Breaking magma: Controls on magma fragmentation and ash formation

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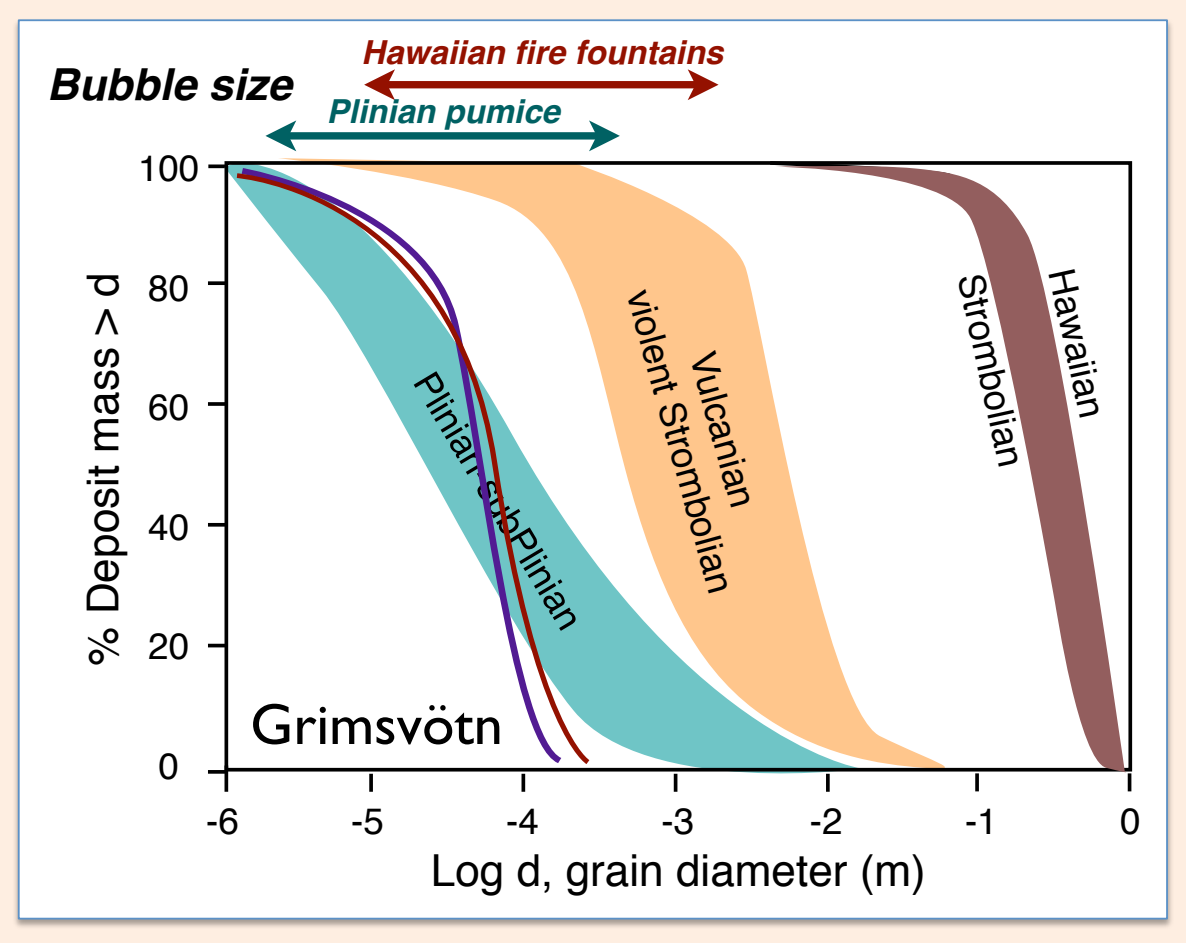
Introduction

The 2010 eruption of Eyjafjallajökull highlighted many deficiencies in our understanding of explosive volcanic eruptions, not the least of which is the absence of a theoretical basis for estimating the amount of fine ash a given eruption might produce. The basaltic Grimsvötn eruption of 2011 underlined this problem by producing abundant fine ash during initial phases of eruptive activity.

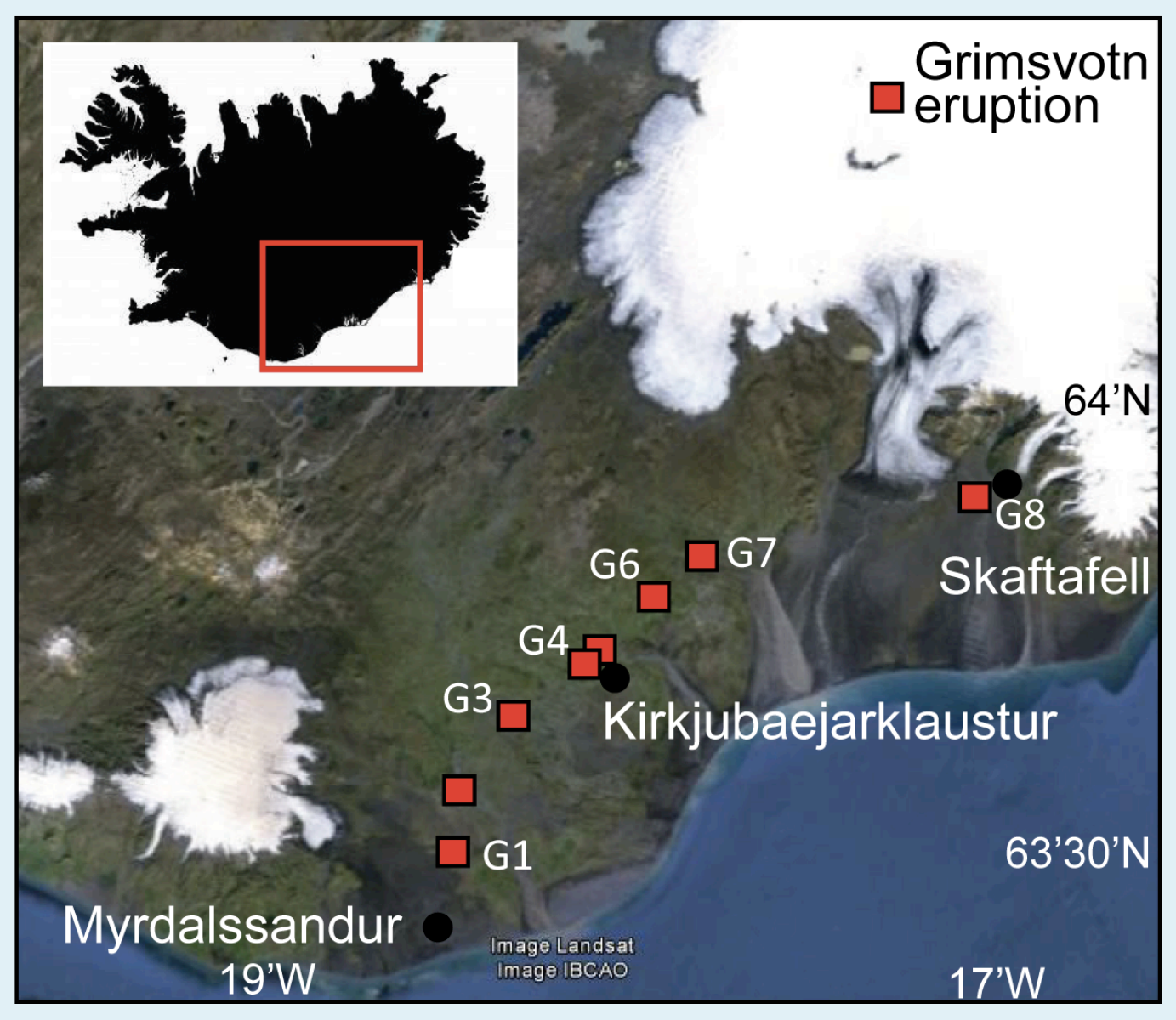


Total grain size distributions (TGSDs) for ash fall deposits (modified from Rust & Cashman, 2011). Corresponding bubble size distributions (BSDs; arrows) show that TGSDs of silicic Plinian deposits are controlled by BSDs. Grain size data for Grimsvötn are from samples collected at 70 (red line) and 115 (purple line) from the vent (from Olsson et al., 2013).

Rust AC & Cashman KV (2011) JGR 116, doi:10.1029/2011JB00849; Olsson J et al. (2013) Geochim Cosmochim Acta 123:134-149.

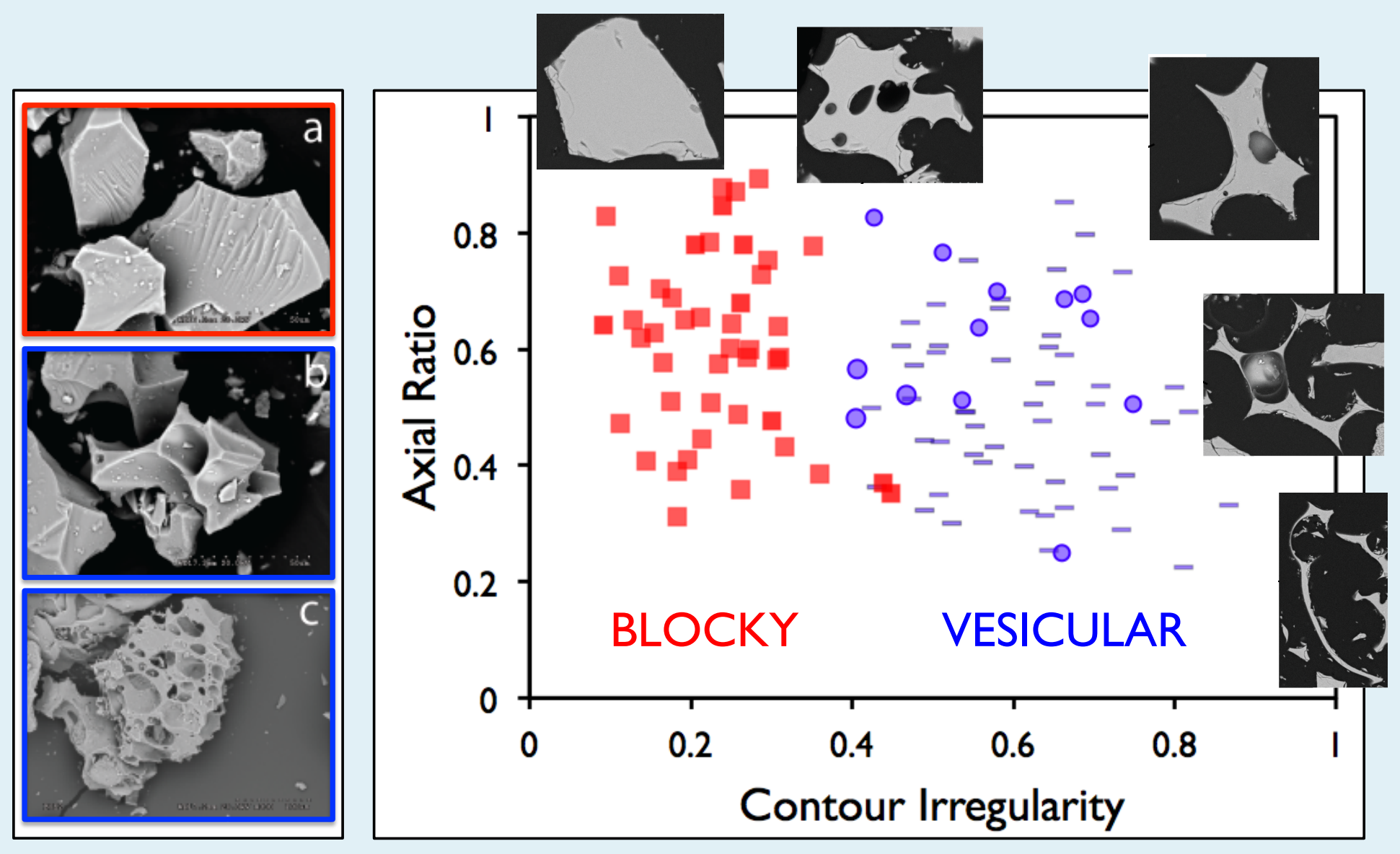
Grimsvötn 2011

The textures of ash produced during early stages of the eruption provides insight into fragmentation conditions



We have examined samples collected within 24 hours of the onset of the eruption, approximately along the dispersal axis. Ash components were defined for individual size classes and quantified by SEM imaging in both 2D and 3D.

Defining components



Two primary ash components:

1) dense particles (either blocky or platey) and
2) vesicular particles (either vesicular fragments or ash shards).

are distinguished in 2D by the shape factor that we term "contour irregularity" (or *indentation intensity*; Heilbronner and Barrett, 2014), where

$$CI = \sqrt{([1\text{-convexity}]^2 + [1\text{-solidity}]^2)}$$

Figure shows examples of characteristic ash particle shapes in 3D (left) and 2D (from polished thin sections, right). Ash particles in thin section were categorized as blocky/plately (red squares), vesicular (blue circles) or shard (blue lines) by inspection. These components are also easily distinguished in a plot of *axial ratio* (short/long axis) against *contour irregularity* (a function of convexity, a measure of perimeter-based roughness, and solidity, a measure of compactness; Heilbronner R and Barrett SD (2014) *Image Analysis in the Earth Sciences*, Springer-Verlag).

Variations with size and distance

The relative proportions of the two components vary with both distance (distal particles have a higher proportion of vesicular particles) and with grain size (smaller particles are more blocky).

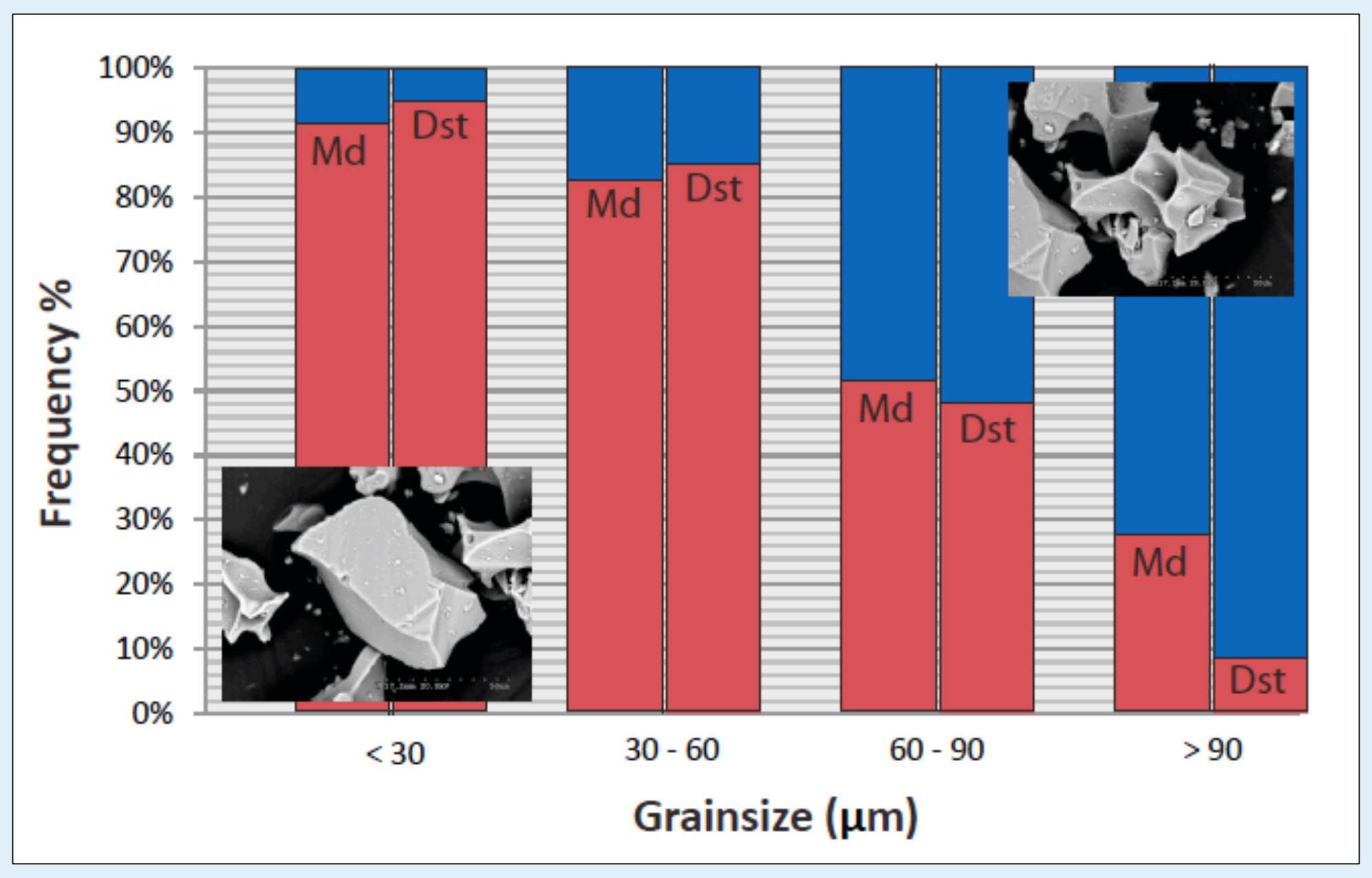
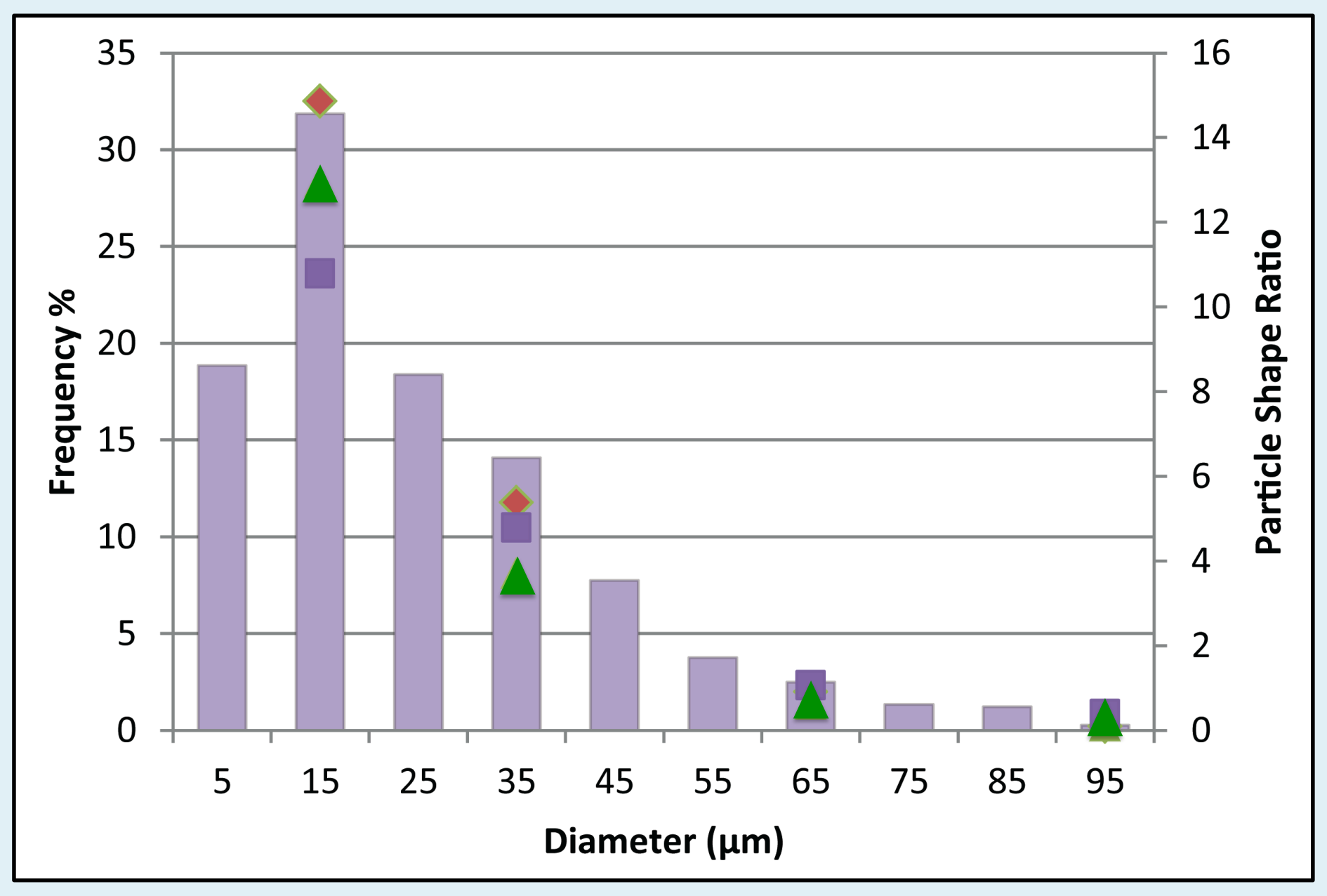


Figure shows the relative proportions of ash particles with blocky (red) or vesicular/shard shapes as a function of grain size and distance from vent. *Medial (Md)* samples are from location 6 (70 km); *Distal (Dst)* samples are from location 1 (115 km).

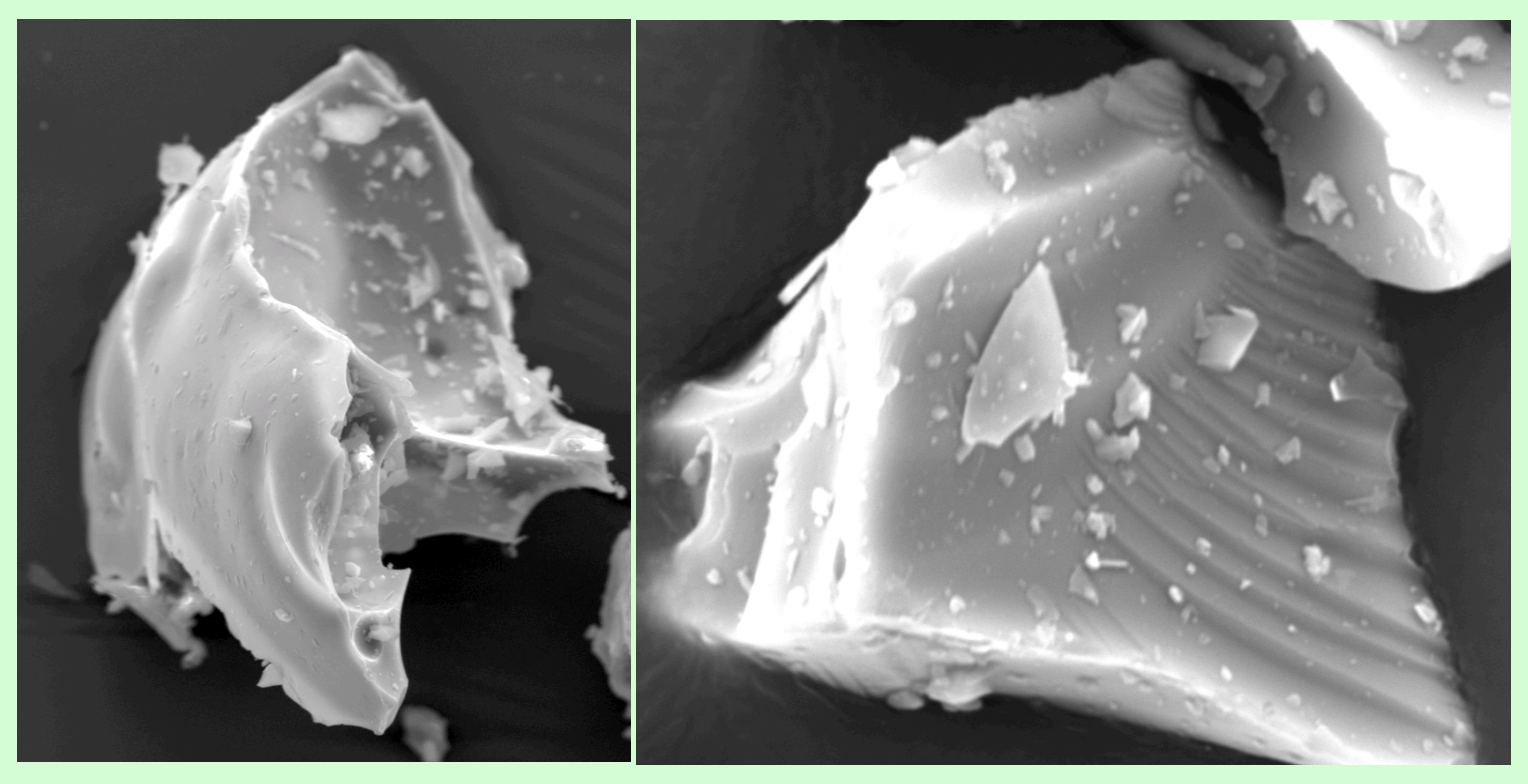
Comparison with bubble sizes



The systematic change in ash shape with decreasing size is consistent with the size distribution of bubbles preserved in vesicular particles. Ash particles smaller than the mode of the bubble size distribution are dense, and represent the melt (glass) interstices between bubbles.

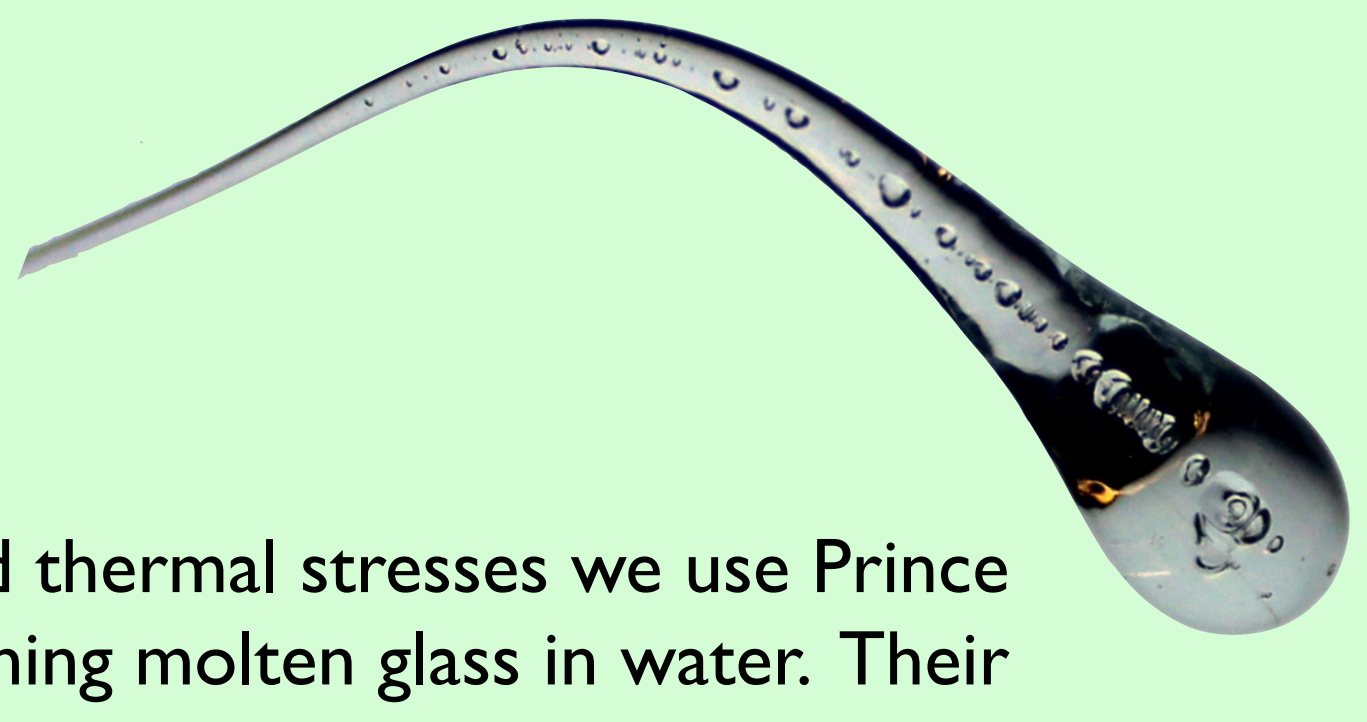
Figure shows measured bubble size distributions (purple bars) and the ratio of blocky:vesicular clasts in samples from locations 1 (red diamond), 3 (green triangles) and 6 (purple squares).

Thermal Stresses



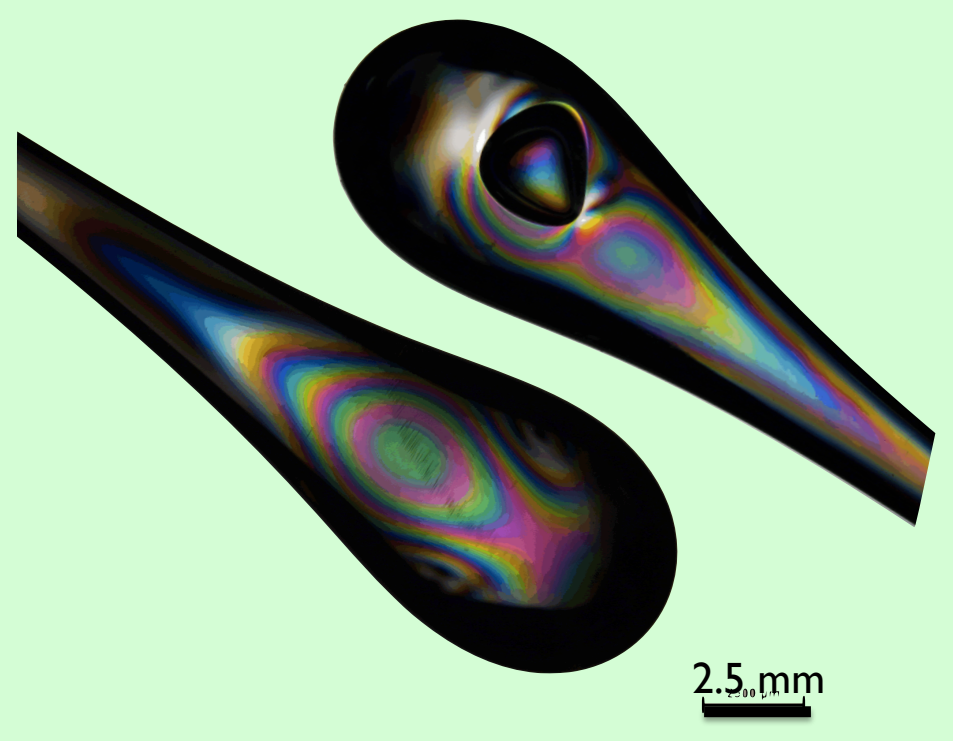
Fine ash particles from Grimsvötn show evidence of both ductile and brittle fragmentation., which suggests multiple fragmentation mechanisms

Differential cooling of magma interacting with water will produce residual stresses that could enhance fragmentation during phreatomagmatic eruptions.



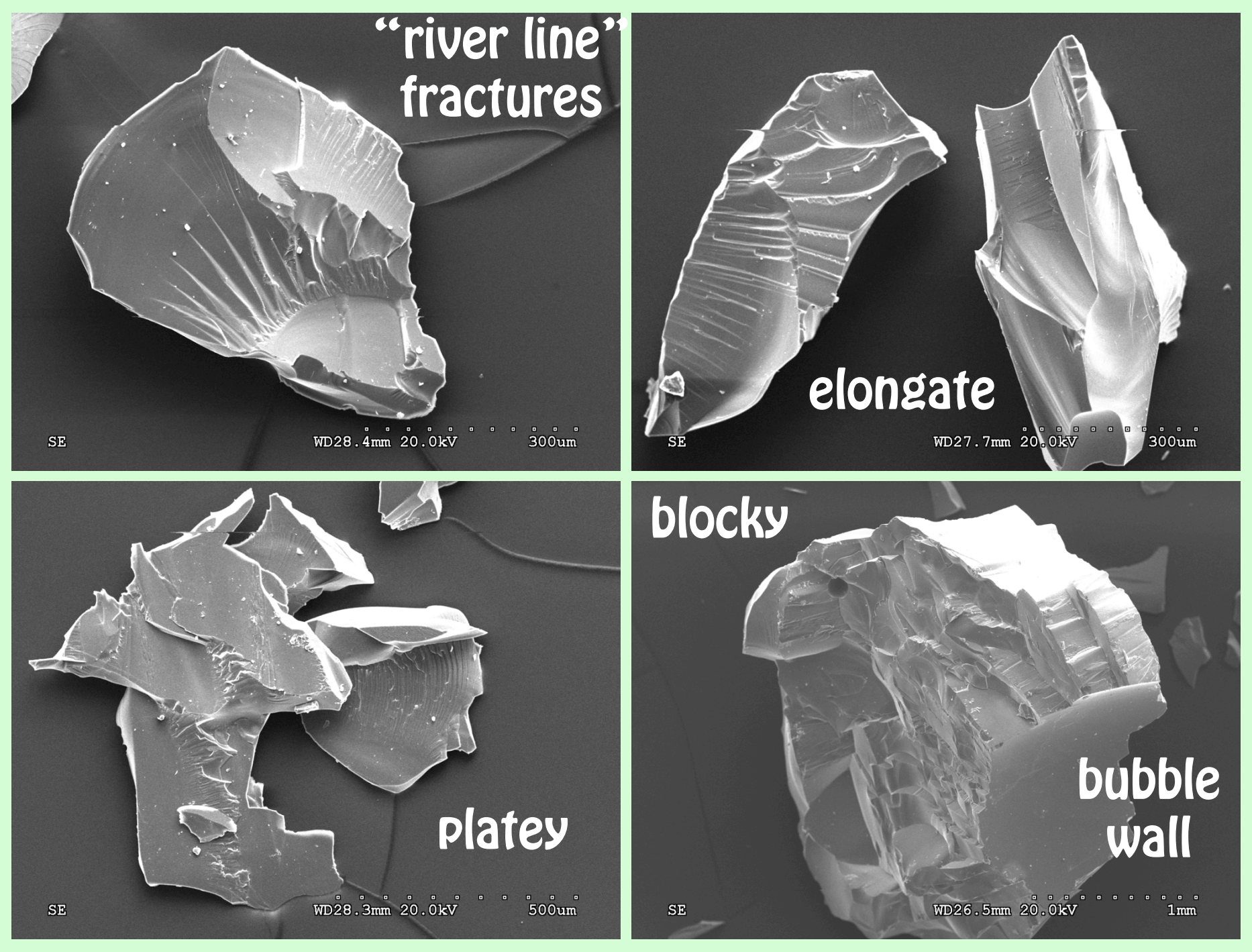
Prince Rupert´s Drops

To study explosive fragmentation driven by stored thermal stresses we use Prince Rupert's drops (PRDs) – glass beads created by quenching molten glass in water. Their characteristic property is that they are very strong until the tail is broken, at which point they undergo explosive self-sustained fracture.



Stored thermal stresses can be seen in the polarized images of PRDs shown above. Note distortion of the stress field by the shrinkage bubble in the upper bead.

Glass particles produced by explosive fragmentation of Prince Rupert's drops have many of the shape and surface characteristics of volcanic ash particles from Grimsvötn



SEM images of particles created by PRD fragmentation. Note the range of particle shape and the complex surface fractures, and their similarity to the surface textures of Grimsvötn particles shown above.

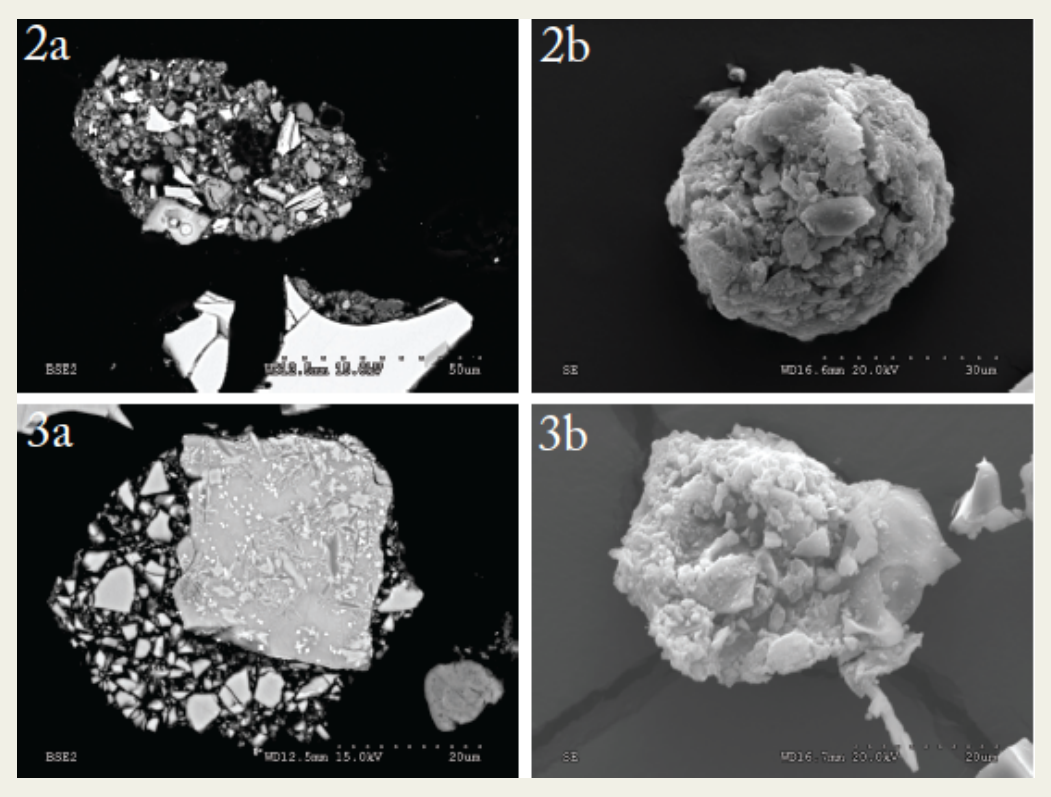
Remobilised ash

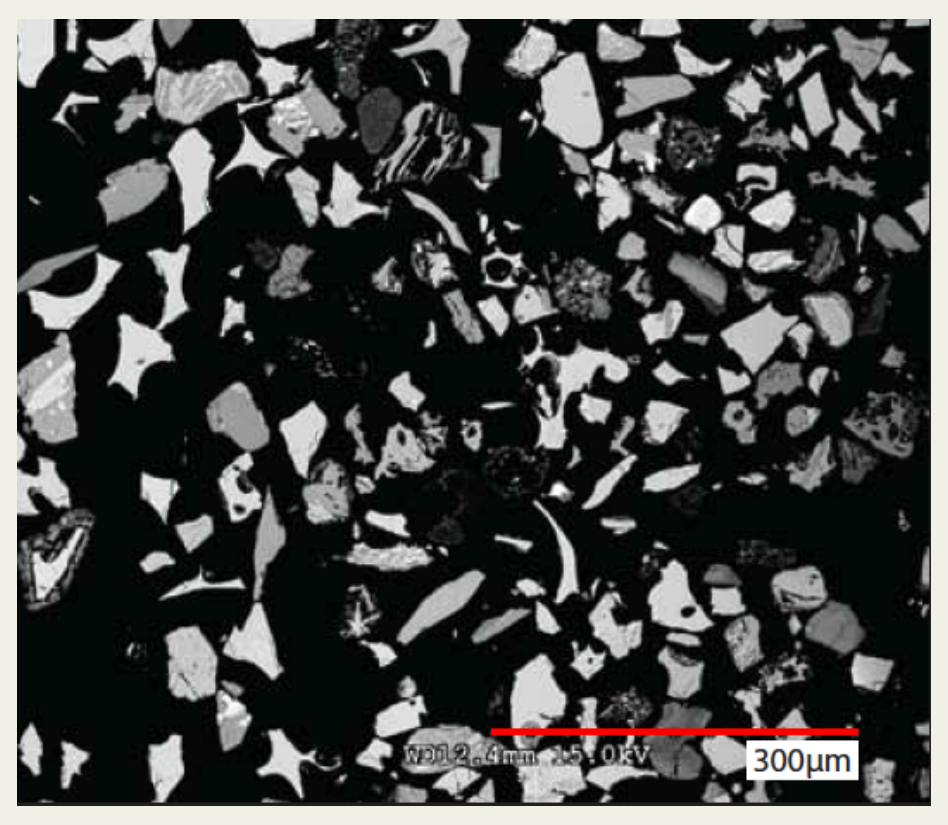
A blizzard on March 6, 2013 transported abundant remobilised ash to Reykjavik, transforming white snow to brown.

Photograph of Reykjavik taken on March 9, 2013; the "brown snow" is still very evident.

Characterising remobilised ash

We sampled the brown snow on March 7, 2013.

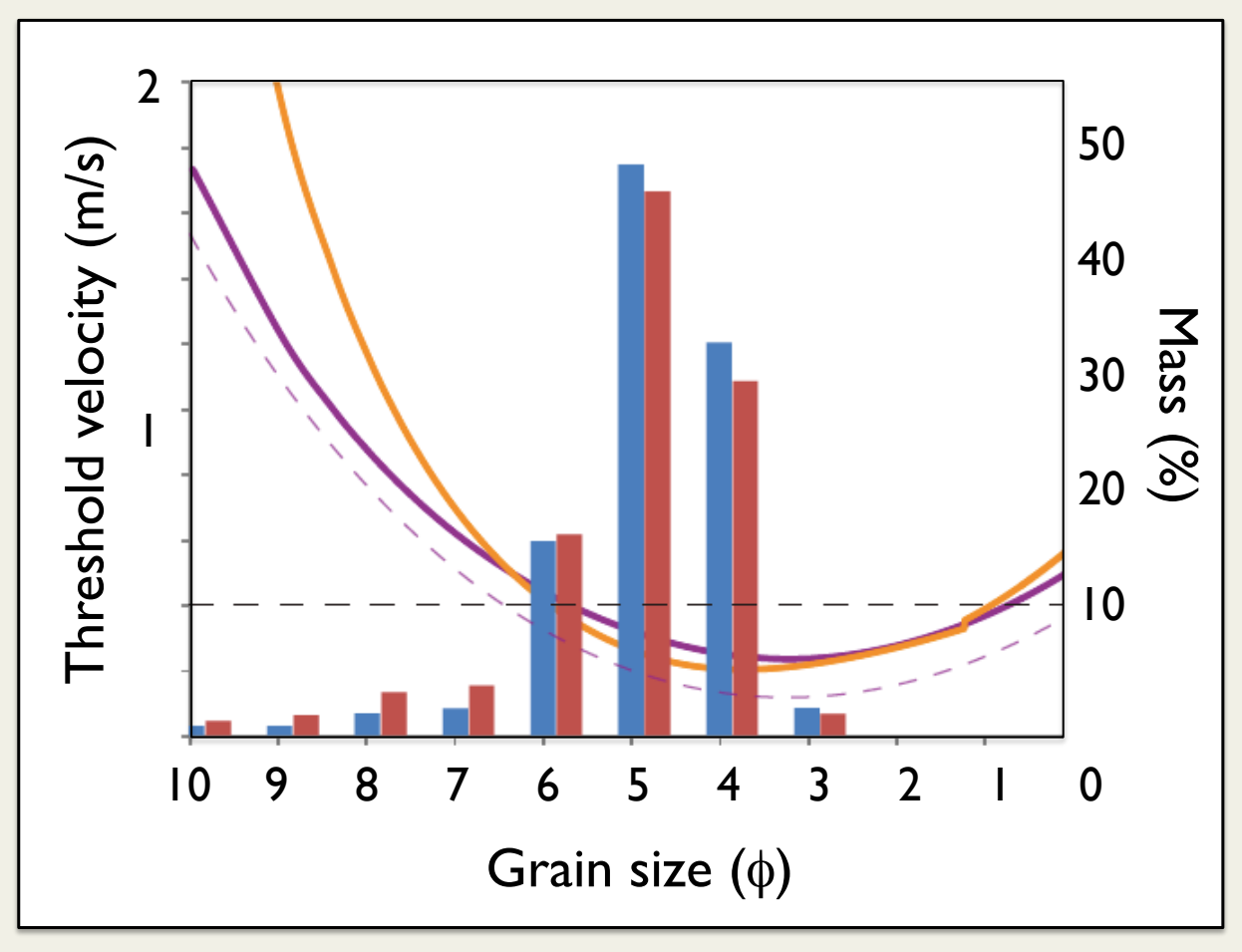




Samples comprise approximately 50% Grimsvötn ash and 50% Eyjafjallajökull ash

Ash aggregates are also common and include components from both sources, which suggests that aggregation occurred during transport

Most particles are 4-6Φ (16-64 µm), consistent with predicted minimum threshold velocities for resuspension



Measured grain size distributions of original (red) and sonicated (blue) ash samples; lines show theoretical threshold wind velocities for resuspension: orange from Marticorena & Bergametti (1995); purple from Shao & Lu (2000); and dashed purple from Goldasteh et al. (2012).

Marticorena & Bergametti (1995) J Geophys Res 100:16415-16430; Shao & Lu (2000) J Geophys Res 105:22437-22443; Goldasteh et al. (2012) J Adhesion 88:766-786.

Conclusions

- Ash characteristics can be quantified and related to formation processes
- Bubble size distributions exert a primary control on the size and shape of very fine ash particles
- Evidence for extensive brittle fragmentation suggests that thermal stresses were important
- An unusual ash remobilisation event in March 2013 carried substantial amounts of recent ash to Reykjavik