Models and experimental investigations of volcanic ash aggregation

Shinmoedake peak January 27, 2011 (REUTERS/Kyodo).

Steve Lane Jennie Gilbert Mike James

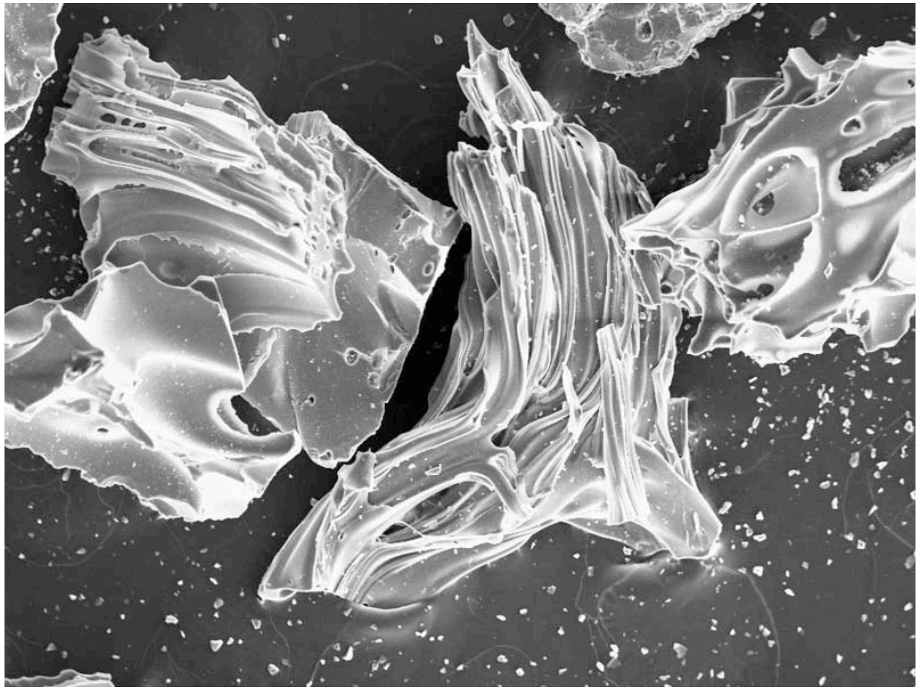
Lancaster Environment Centre
LANCASTER UNIVERSITY

2nd IUGG-WMO workshop on ash dispersal forecast and civil aviation

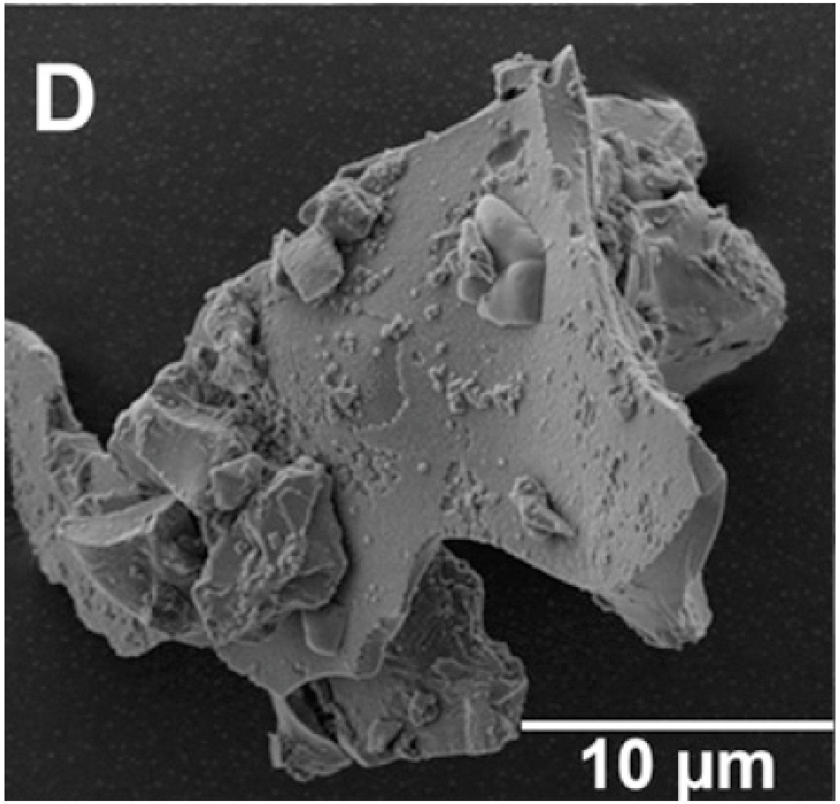
s.lane@lancaster.ac.uk

Volcanic ash

Pieces of rock
- ~ 2mm > *d* > 1 μm (smaller?)
- magma fragmentation
- large pressure/shear gradient in bubbly liquid rock
- comminution
- brittle failure



Volcanic ash shards from Mt Erebus, Antarctica
http://geoinfo.nmt.edu/labs/microprobe/description/sem.html
0.4 mm across frame

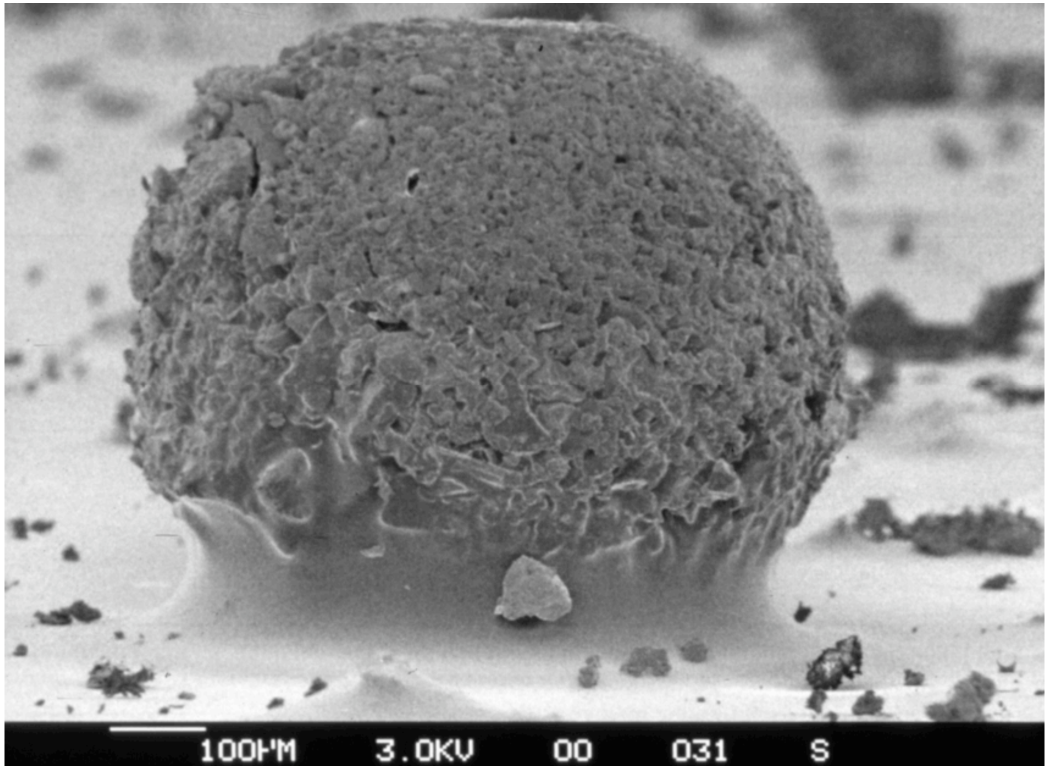


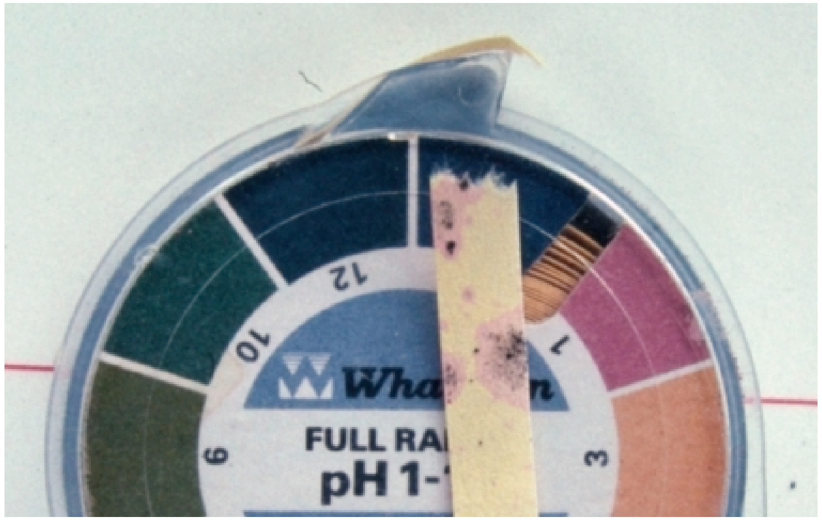
Eyjafjallajökull
Gislason et al., 2011
10.1073/pnas.1015053108

Evidence for aggregation: proximal (4 km) fallout

3-phase pellet

- liquid phase
  - chemically reactive
  - hygroscopic
- solid phase
  - < 100 μm
- gas phase
  - surface tension bridges





Physically preserved in the geological record

Sakurajima 1991

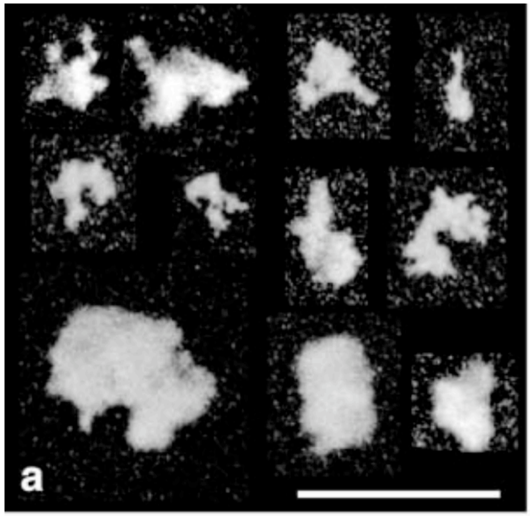
Evidence for aggregation: proximal (4 km) fallout

2-phase aggregate

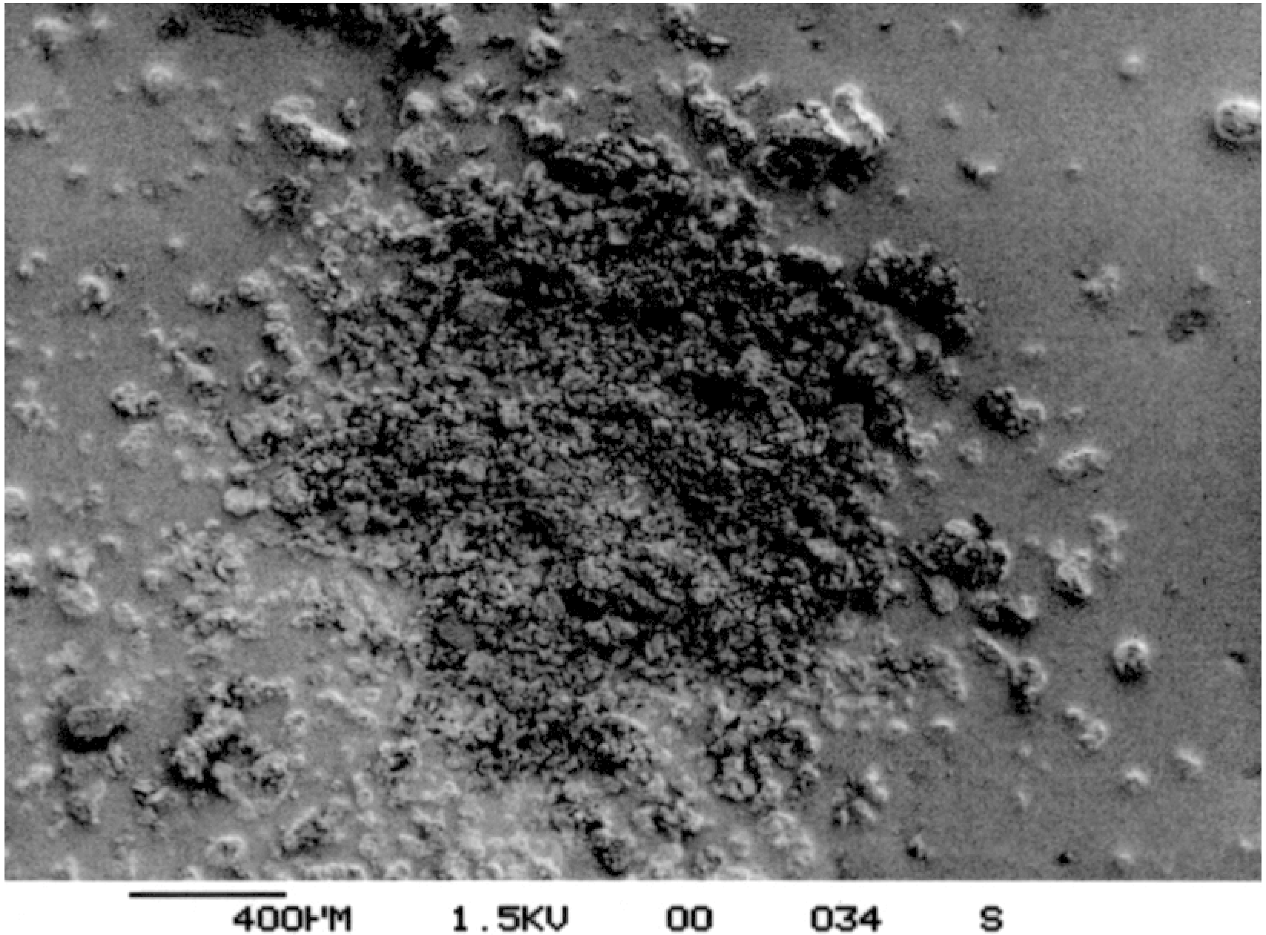
- solid phase
  - < 100 µm
- gas phase
- electrostatically bound

Proxied in the geological record by:

- particle size distribution
- deposit thickness 'anomaly'



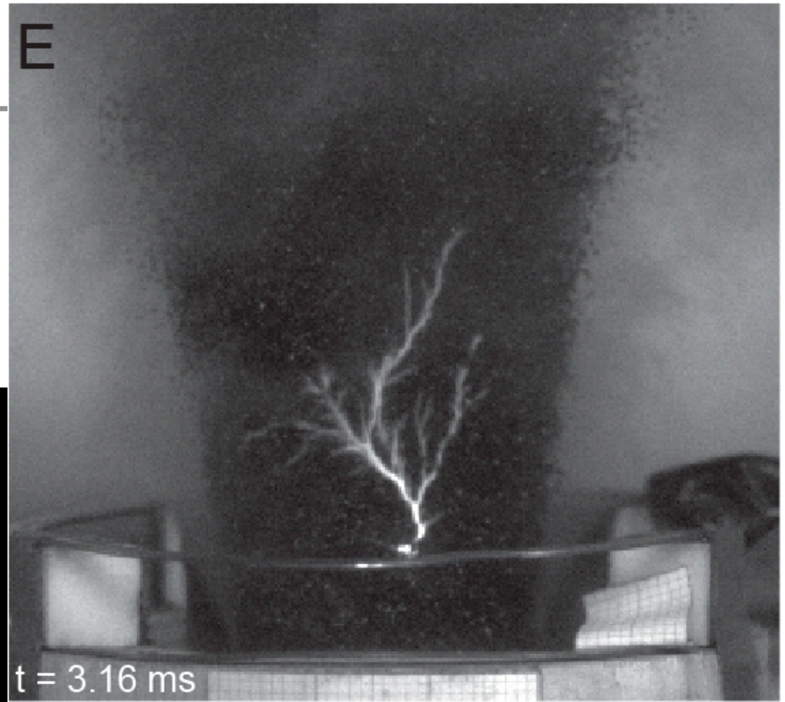
Experiment 2000

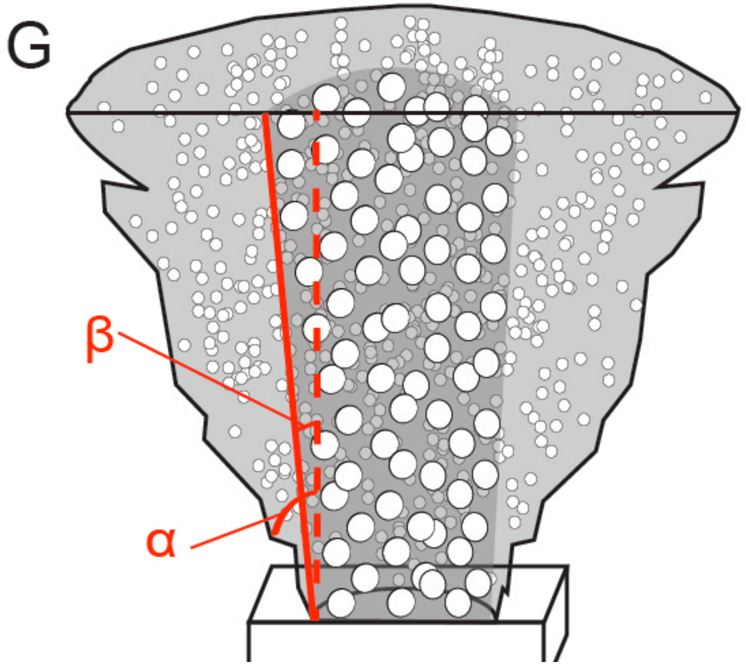


Sakurajima 1991

Volcanic lightning

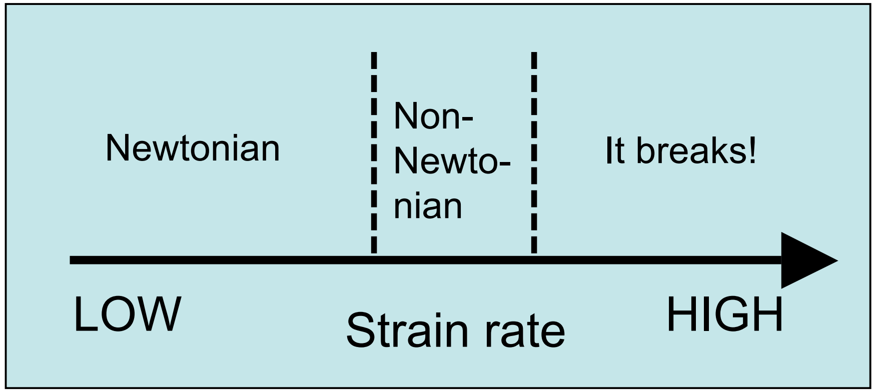
Orthogonal expansion separates charged particles (ions) as a function of Stokes number (particle size)

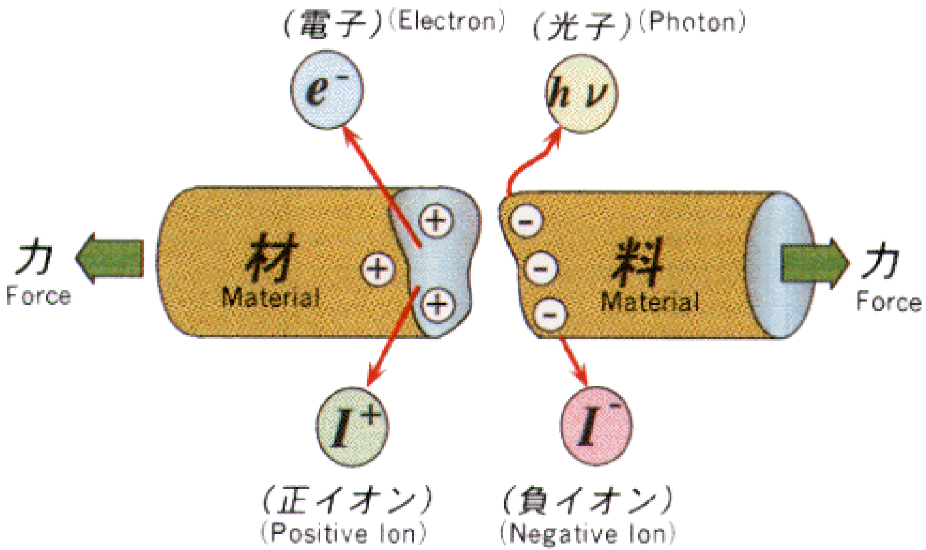




Cimarelli et al., in press

Charging mechanism: fracto-emission





材料破断面からのフラクトエミッション
Fracto emission from the Fracture Surface

http://www.cniri.go.jp/seisan_hyomen_04.html

Fragmentation

- brittle fracture as gas pressure exceeds confinement strength (e.g., Speiler et al., 2004)
- comminution from impacts (e.g., Manga et al., 2011)

Fracto-emission (Dickinson et al. 1981)

- electrons & ions
- charged silicate fragments (ash)
- neutral particles
- gases
- photons (to X-ray)
- phonons (high temperatures)
- recombination
- aggregation

Gravity and flow

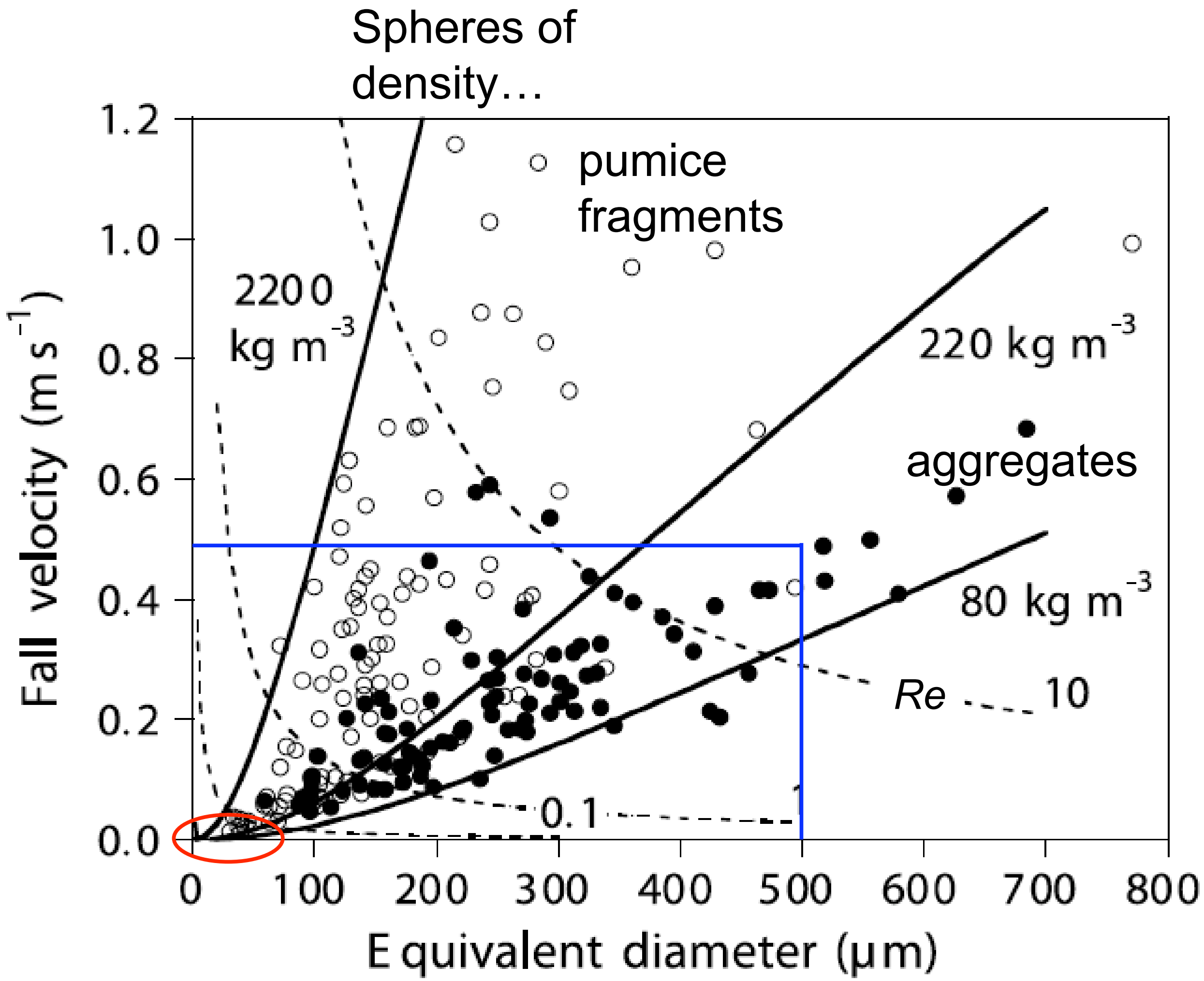
- separation
- e fields & discharge

Kajdas et al., (http://www.tribologia.org/ptt/kaj/kaj05.htm)

Experimental insights

Modified aerodynamic behaviour/increased fall velocity

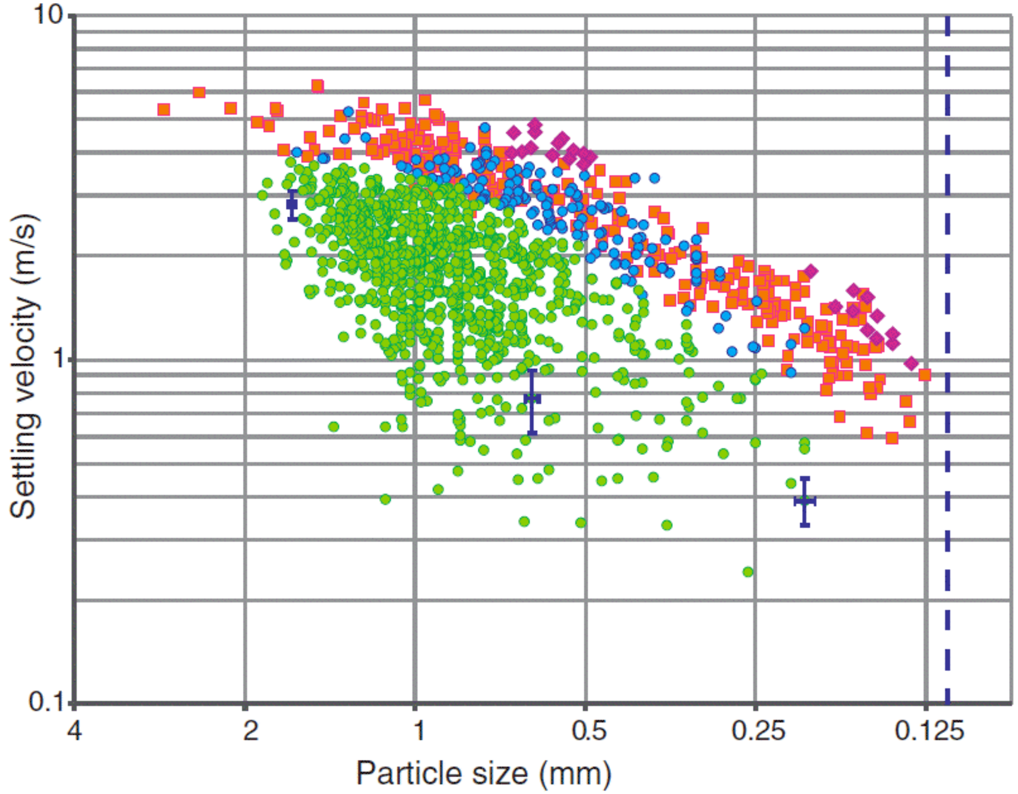
(e.g., Sorem 1982, Carey and Sigurdsson 1982, Lane et al 1993, Scarlato et al 2010, Folch et al. 2010, Taddeucci et al. 2011)

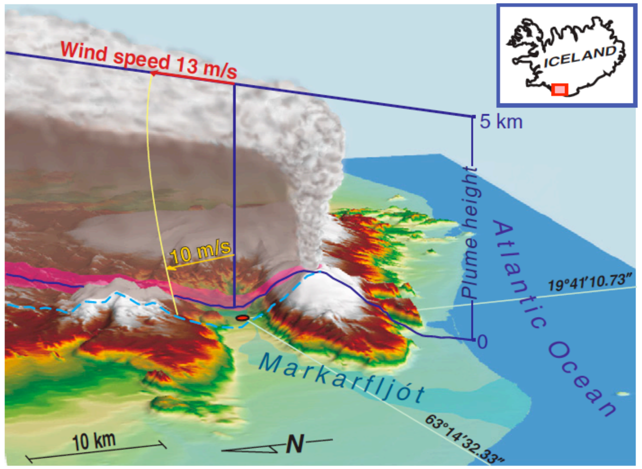


modified from James et al 2002

- **dry**
- particles < 100 µm form aggregates
- aggregate fall velocity > than that of constituent particles
- aggregated particles sediment rapidly
- large density range of particles and aggregates
- modelling challenge

Proximal (7 km) Field Evidence





Taddeucci et al., 2011

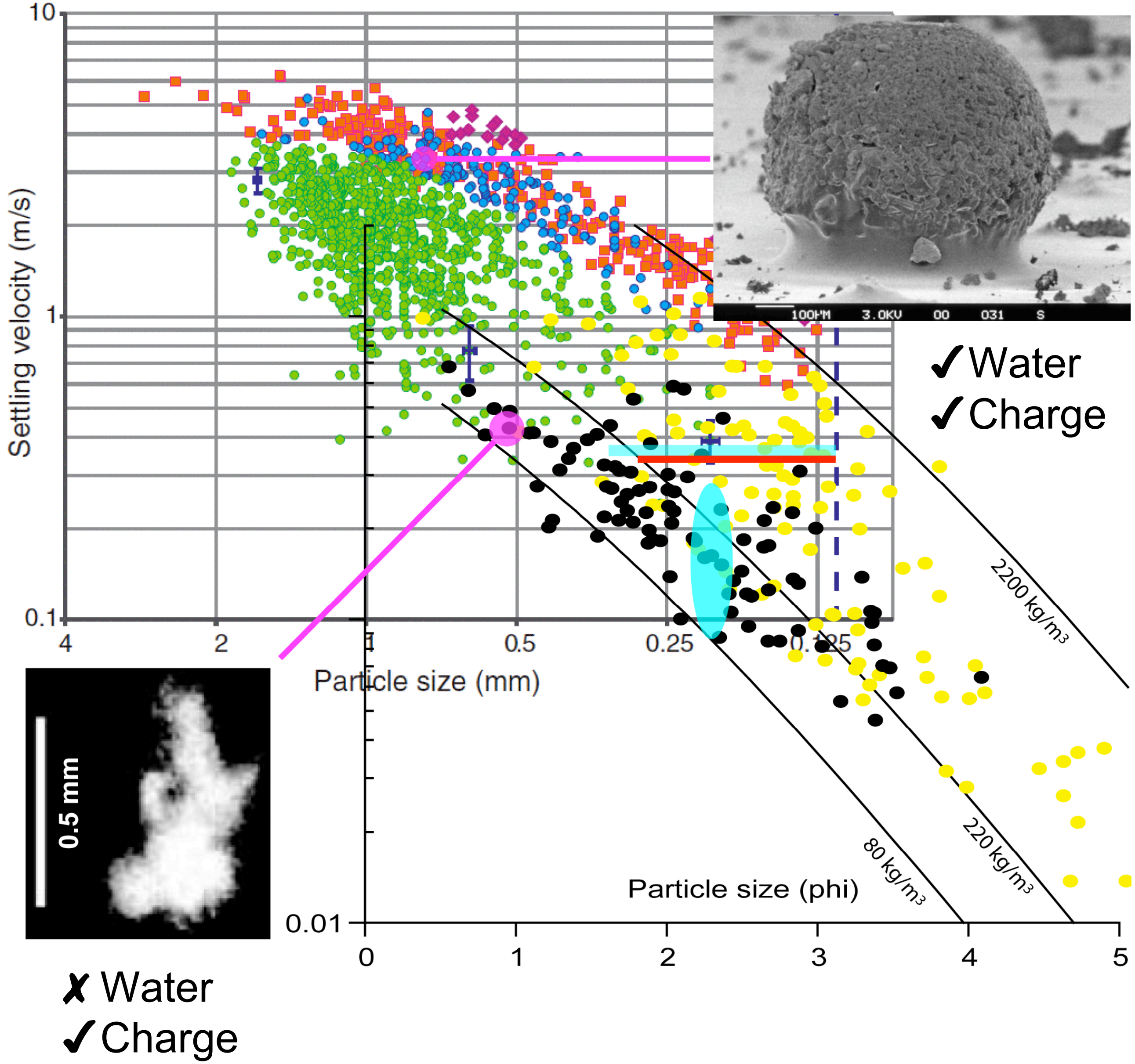
Orange/**Purple** data points are experimental single particle fall velocities.

Green/**blue** data points are field measurements from **Eyjafjallajökull 2010**.

Blue data points are interpreted as single particles from **Orange**/**Purple** data.

Green data points are then interpreted as aggregates.

Combined Evidence



Yellow data points are single particles.

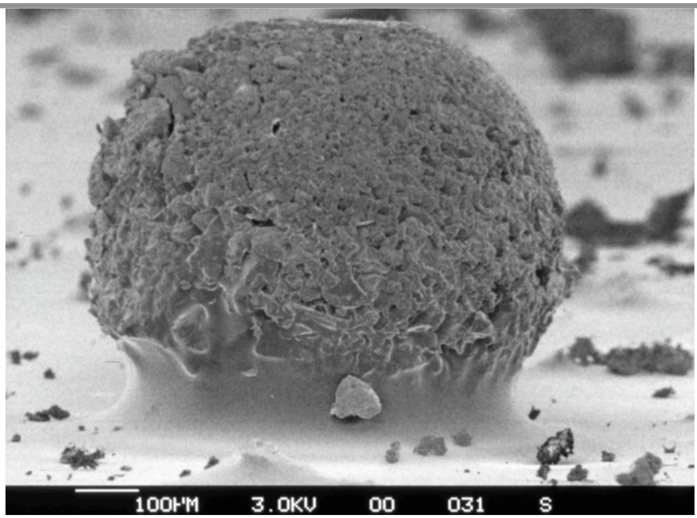
Black data points are aggregates

Red line Carey and Sigurdsson [1982]

Cyan Matthews et al [2012]; Cornell et al [1983]; Costa et al [2012]

- field (wet) and lab (dry) data merge well
- **electrostatic aggregation ubiquitous?** [Telling & Dufek, 2012]
- **role of water?**
- field interpretation excludes overlap

Electrostatics always important?

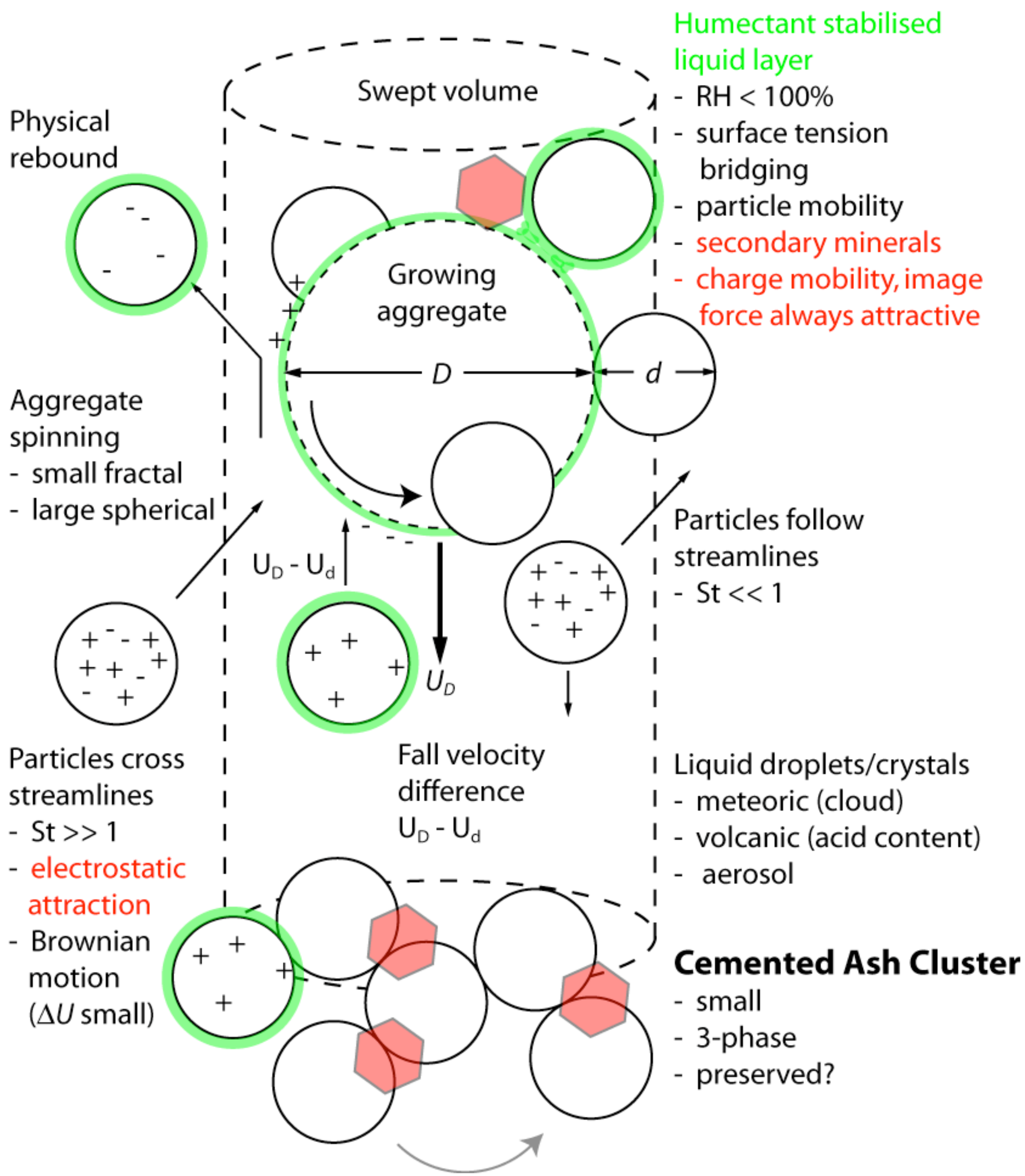


3-phase aggregate

solid, gas, **add liquid**

collision mechanisms:
- fall velocity difference
- electrostatic (image forces always attractive)

binding mechanisms:
- surface tension forces
- mineral/ice growth



Electrostatic control?

Summary

- magma fragmentation generates (initial separation) charged particles
- charged particles (ions, silicates) aggregate (rapidly)
- electrostatic charge likely to always play an aggregation role in proximal plumes, dry and wet
- aggregation increases sedimentation rate and reduces the timescale of atmospheric transport (order of magnitude)

Modelling challenges for transport and deposition

- large range of aggregate size, shape and density (aerodynamics)
- complex and evolving aggregate size distribution (timescales)
- > PM_{10} aggregation probabilities very approximate (scaled experiments)
- no data for PM_{10}; what proportion of particles *escape* aggregation

Validate with, and test against, primary field and experimental data.

Steve Lane Jennie Gilbert Mike James

Lancaster Environment Centre LANCASTER UNIVERSITY

s.lane@lancaster.ac.uk