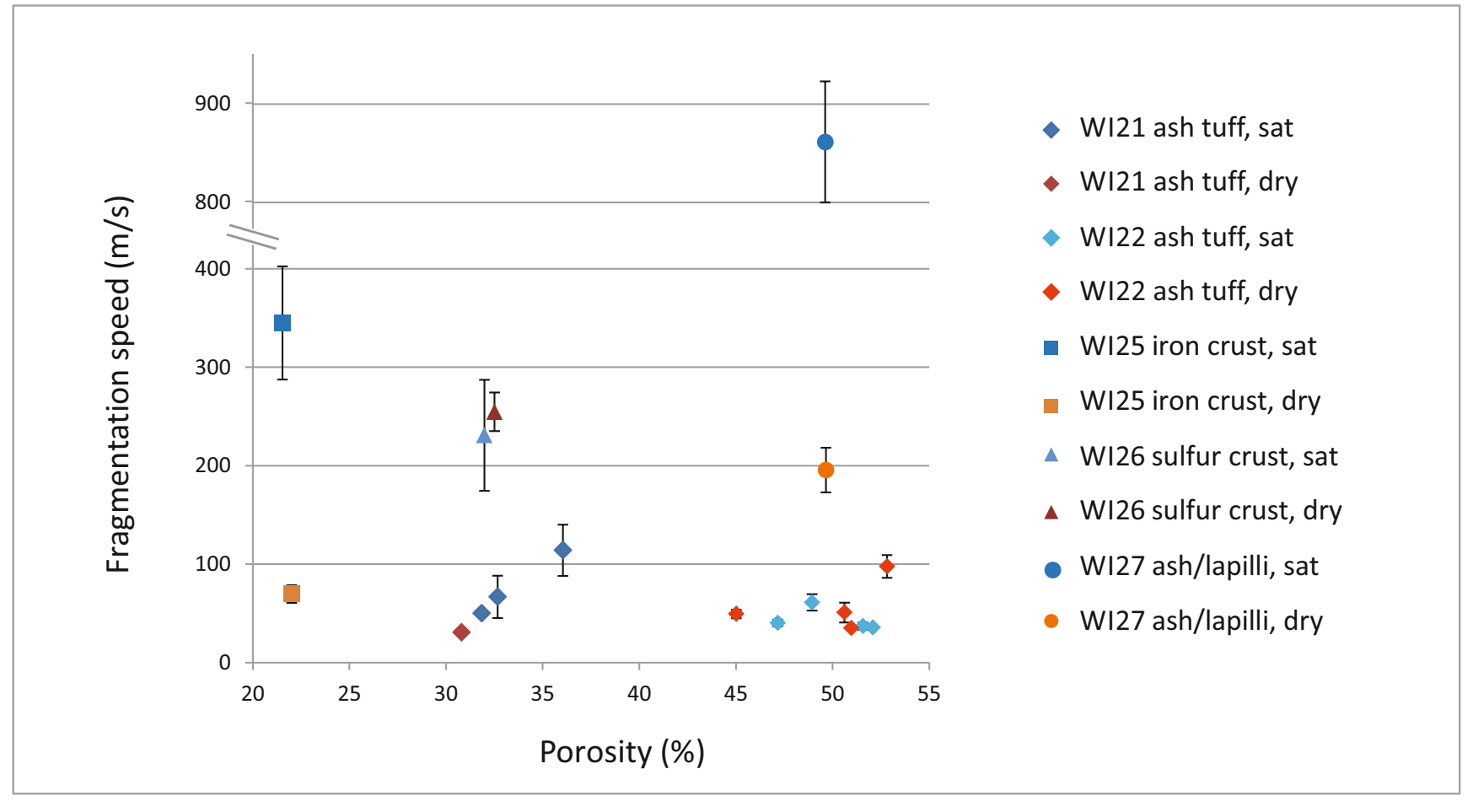
$$\text{Frag. speed} = \frac{\text{distance between the dynamic pressure transducers}}{\text{time delay } \Delta t \text{ of the pressure drops}}$$

- drop of upper sensor immediately after opening of diaphragm
- drop of lower sensor indicates complete fragmentation of sample

Note: upper pressure sensor is 226 mm above the top of the sample (due to the temperature stability)

→ correction for time delay neccessary





Fragmentation speed of dry and saturated samples at 270°C and 6.5 MPa

- saturation increases the fragmentation speed of WI21 ash tuffs and iron crusts
- no clear trend with high porous ash tuffs
- no difference with sulfur crusts (within error) as sample is mainly molten at experimental condition
- substantial increase in unloading speed with loose ash / lapilli sample

Results / Implications

- Samples with higher porosity fragment at lower initial pore pressure – following the trend observed for pristine volcanic rocks.
- Higher initial pressure as well as water saturation of samples leads to an increased production of fines and thus a higher fragmentation efficiency than for dry samples.
- The ejection velocity of particles increases with applied pressure and porosity as well as water saturation of samples.

→ characterisation of fragmentation behaviour of magmatic (dry) with phreatic (saturated) explosions to better constrain their hazard potential

→at White Island phreatic eruptions are likely to involve high amounts of unconsolidated material → high ejection speeds and large distribution of ejecta

Ongoing work

- steam driven fragmentation experiment (without argon gas)
- investigation of grain shape and comparison of grain size distribution with initial clast sizes of sample
- investigation of changes on mineralogy due to pressurisation & heating

References
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Ejection behaviour

Fragmentation of dry samples:

- energy release due to expansion of pressurized gas in the vesicles

Fragmentation of water saturated samples:

- energy release due to transition from superheated liquid water to vapour and expansion of vapour phase

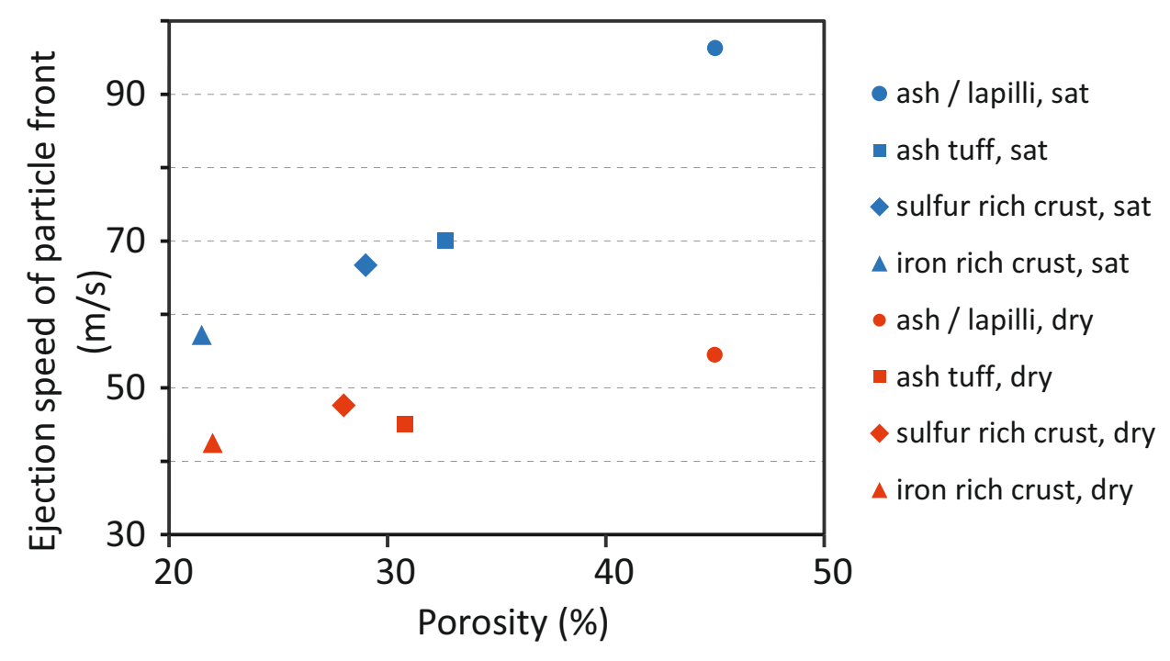
→ increased explosivity of fragmentation leads to higher sample ejection speed

Parameters analysed with high-speed camera:

- maximum ejection speed of particles
- ejection speed of particle front
- temporal decrease of particle speed

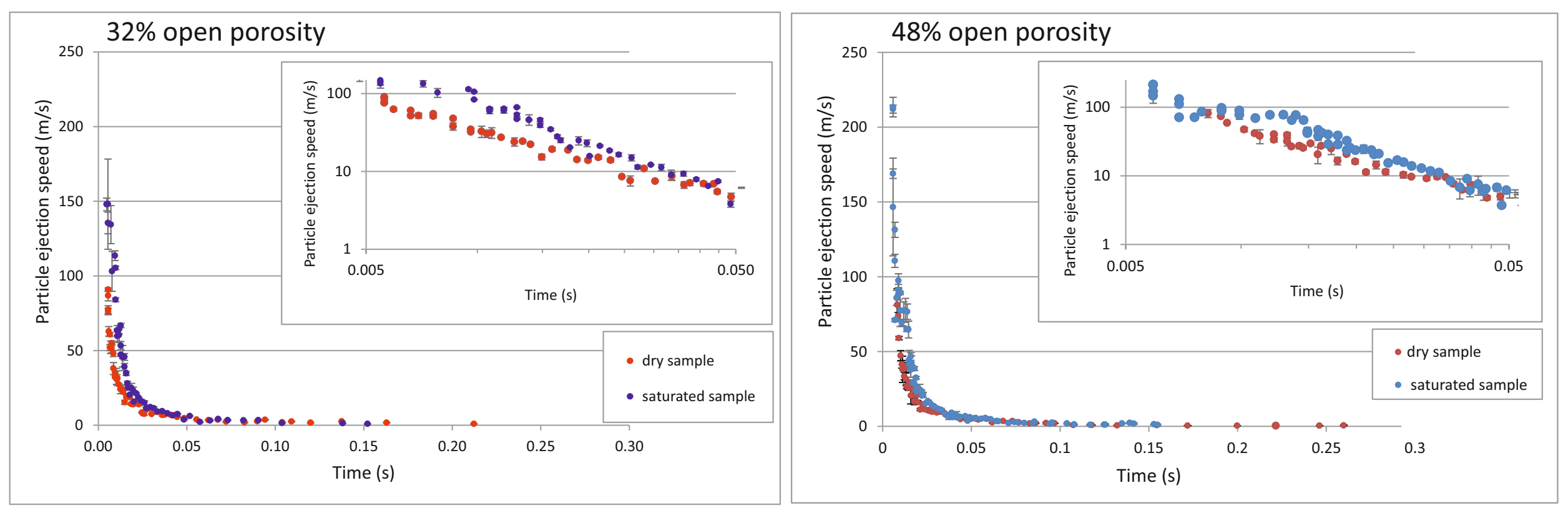
Ejection speed of particle front

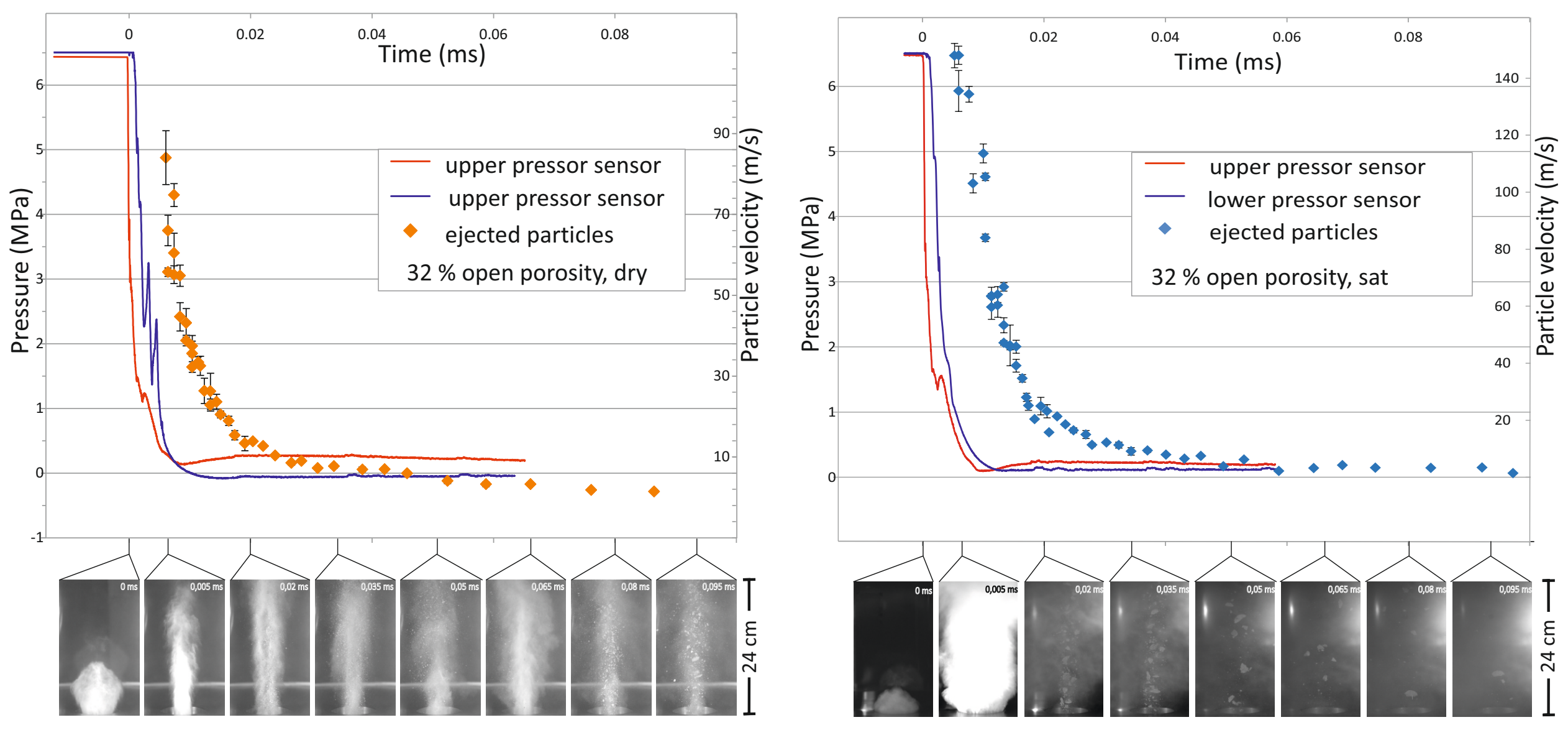
- speed increases with porosity
- speed increases with water saturation



Ejection speed and temporal decrease

Ejection behaviour of dry and saturated samples of different porosity





Fragmentation efficiency

Sieving of recollected particles at half-Φ steps
(Φ =log2d with d =particle diameter in mm)

- clear shift to more fines with saturation
- increase of energy conversion involved in phreatic eruptions due to steam flashing
- strength reduction of samples caused by water weakening effect
- saturation causes a greater grain size distribution