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Reconstructing palaeo-ice thicknesses:
On what type of volcano can the magma degassing technique be used?

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INTRODUCTION

Why reconstruct palaeo-ice thicknesses?
They provide a useful proxy to reconstruct palaeo-environmental change and help us to better understand the link between
1) Ice thickness and eruptive behaviour[1]
2) Ice thickness and subglacial hazards, such as jökulhlaups and tephra dispersal[2]
3) Ice thickness and eruption frequency[3]; Can the 21st century expect an increase in volcanism if anthropogenic climate change continues to cause deglciation[4]?

What is the magma degassing technique?
Samples are collected from a range of elevations and analysed for their dissolved H_2O content. Towards the top of a subglacial edifice, the ice will be thinner; less loading pressure will allow more H_2O to degas. Consequently erupted products should show a decreasing trend of dissolved H_2O with elevation[5]. Solubility pressure curves (SPCs) can be drawn to show the dissolved H_2O content one would expect at each elevation for a given palaeo-ice thickness. This provides a quick and easy way to compare actual data to theoretical palaeo-ice surfaces, until the best match is found[6].

So, what's the problem?
There has not been a single study to date, where all the data has fitted convincingly to a single SPC. For the majority of cases, an explanation has been provided for the discrepancy; examples include, under-saturated magma[6,7], underpressurised cavities due to meltwater drainage[8,9], and additional loading from hyaloclastite[6,10].

Our aim
To determine the type of rhyolitic edifice for which the magma degassing technique can effectively reveal palaeo-ice thicknesses

METHOD

- Samples were collected from SE Rauðfossafjöll, Dalakvísl and Kakafjall; three subglacial rhyolitic edifices, that formed contemporaneously, but with contrasting styles[11,12], during the 70 ka ring fracture eruption at Torfajökull[13] (Fig. 1).
- Dissolved H_2O was measured using FTIR
- For each edifice, H_2O data was compared to SPCs, to find the most representative palaeo-ice thickness
- Subglacial-subaerial lithofacies transitions from ring fracture tuyas indicate an ice surface at ~1090 m a.s.l.[13], does the magma degassing technique agree?

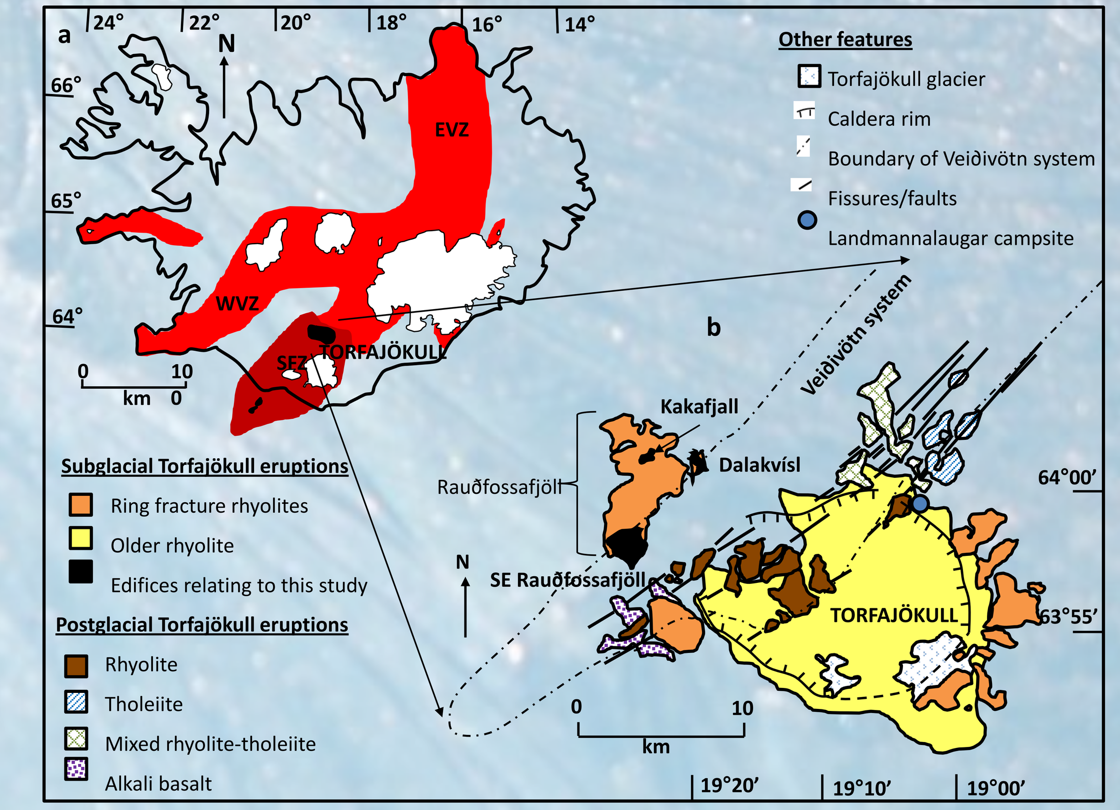

Figure 1: Geological maps of (a) Iceland and (b) Torfajökull. Modified from [6].

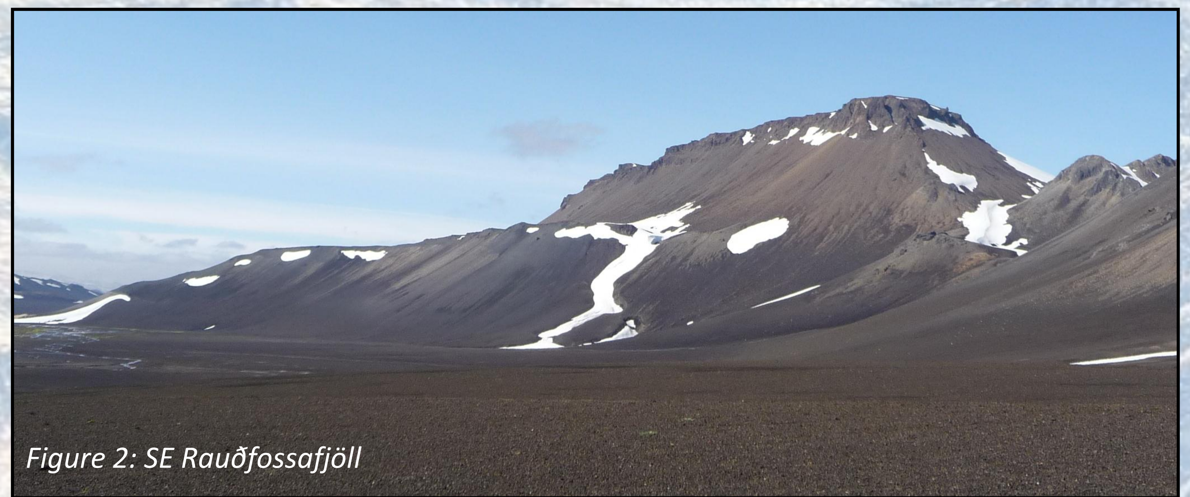
Figure 2: SE Rauðfossafjöll

Samples from upper and lower lava caps contain 0.1-0.2 wt% H_2O (Fig. 3), consistent with a subaerial emplacement[10,11].

However, lower-elevation subglacially-erupted obsidian (peperite, columnar-jointed lava and variably perlitised obsidian) also contains between 0.1-0.2 wt% H_2O. This suggests that the cavity was under-pressurised, either through a connection with the glacial snout, or through a connection to the air above, with our samples perhaps quenching after the eruption became emergent. This implies that tuyas may be unsuitable for reconstructing palaeo-ice thicknesses.

Another problem with SE Rauðfossafjöll was the scarceness of suitable obsidian for FTIR analysis amongst the subglacial deposits. Fine-grained, vesicular material , such as that which formed during the explosive subglacial phase of the eruption[11], has a tendancy to become hydrated and is thus unsuitable for the magma degassing technique.

SE Rauðfossafjöll

SE Rauðfossafjöll is a large (>1 km^3) explosively formed tuya[11] (Fig. 2). The subglacial to subaerial transition is consistent with other ring fracture tuyas suggesting a palaeo-ice surface at ca. 1090 m. However, a second lava cap at ca. 900 m suggests that the ice level was considerably lower for part of the eruption.

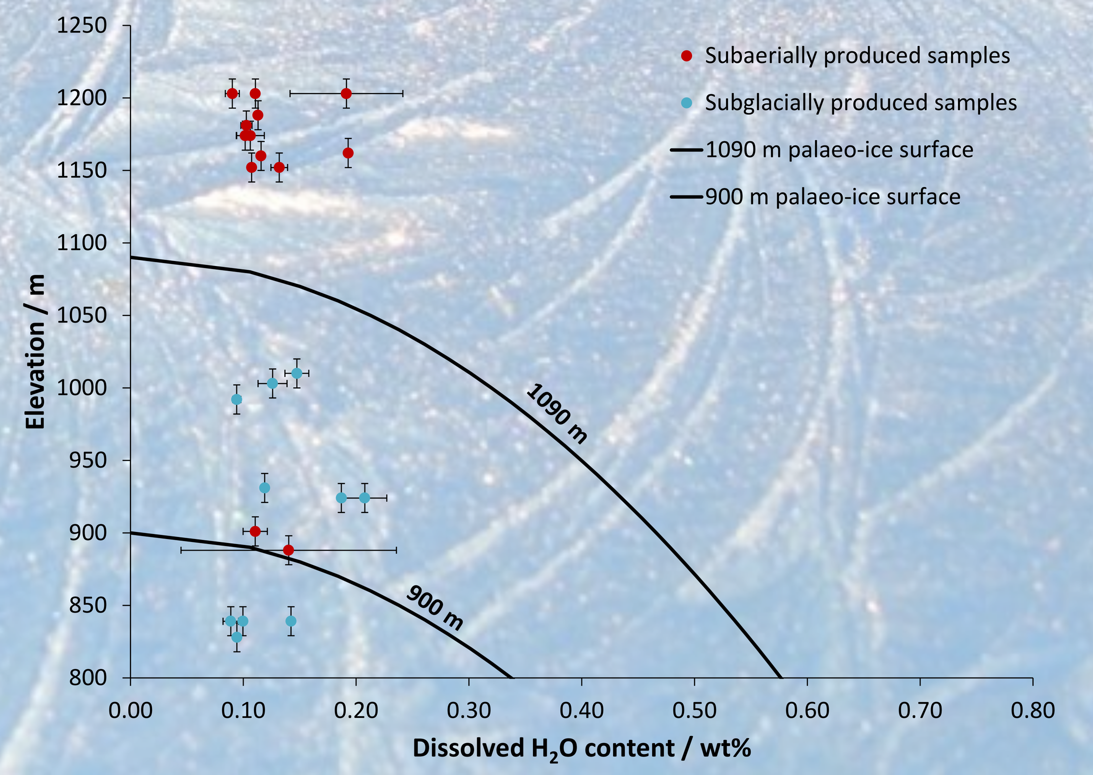

Figure 3: Water contents of SE Rauðfossafjöll samples, plotted as a function of sampling elevation, with two SPCs at 1090 and 900 m, which are inferred palaeo-ice levels based on the morphology of the edifice.

Dalakvísl

Dalakvísl was a small (0.2 km^3) mixed explosive-effusive eruption[12]. Lithofacies interpretation suggests an entirely subglacial eruptive environment but there is a potential embryonic lava cap[12]. However, at 810 m this would suggest a considerably lower ice surface than the other ring fracture rhyolites[13].

Samples where collected from the full range of lithofacies including effusive lava lobes[12] (Fig. 4a) and obsidian sheets thought to have formed during the transition in style[12] (Fig. 4b).

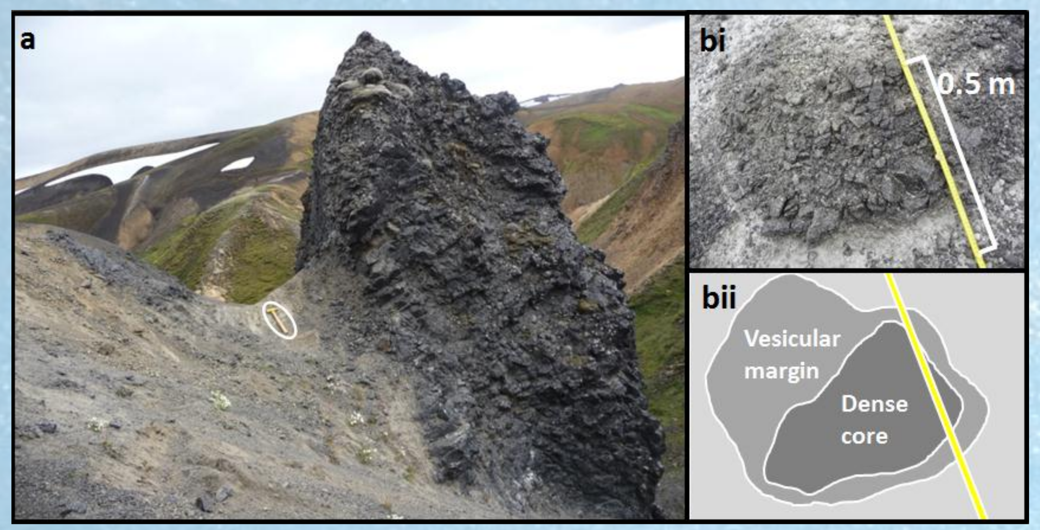

Figure 4: (a) a lava lobe with a circled hammer for scale, (b) an obsidian sheet shown (i) by photograph and (ii) schematically

Our conceptual model - to meet the observations outlined above
- A syn-eruptive jökulhlaup rapidly decreased confining pressure[14]; the obsidian sheets were quenching during this jökulhlaup-induced pressure drop.
- Vesicular sheet margins could degas to their new pressure environment (as short diffusion distance to bubble walls) whereas the vesicle-poor sheet cores could not re-equilibrate.
- The pressure difference between SPCs A & B corresponds to a 130 m drop in water level[14], comparable to observed water-level drops during jökulhlaups at Grímsvötn[15].
- This highlights a possible mechanistic links between explosive-effusive transitions and changes in subglacial meltwater pressure

Observations from the data (Fig. 5)[14]
1. When grouped in terms of lithofacies, the data fits well to SPCs that represent loading from both fragmental material and ice
2. The effusive lava lobes fit well to SPC B
3. The more explosively produced sheet margins fit to SPC A which represents a lower pressure environment
4. Sheet cores (from same sheets) plot in between these two SPCs and show a particularly rapid decrease in H_2O with elevation

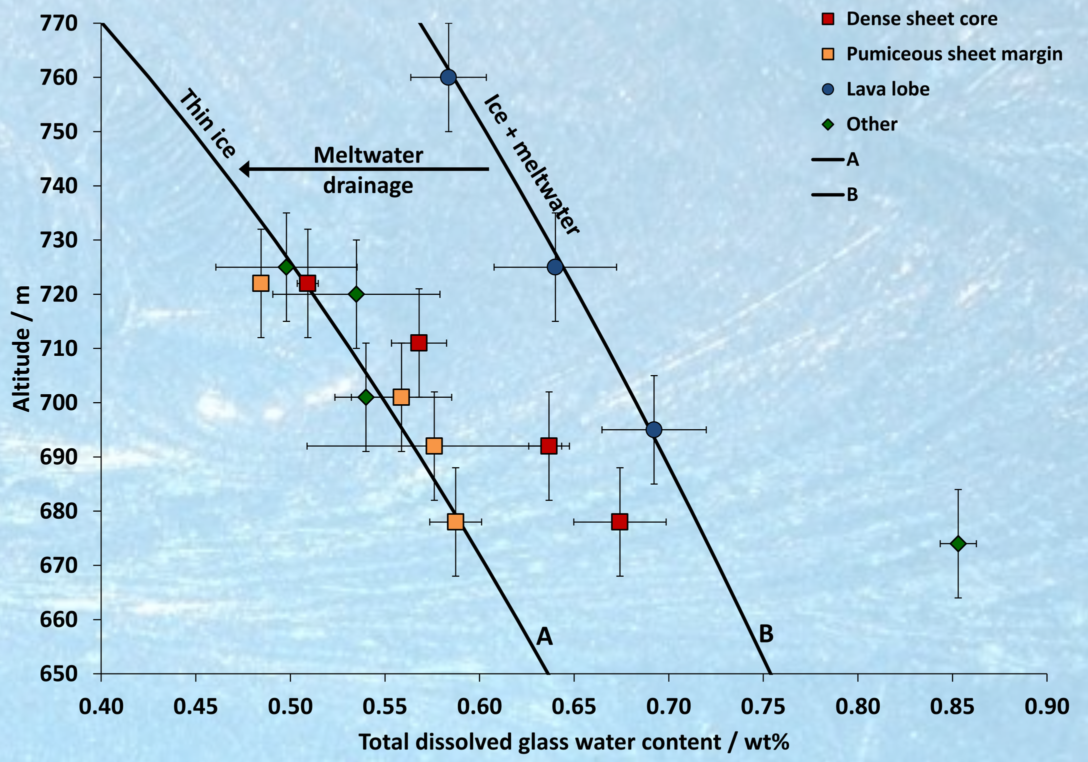

Figure 5: Water contents of Dalakvísl samples, plotted as a function of sampling elevation, with two SPCs that show partial loading from fragmental material, modified from [14].

Reconstructing a palaeo-ice thickness
Our best fit SPCs (Fig. 5) require loading by fragmental material, ice and meltwater. This makes it impossible to provide a single value for the palaeo-ice surface because the ratio of loading materials is unknown. Furthermore, the data fits onto <u>two</u> SPCs.

However, by assuming that SPC B represents pre-jökulhlaup conditions, the palaeo-ice surface can be confined to 930 - 1020 m a.s.l.[14]. The inferred palaeo-ice surface from ring fracture tuyas[13] suggests that the upper estimate is more accurate.

Kakafjall

Kakafjall formed during an entirely-subglacial, small volume (ca. 0.1 km^3) effusive eruption (Fig. 6). Abundant columnar-jointed lava with close fracture spacing, suggests ice contact[16] (Talk to Anne Forbes: XL263 EGU2012-67).


Figure 6: Kakafjall

FTIR data fits well with a SPC representing a palaeo-ice surface at 1120 m (Fig. 7), consistent with estimates (~1090 m) from lithofacies transitions of ring fracture tuyas[13]. This is the first example of volatile data matching a single SPC, and provides a convincing palaeo-ice thickness.

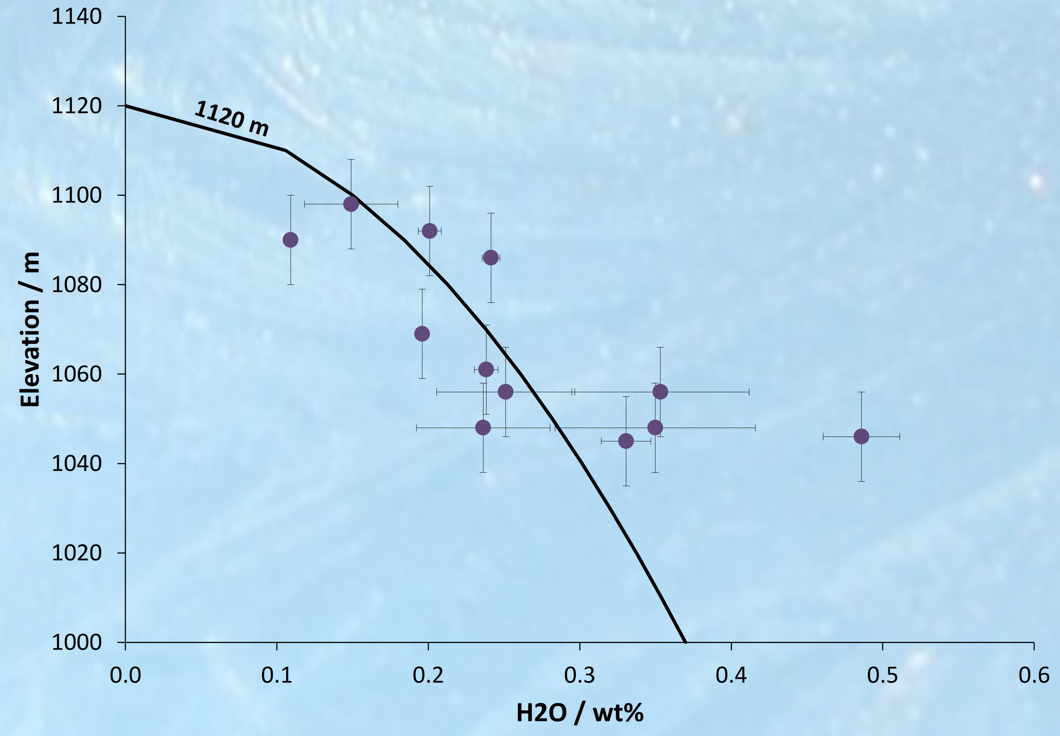

Figure 7: Water contents of Kakafjall samples, plotted as a function of sampling elevation, with a SPC representing an ice surface at 1120 m

CONCLUSION

On what type of volcano can the magma degassing technique be used?

Unfavourable edifices
1. Tuyas because the emergence of the edifice may lead to complete degassing
2. Explosively formed edifices because they tend not to preserve suitable obsidian
3. Well-eroded edifices where the samples exposed today originally formed intrusively
4. Lithofacies that suggest a change in cavity pressure may produce multiple SPCs

Favourable edifices
1. Effusive eruptions because this favours the production of in-situ, non-hydrated obsidian lava bodies
2. Entirely subglacial edifices because confining pressure is more likely to be equal to glaciostatic pressure (i.e. ice loading) rather than atmospheric pressure
3. Edifices that show strong evidence for ice contact because then loading pressure can be solely attributed to ice

However, it should be noted that although SE Rauðfossafjöll and Dalakvísl showed ambiguous results for reconstructing palaeo-ice thicknesses, use of the magma degassing technique has provided useful additional insights into loading materials, erosion quantities and subglacial pressure regimes; the latter possibly being connected to changes in eruptive style[14] which has significant consequences for subglacial hazards.

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