IUGG General Assembly
Prague
June 22-July 2, 2015
IUGG-5290
VS15p-485

Magma Degassing and Fragmentation during the 1918 Katla Eruption

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Introduction

- Katla is located in south Iceland under the Mýrdalsjökull glacier (Fig. 1)
- The eruption record[1] coupled with recent unrest[2] suggests that an eruption at Katla is imminent
- For the past ~750 years eruptions have typically been large subglacial basaltic events (approximately 2 per century)[1]
- The last eruption of Katla was in 1918
- We are studying the 1918 deposits to investigate why Katla eruptions are so explosive

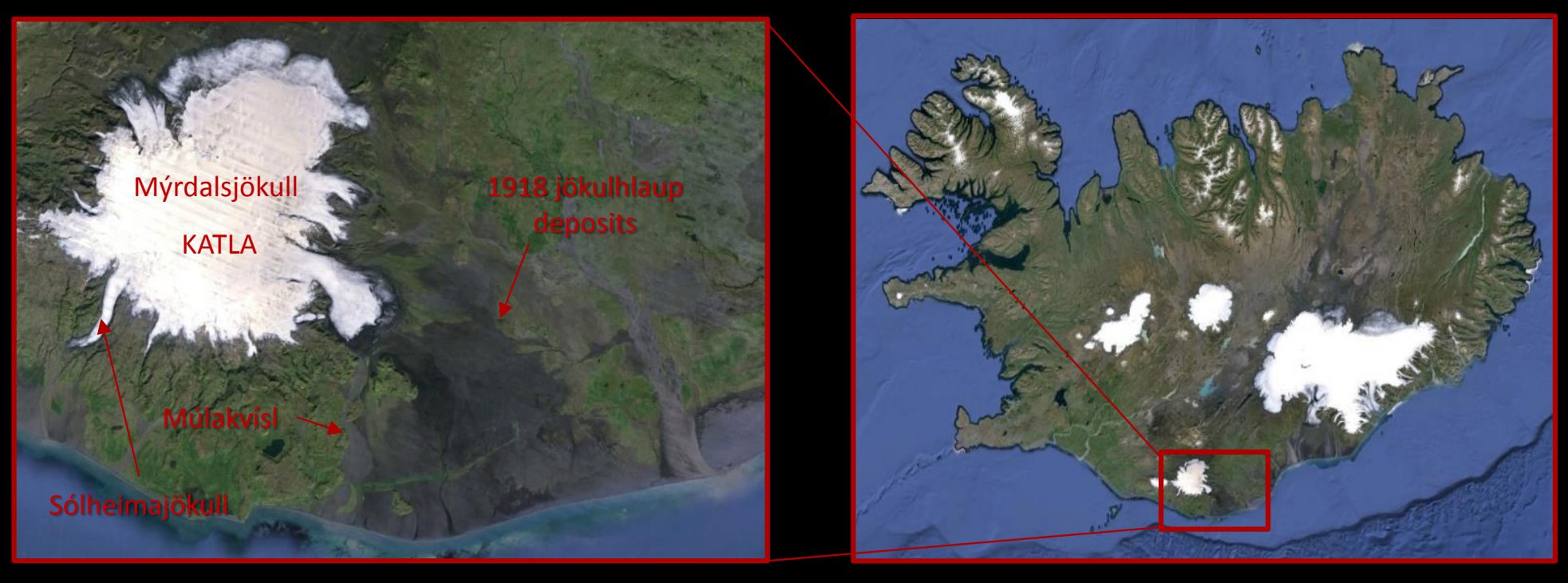

Figure 1: A map showing the location of Katla volcano (residing under the Mýrdalsjökull glacier) in South Iceland.

The 1918 eruption

- Produced an 14 km high plume which distributed ash over half of Iceland[3] (Fig. 2)
- Generated a jökulhlaup (meltwater flood) with discharge rates of 300,000 m^3s^{-1}, which transported great quantities of sediment, extending the Icelandic coastline by several km[4] (Fig. 1)
- In total emitted 1 km^3 of tephra (DRE)[5] making it five times larger than the 2010 Eyjafjallajökull eruption

Figure 2: The Katla 1918 ash plume.

Sampling jökulhlaup deposits

- The extent of the jökulhlaup deposits is clear from satellite images (Fig. 1)
- We sampled next to the Múlakvísl river (Fig. 1), where incision has created a fantastic cross-section through the deposit which is several meters thick (Fig. 3)
- We identified and sampled four depositional units (Fig. 4), corresponding to the stratigraphy described by Duller et al., (2008)[6]

Figure 3: The Mýrdalsjökull glacier overlying Katla (left). From this drains the Múlakvísl river which has cut through the 1918 jökulhlaup deposits (right).

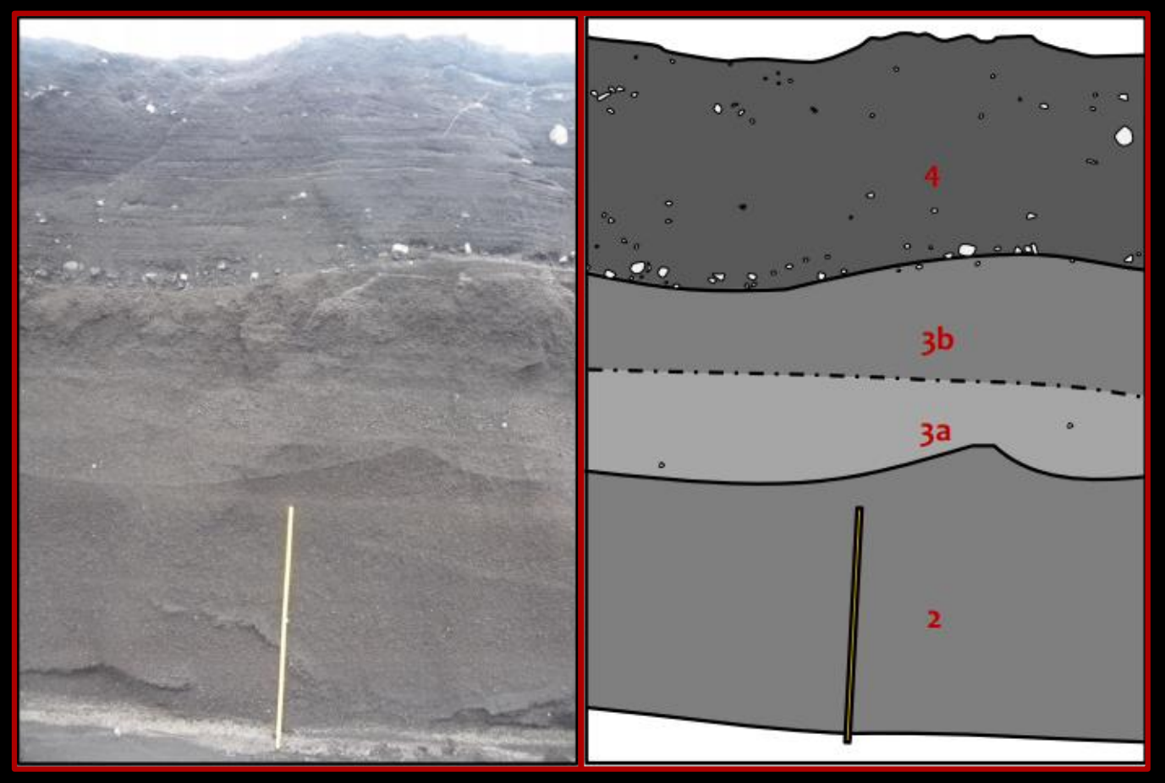

Figure 4: a cross section through the jökulhlaup deposit depicting the 4 units sampled (meter rule scale).

Sampling air-fall deposits

- Air-fall tephra is best preserved on Mýrdalsjökull (Fig.1)
- We sampled from the Sólheimajökull glacier tongue (Figs. 1, 5)
- Here a ~40 cm thick layer is preserved (Fig. 5,6)
- We identified six layers and sampled from each (Fig. 6)

Figure 6: Sólheimajökull glacier looking NW with the pro-glacial lake on the left and Mýrdalsjökull glacier beyond the horizon to the right. The black stripe on the glacier is tephra from the 1918 Katla eruption.

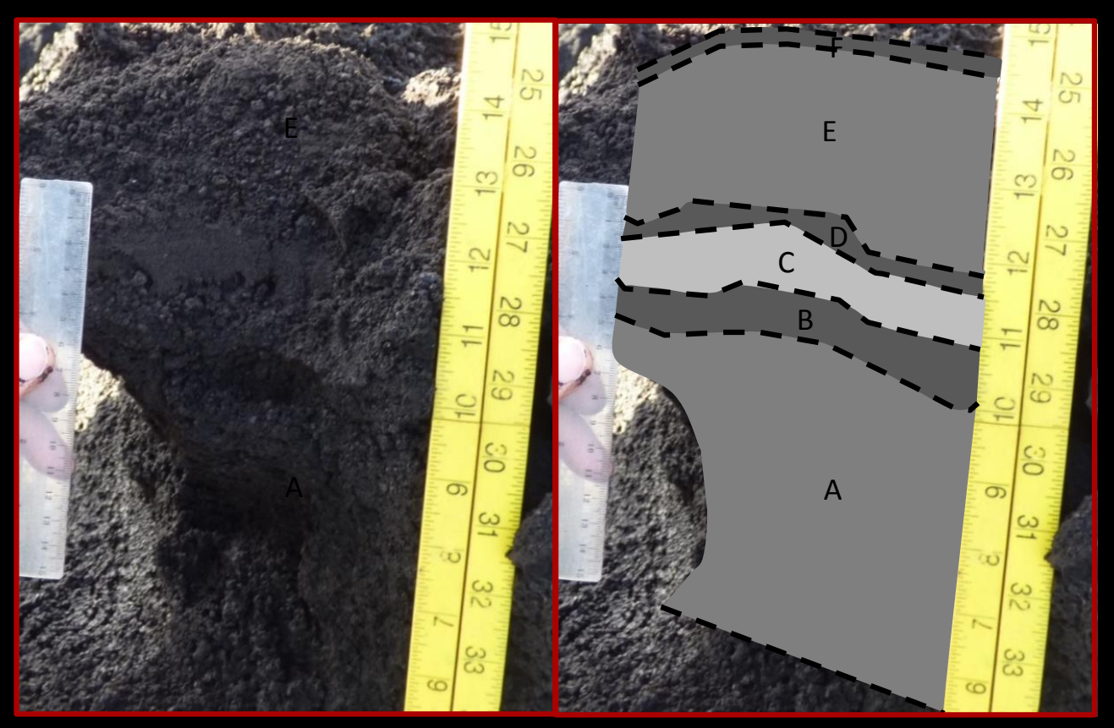

Figure 7: A cross section through the air-fall tephra on Sólheimajökull (Fig. 6) depicting the 6 layers sampled.

Grain size distributions

- The grain size distribution of the air-fall tephra is shown in Fig. 8
- The top layer (F) is depleted in fines, which we attribute to the wind
- Layer C is particularly fine-rich (36% < 63 µm). An artefact of a change in wind-direction or does it signify a change in fragmentation efficiency/mechanism?
- The rest of the deposit shows little variation and has a significant amount of fine material
- The grain size distribution of the jökulhlaup deposit reflects flood deposition dynamics so not shown

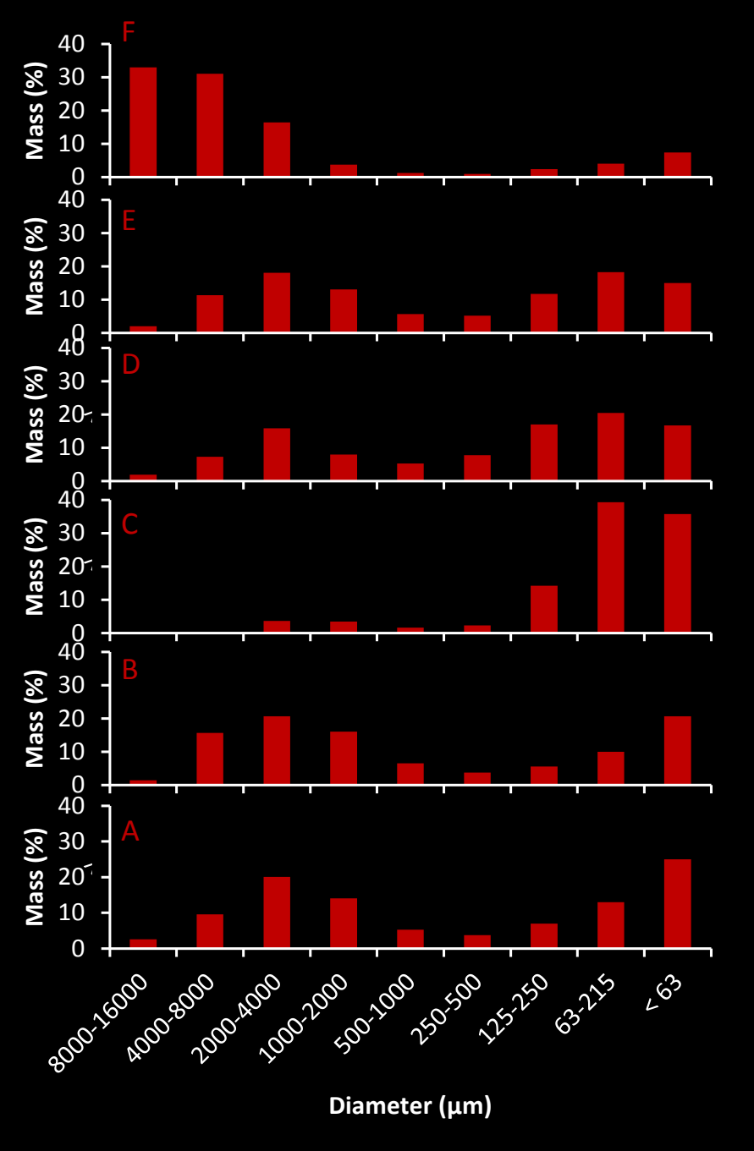

Figure 8: Grain size distributions for the 6 layers depicted in Figure 7.

Volatiles

- FTIR was used to determine matrix glass H_2O concentrations
  - The air fall tephra has a matrix glass water content of ~0.1 wt.% consistent with degassing to atmospheric conditions
  - The jökulhlaup samples have water concentrations of ~0.2 to 0.3 wt.%. The elevated H_2O concentrations may be caused by loading from water (<130 m) and/or ice (<120 m; i.e. ~30% of the original ice thickness) or fragmentation within the conduit (~40 m depth) and/or post quenching hydration.
- TGA was used to determine total volatile concentrations of bulk samples
  - TGA data supports FTIR data
  - The jökulhlaup clasts have retained more volatiles than the air-fall clasts

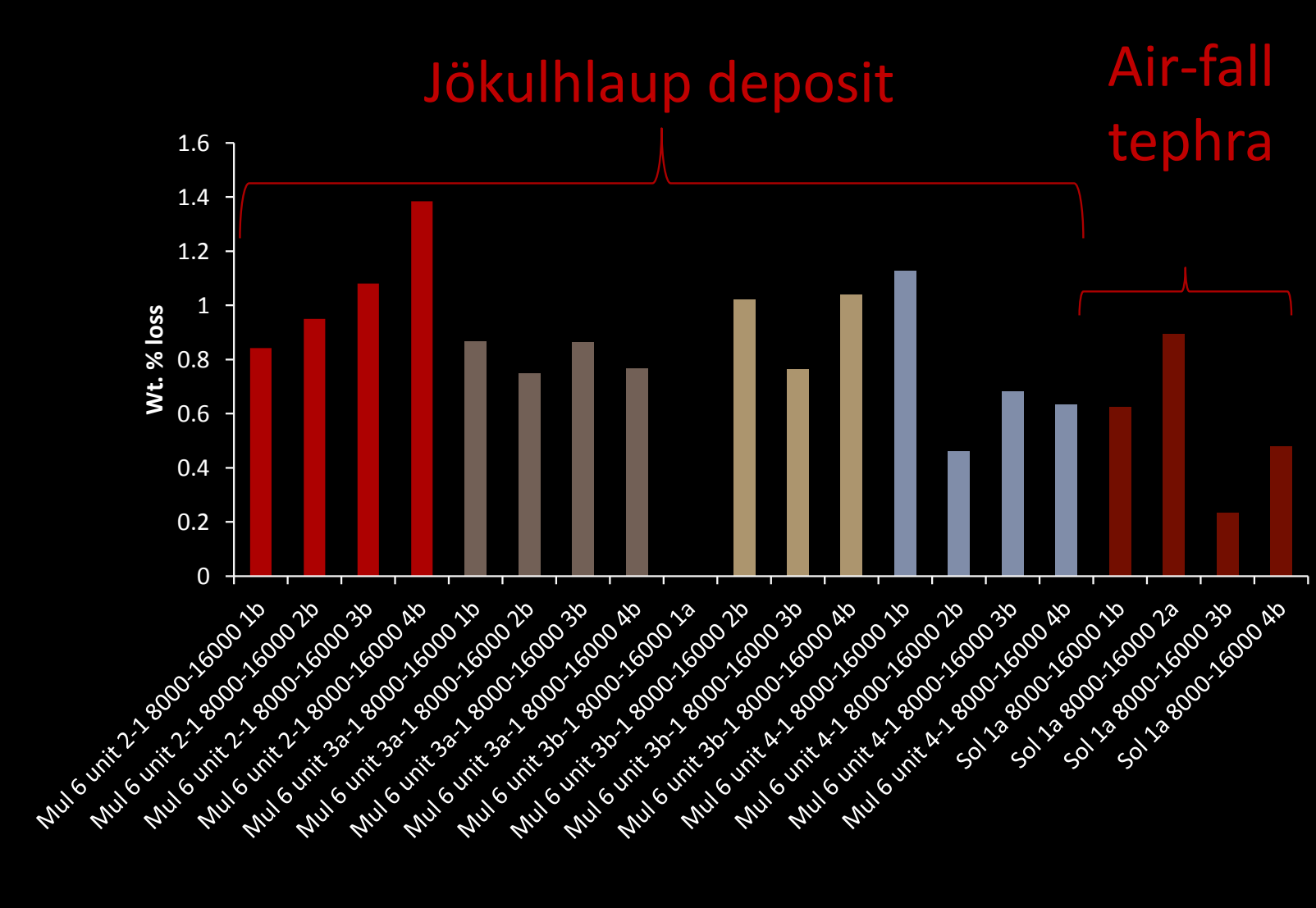

Figure 9: Total volatile loss determined using TGA. The units coincide with those labelled in Fig. 5

Hotstage

- Bubble growth rates of ~1 µm s^{-1} were determined for Katla 1918 melts at typical eruptive temperatures and atmospheric pressure

Microscope observations

- There are two main clast types: brown and black (Figs. 10, 11)
  - Brown clasts typically have abundant spherical bubbles and good quality glass (sideromelane)
  - Black clasts seem to have fewer bubbles which are more deformed and the matrix is microlite-rich (tachylite)
- Many clasts themselves contain smaller clasts, suggesting multiple cycles of fragmentation (Fig. 12)
- Some air-fall clasts have larger bubbles in their centres and are generally more microlite-rich than the jökulhlaup clasts (Fig. 13)

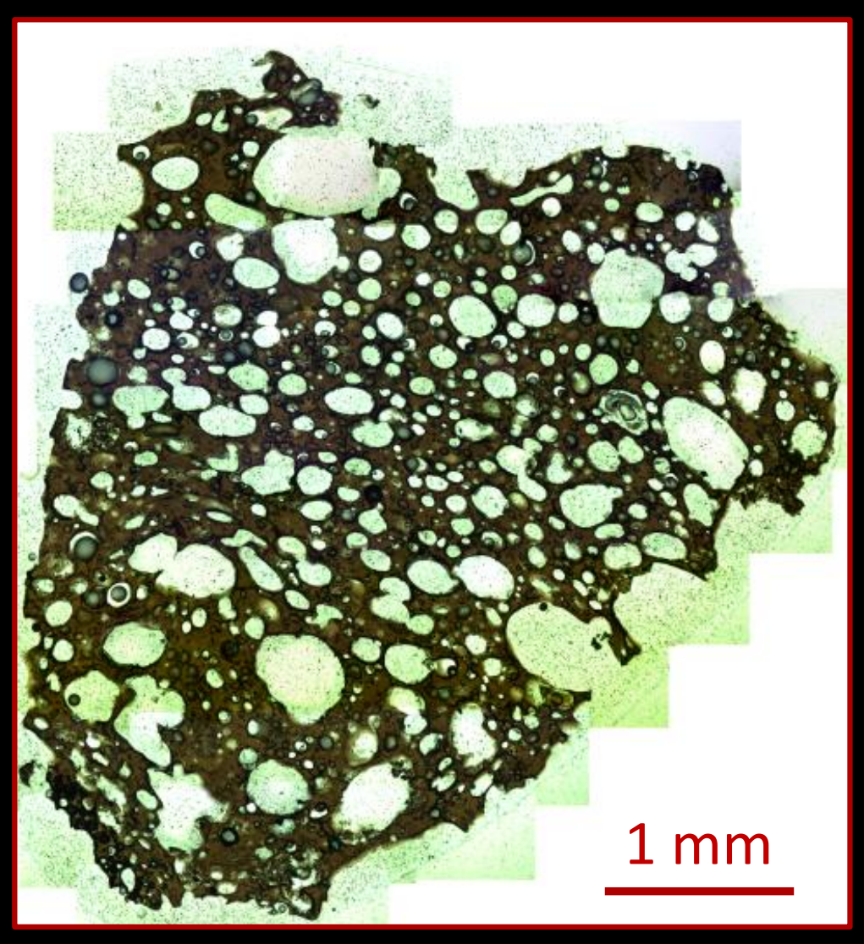

Figure 10: A typical brown (sideromelane) clast

Figure 11: A typical black (tachylite) clast

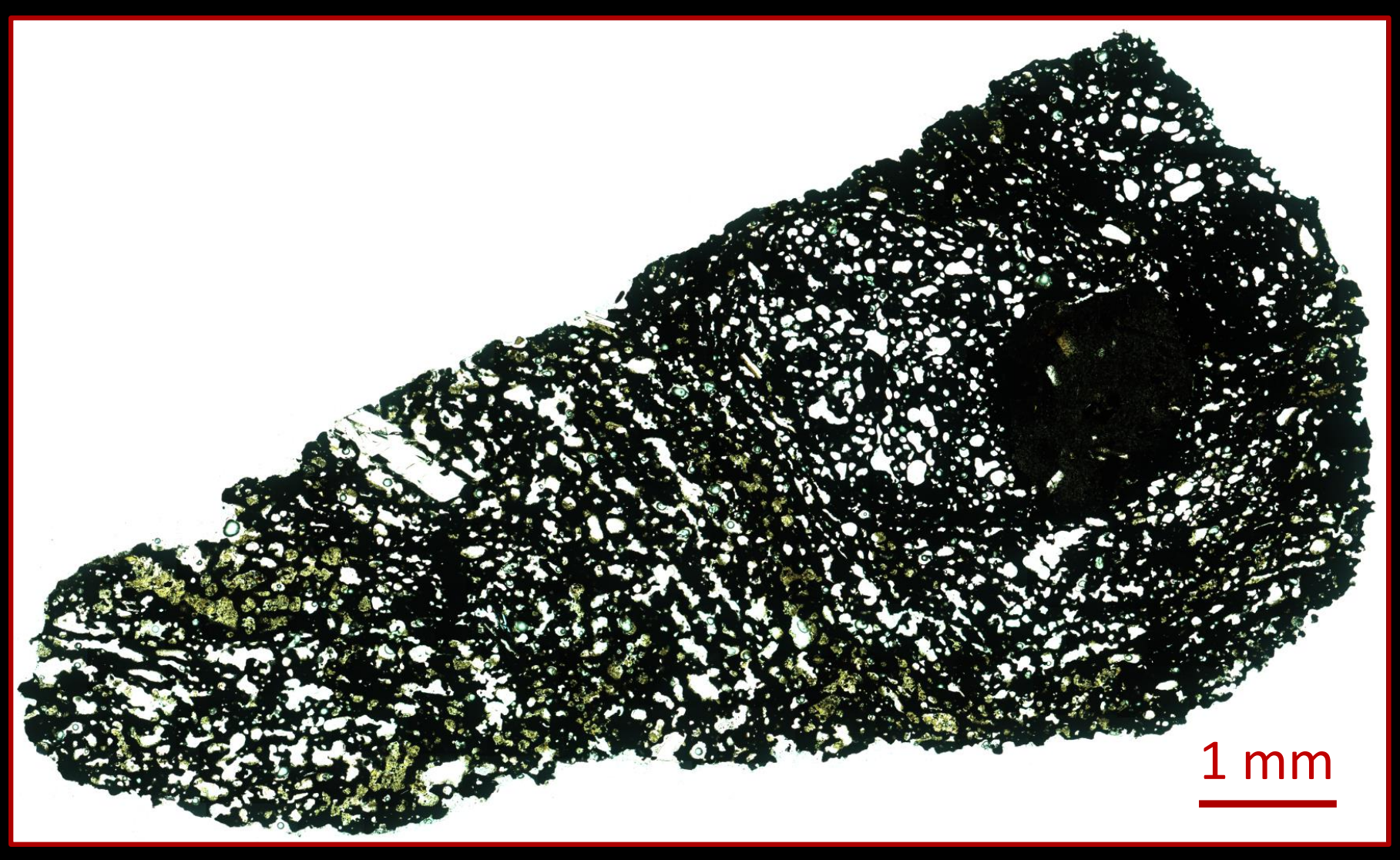

Figure 12: A clast with another clast inside, suggesting multiple fragmentation events

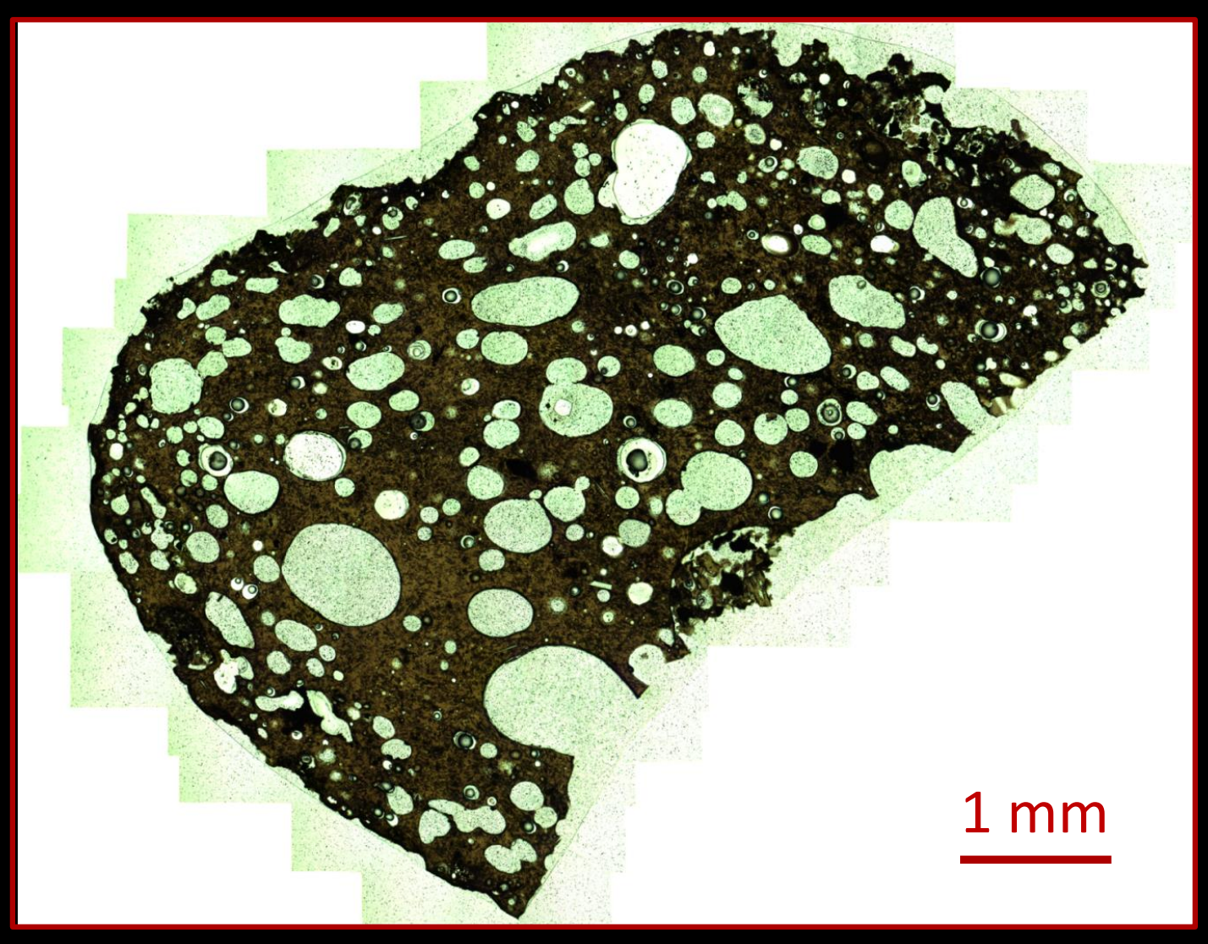

Figure 13: An air-fall clast showing post-fragmentation vesiculation

Geochemistry

- EPMA was used to determine major element, F, Cl and S concentrations (Fig. 14)
  - Most clasts have ~47 wt.% SiO_2
  - Brown and black clasts have similar chemistry
  - There is a small percentage of rhyolitic clasts
  - The overall spread shows a bimodal distribution
- LA-ICP-MS was used to determine trace element chemistry (Fig. 15)
  - Brown and black clasts have similar chemistry
  - The higher (and therefore later) jökulhlaup deposits show a slightly less evolved chemistry than lower (and therefore earlier) deposits suggesting a compositionally stratified chamber

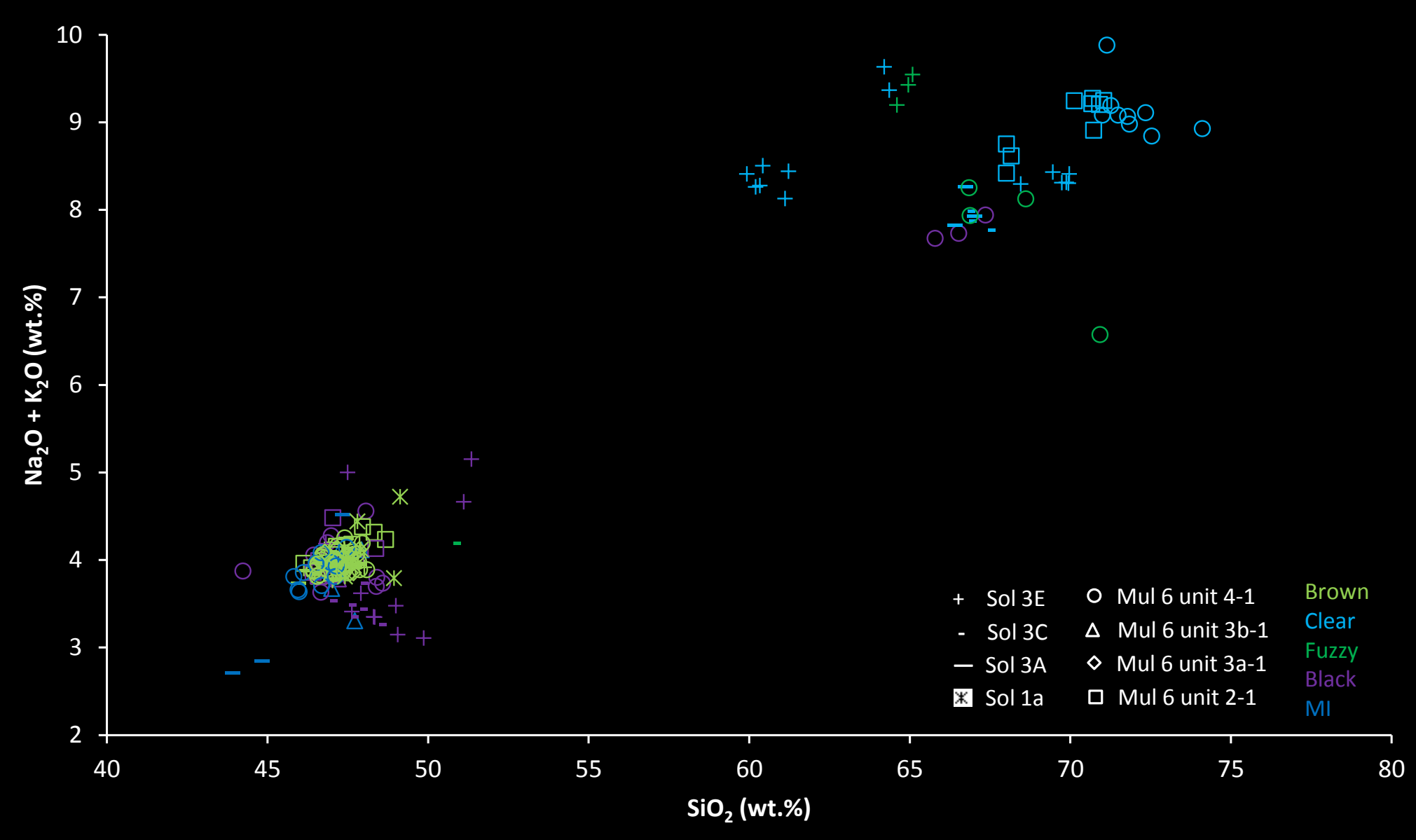

Figure 14 : EPMA data from Katla 1918

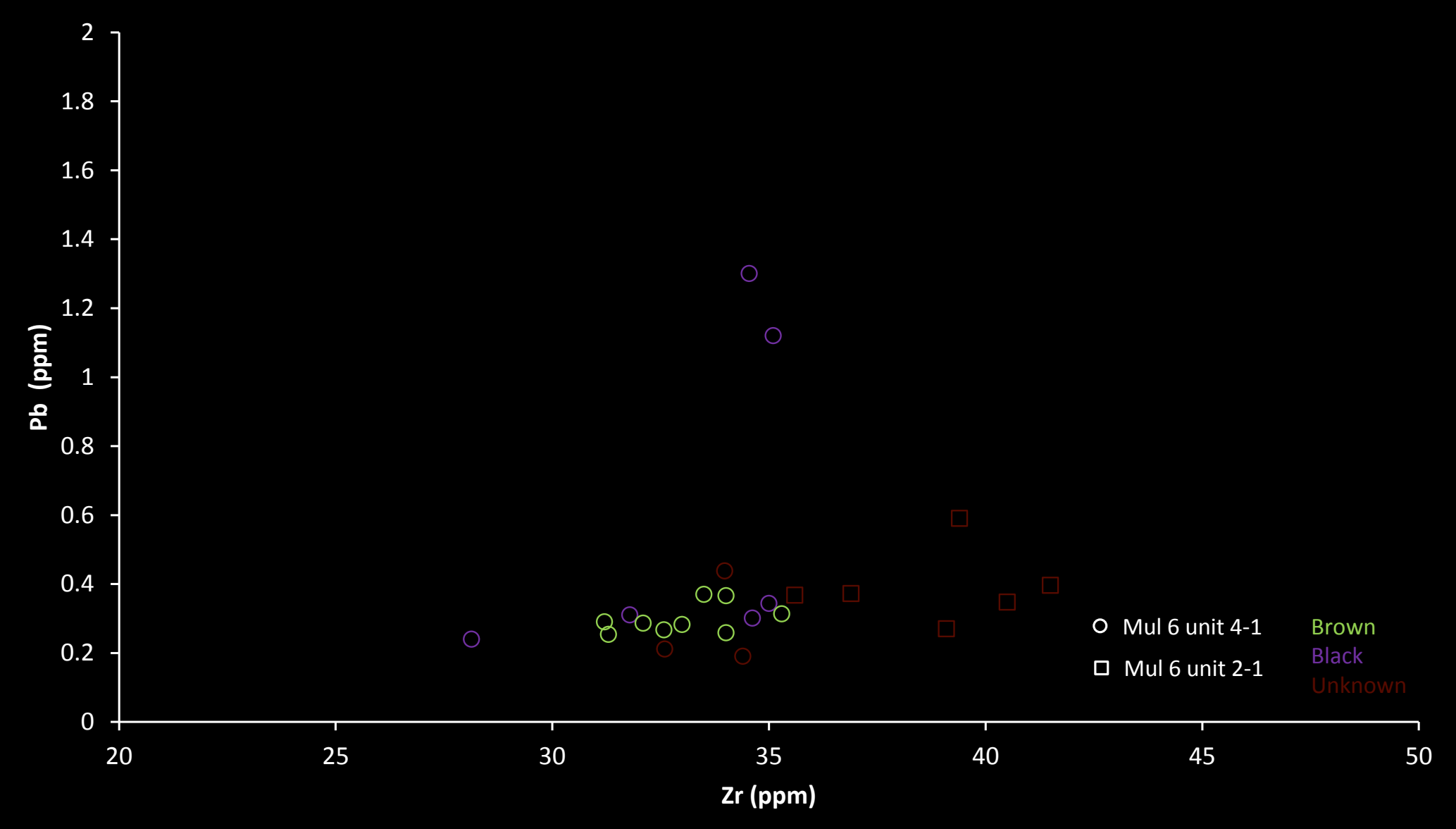

Figure 15 : LA-ICP-MS data from Katla 1918

Energy transfer modelling

- Based on the model of Woodcock et al., (2012)[7], the largest Katla clasts (up to 1.6 cm) should have taken a few seconds to cool, had they cooled in water

Evidence of air vs water cooling

- Some of the air-fall tephra shows evidence of cooling in air:
  - Glass H_2O is degassed to atmospheric pressure
  - The glass is relatively microlite-rich
  - Bubble textures
    - Bubbles in clast cores are hundreds of µm larger than bubbles at the clast margins (Fig. 13) suggestive of post-fragmentation vesicle growth
    - Had the clasts cooled in water they would have taken seconds to cool
    - During this time the bubbles would only have had time to grown a few µm
- It is more likely hat the jökulhlaup samples quenched in water:
  - Glass H_2O suggests quenching under slightly elevated pressure
  - Glass tends to be very microlite poor (indicative of rapid quenching)
  - There is no significant core-margin variation in bubble size

Conclusions

- Variations in volatile and bubble textures probably indicate differences in quenching setting with clasts cooling both in air and water
- Geochemistry suggests a small but significant rhyolitic component and a stratified magma chamber
- It is likely that there were repeated episodes of fragmentation suggesting clast recycling

Further work

- SEM images showing clast morphologies will be used to distinguish between magmatic and phreatomagmatic fragmentation
- Back-scatter images of internal textures will be used to quantify vesicle and microlite populations

References

1: Óladóttir et al., (2008) Katla volcano, Iceland: magma composition, dynamics and eruption frequency as recorded by Holocene tephra layers, *B Volcanol*, 70: 475-493; 2: Icelandic Met Office: http://en.vedur.is/; 3: Larsen (2010) Katla: tephrachronology and eruption history, *Dev Quaternary Sci*, 13: 23-49; 4: Tómasson (1996) The jökulhlaup from Katla in 1918, *Ann Glaciol*, *22*, 249-254 ; 5: Sturkell et al., (2010) Katla and Eyjafjallajökull volcanoes, Dev Quaternary Sci, 13: 5-21 ; 6: Duller et al., (2008) Architectural analysis of a volcaniclastic jökulhlaup deposit,; southern Iceland: sedimentary evidence for supercritical flow, *Sedimentology*, 55: 939-964; 7: Woodcock et al., (2012) Particle-water heat transfer during explosive volcanic eruptions, *J Geophys Res, 117(B10)*