Volatile degassing in subglacial rhyolitic eruptions: Evidence for palaeo-ice thicknesses and eruptive mechanisms

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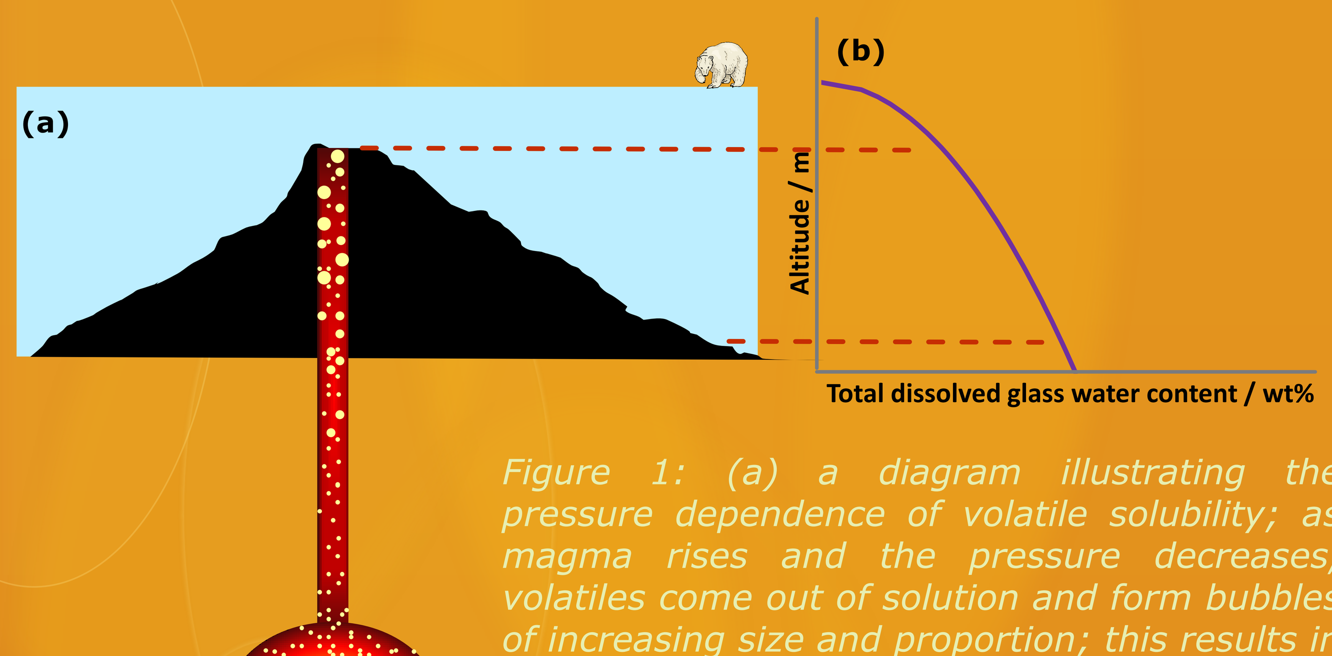

Figure 1: (a) a diagram illustrating the pressure dependence of volatile solubility; as magma rises and the pressure decreases, volatiles come out of solution and form bubbles of increasing size and proportion; this results in the dissolved volatile content getting lower, (b) a graph showing how the total dissolved volatile content will decrease with elevation on a subglacial volcano, thus there should be less magmatic volatiles at the summit of a subglacial volcano, compared to the base, as depicted by the dashed lines

The volatile degassing of subglacial volcanoes is a useful indicator of palaeo-ice thicknesses. This is because the solubility of water is pressure dependent, therefore the amount of water which is retained within the magma can be used to estimate the pressure at which it quenched (Fig. 1). If one assumes that this pressure is caused by overlying ice of a uniform density, then one can estimate the thickness of ice that was covering the volcano at the time of the eruption[1].

The degassing technique has been applied to three subglacial rhyolitic volcanoes within the Torfajökull complex in southern Iceland (Fig. 2). It has been discovered that the method also provides useful insights into the eruptive mechanisms of these volcanoes.

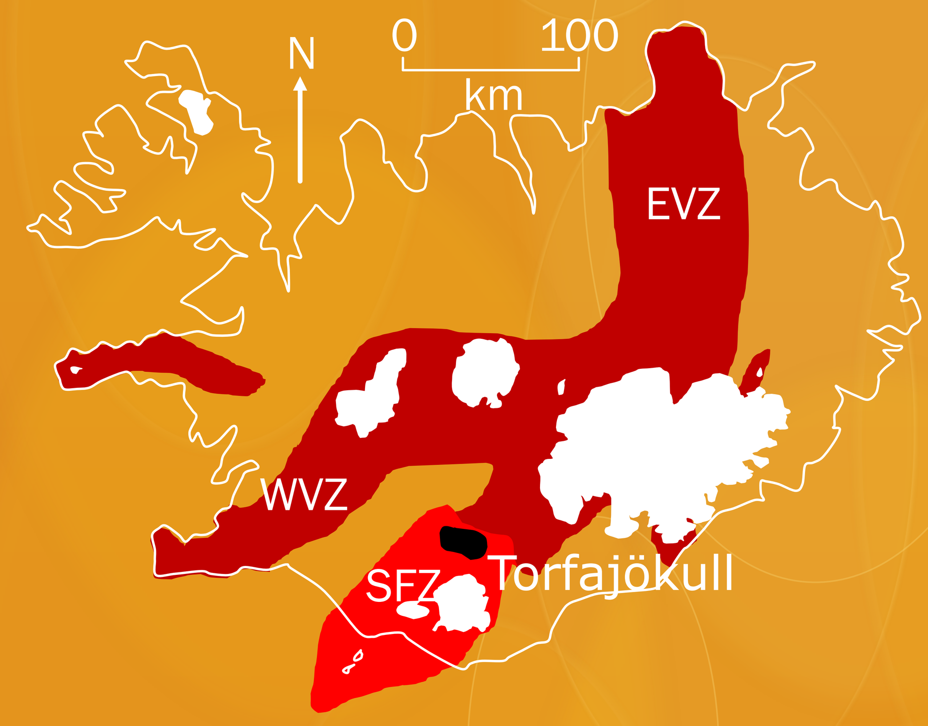

Figure 2: A map of Iceland with the main volcanic belts highlighted in red, glaciers in white and the Torfajökull complex in black. EVZ: Eastern Volcanic Zone, WVZ: Western Volcanic Zone, SFZ: Southern Flank Zone (Modified from [2&3])

Case Study 1: Bláhnúkur

Bláhnúkur is a small volume, effusive volcano that never made it through the ice sheet[4,5] (Fig. 3). This means that the ice must have been at least 350 m thick when Bláhnúkur formed (because this is the height of the volcano) but not much more can be said from field observations.

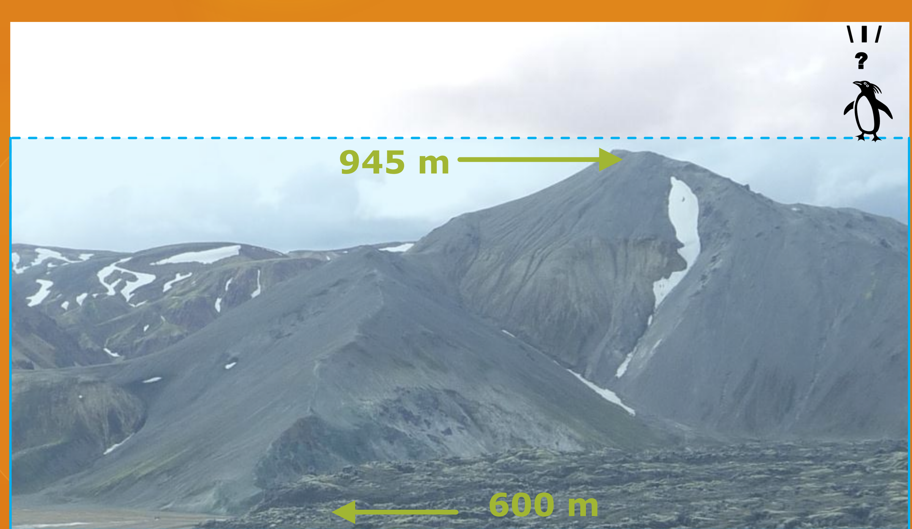

Figure 3: A photograph of Bláhnúkur with the summit and base elevations shown. The eruption was entirely subglacial hence the dashed line of uncertainty on the upper surface of the ice box (pale blue) marking the minimum thickness.

Data from top ridge, the feeder dyke, the northern slope and Graenagil suggest that the ice surface was at 1000 m a.s.l. when Bláhnúkur erupted (Fig. 4) i.e. the ice was 400 m thick. However, samples from the lobe slope and Brandsgil are water-rich by comparison. This suggests that these locations formed intrusively where they experienced loading from both volcanic material and ice and hence formed under higher pressure. In contrast, the samples from A rich are water-poor. This suggests either low pressure conditions (e.g. if there was a hydrological connection to the glacier snout) or a low initial water content[6].

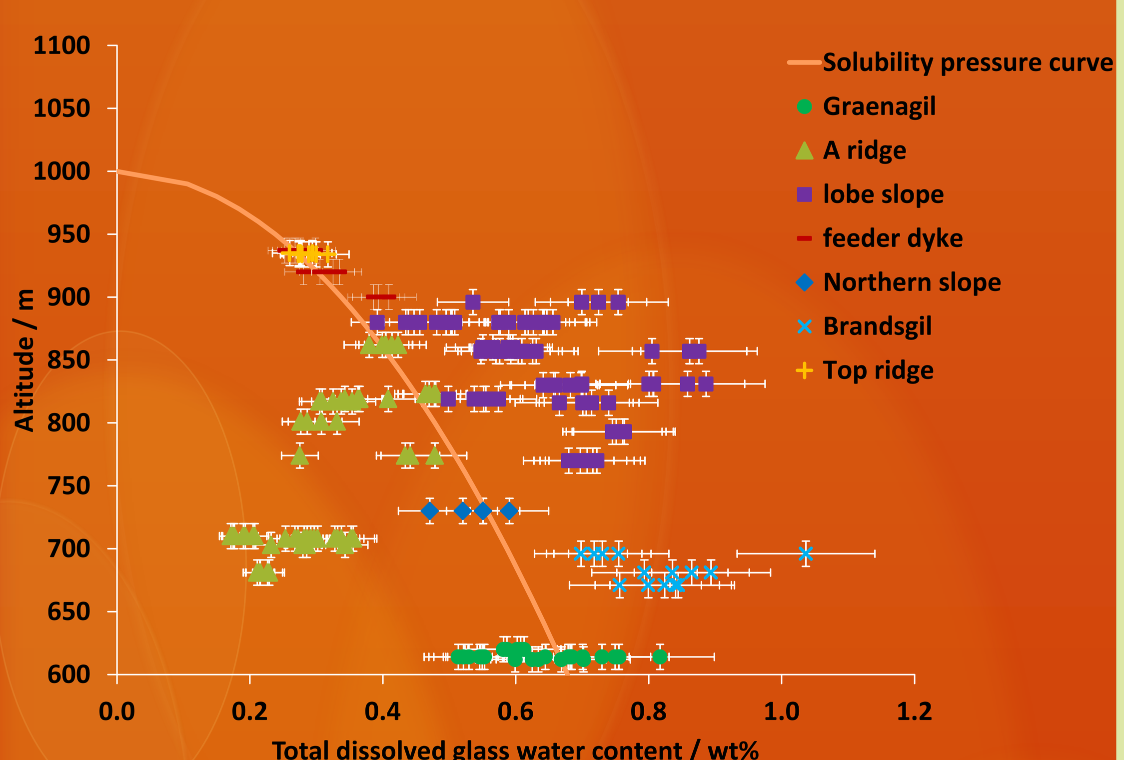

Figure 4: Bláhnúkur water content plotted as a function of elevation. Each symbol represents a single FTIR measurement of which at least 5 were made per sample. Error bars are ±10% (the standard for FTIR[1]). The different shapes and colours of the symbols denote different sampling locations. The solubility pressure curve represents the water content one would expect with an ice surface at 1000 m (using VolatileCalc[7] and assuming a temperature of 800°C, 0 ppm of CO_2 and a rhyolitic composition)

Case Study 2: Dalakvísl

The eruption of Dalakvísl, like Bláhnúkur, was also entirely under ice, meaning that field observations provide just a minimum estimate of ice thickness (Fig. 5). However, the eruption was slightly more explosive than Bláhnúkur[8].

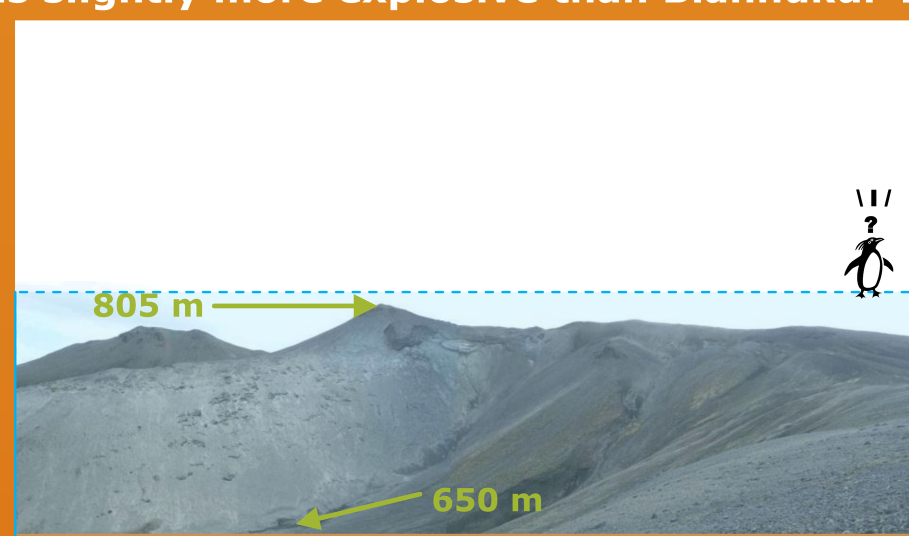

Figure 5: A photograph of Dalakvísl with the summit and base elevations shown. The eruption was entirely subglacial hence the dashed line of uncertainty on the upper surface of the ice box (pale blue) marking the minimum thickness.

Water contents from Dalakvísl are on average marginally higher than Bláhnúkur and suggest a slightly greater ice thickness. However, the gradient of the curve is too great to provide a good fit to the data, unless hyaloclastite is also considered (compare solubility pressure curves A & B in Fig. 6). This suggests that there has been considerable erosion from all over Dalakvísl to expose samples that originally formed under volcanic material.

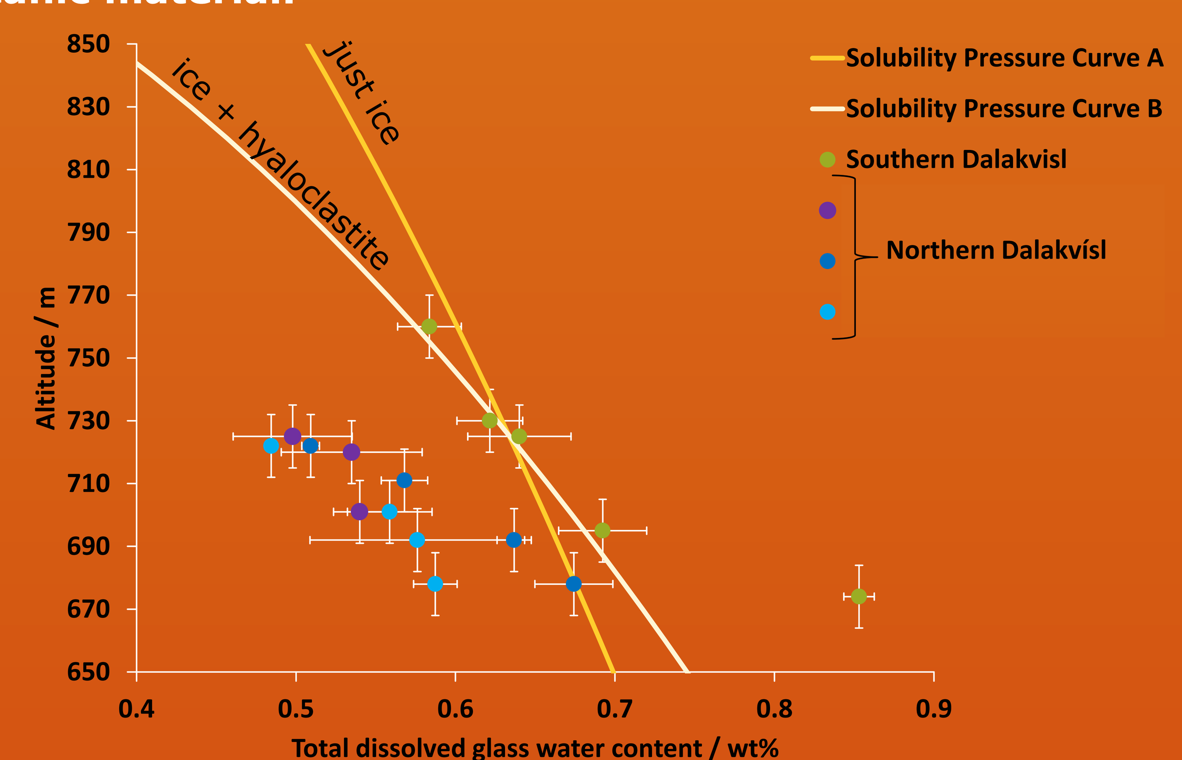

Figure 6: Dalakvísl water contents plotted as a function of elevation. Each symbol represents the average of at least 5 FTIR measurements. Error bars are the standard deviation. The different colours of the symbols denote different sampling locations. The solubility pressure curve represents the water contents one would expect with either A: solid ice up to 1050 m or B: a mixture of hyaloclastite and ice (using VolatileCalc[7] and assuming a temperature of 800°C, 0 ppm of CO_2 and a rhyolitic composition)

The eruption of Dalakvísl began explosively but later became intrusive. The obsidian sheets with their dense cores but highly bubble-rich outer margins (Fig. 7) are thought to have formed during this transition in style[8]. The change in bubble content could be explained by a very rapid drop in pressure e.g. by a jökulhlaup (meltwater flood). This explanation is supported by the water data which suggests that the more bubble-rich zones formed under higher pressure than the bubble-poor zones (Fig. 8). Thus, it is my belief that a jökulhlaup was occurring as the obsidian sheets formed.

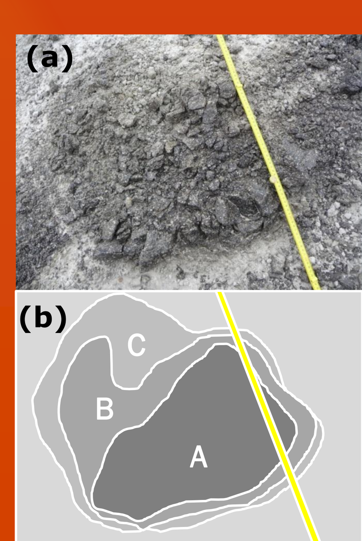

Figure 7: (a) a photograph of an obsidian sheet, (b) a schematic of an obsidian sheet
A=dense interior,
B=transition zone,
C=bubbly outer zone

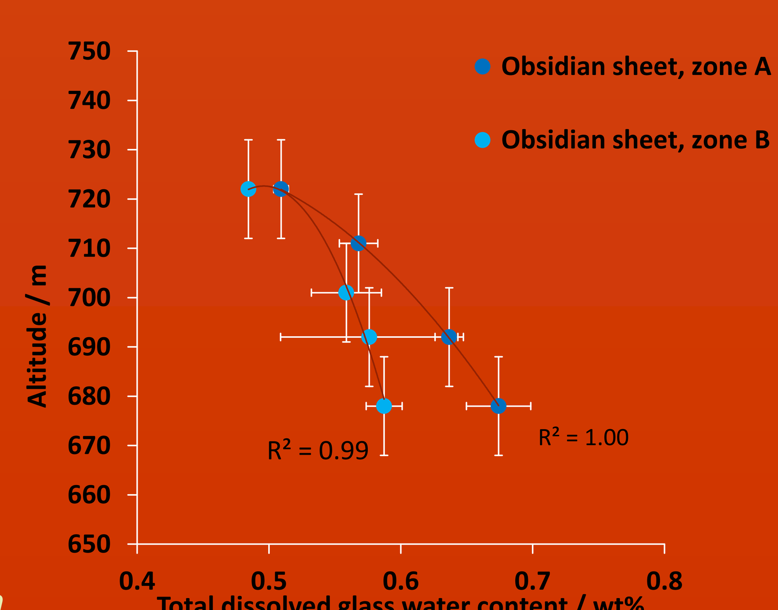

Figure 8: The obsidian sheet samples taken from Figure 6, with trend lines added in dark red

Case Study 3: SE Rauðfossafjöll

The eruption of SE Rauðfossafjöll was even more explosive, allowing the volcano to erupt through the ice sheet and produce a tuya[9]. The change observed in the field, from subglacially formed to subaerially formed rocks, allows one to confine the ice surface to ~1150 m, but will the degassing method agree?...

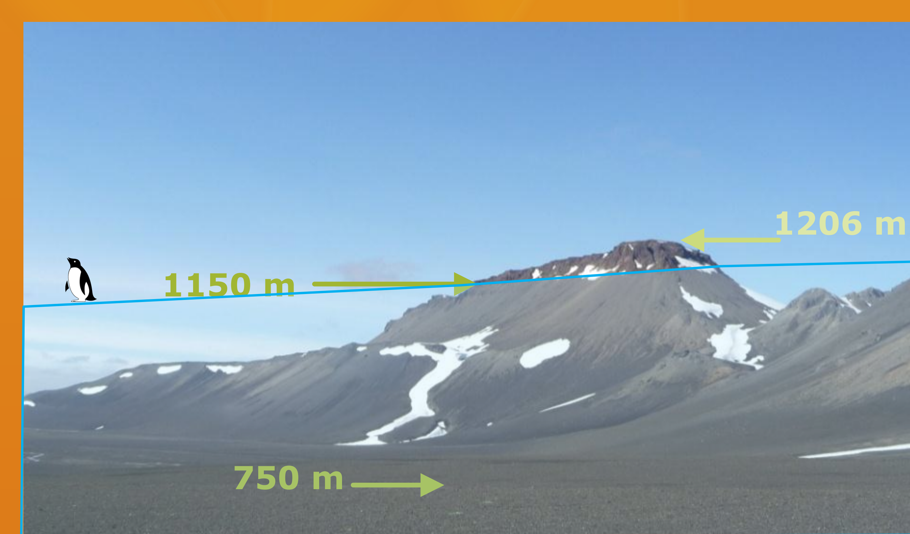

Figure 9: A photograph of SE Rauðfossafjöll with the summit and base elevations shown. The eruption burst through the ice, therefore it is possible to constrain the ice thickness based on observing in the field the transition from subglacial to subaerial. This is marked at 1150 m by a solid blue line on the upper surface of the ice box (pale blue)

... No! All the samples from SE Rauðfossafjöll have almost entirely degassed to atmospheric conditions; 0.1 – 0.2 wt% H_2O (Fig. 10). This is a consequence of the eruption becoming emergent.

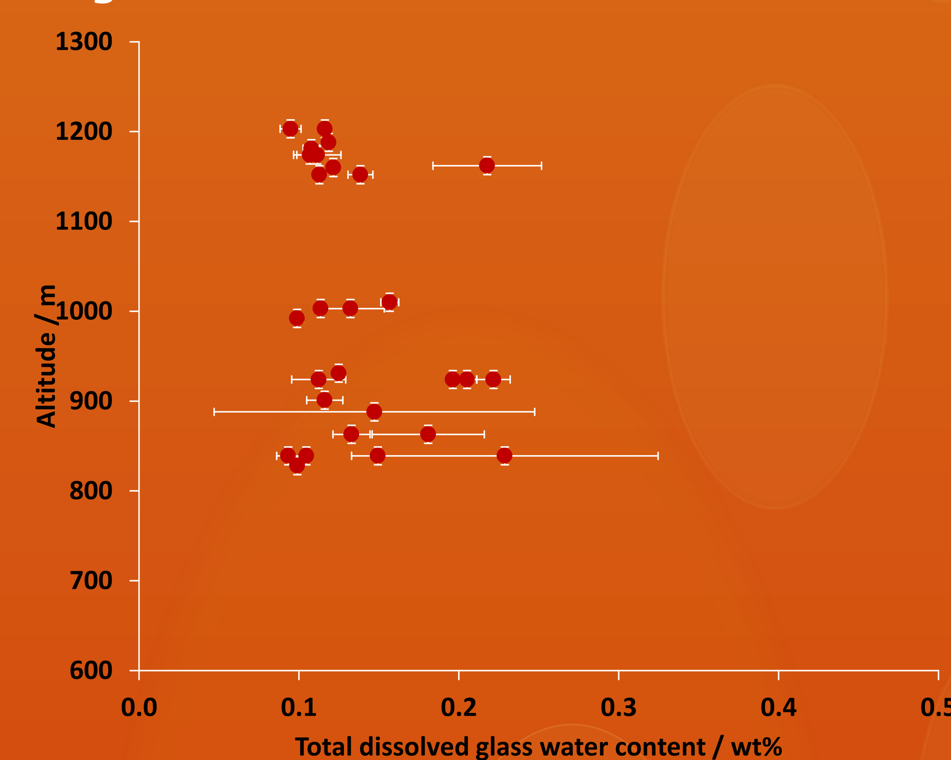

Figure 10: SE Rauðfossafjöll water contents plotted as a function of elevation. Each symbol represents the average of at least 5 FTIR measurements. Error bars are the standard deviation.

Conclusions

- **It is important to collect a large data set as the story seems seldom simple**
- **Only eruptions that were entirely subglacial, can be used with the degassing technique**
- **Uncertainties in some parameter conditions e.g. eruptive temperature, CO_2 content or overlying medium (just ice or volcanic debris too?), can make a quantitative estimation difficult**
- **Relative pressure conditions offer a useful insight into eruptive mechanisms e.g. the occurrence of a jökulhlaup mid-eruption**

References

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