Hrútfjall geological remote sensing investigation

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Introduction

Öræfajökull

The Bruhnes age (i.e., less than 780 ka, Prestvik, 1979) Öræfajökull stratovolcano is almost entirely composed of subglacially erupted volcanics along with glacio-fluvial sediments, tillites, and subaerial lava flows (Helgason and Duncan, 2014). The active stratovolcano unconformably overlies two older central volcanoes (Stevenson, 2005) and lavas of Miocene and Pleistocene (Matuyama) age. Mapping and age dating by Helgason and Duncan (2001, 2014), suggested the area was under variable but almost constant ice cover from up to 1 Ma, this explains the abundance of hyaloclastite formations in the Öræfajökull sequence. Subaerial lava flows are more common in the upper portions of the formation, a consequence of retreating ice following the Last Glacial Maximum and common basaltic volcanism. In historical times there have been 2 eruptions, first in AD1362, which was a devastating explosive silicic eruption, and later with a basaltic eruption in 1727 (Thórarinsson, 1958).

Hrútfjall

Hrutfjall can be broadly split into 2 main formations, the older, predominantly subaerial lavas of the Hafrafell formation (Helgason and Duncan 2013, 2014), and the younger, Bruhnes age rocks of the Öræfajökull volcano formation (ÖF). The glacier of Svínafellsjökull has incised a steep sided valley into the formations, giving a cross-sectional view of the ÖF and its basement. The face of Hrútfjall is an impressive feature, displaying a relatively uninterrupted view of the rocks, with relatively few talus slopes covering the area due to the glacier sweeping away material falling onto it. The stratigraphy is probably similar to that mapped and described by Stevenson et al. (2005) at Vatnafjall, Kvíarjökull.

The sheer cliff of Hrutfjall is both a 'blessing and a curse', as the exceptional exposures are almost entirely inaccessible safely during the summer months when the face is snow and ice free. This short report details the mapping that was possible during the summer, utilising remote mapping by drones and a short excursion to sample and map the base of the face.

Method

Fieldwork was undertaken during August 2021, the drone mapping was undertaken in 2 stages, firstly from the base of the Hrútfjall cliff during a bedrock mapping and sampling excursion and secondly from close to the summit of Skarðatindur. Both surveys gave better-than expected results, and the imagery acquired was used for analysis and processing into 3D models.

Bedrock mapping was limited due to the difficulty of access to the cliff and the loose and dangerous access to higher up the cliff. As such, much of the work needs to be inferred from other localities or rocks in scree.

Image processing into 3D models was undertaken using Agisoft Pro at the Icelandic Institute of Natural History. The model will be published on V3Geo, an open platform for viewing geological models, when final checks and georeferencing has been completed (Figure 1).

Results and interpretations

Our preliminary study into the geology and geomorphology of Hrútfjall found a complex interplay between intrusive and extrusive rocks, as well as glacial and interglacial volcanics (Figure 2). A detailed figure is available at https://jardfraedi.github.io/hrutfjall/.

Dykes and sheets

Initial mapping discovered intrusive sheets and dykes throughout the sequence, the high density of the intrusive activity (>10%) is indicative of central volcano activity (Walker 1963; Figure 3). Interestingly, 2 general trends of intrusives were found, one set with a dip direction (direction of source) to the west, and the other to the west. The juxtaposition of these swarms in this small locality indicates that there are 2 separate sources for the intrusions, suggestive of two separate central volcanoes, one being Öræfajökull, the other an extinct volcano to the west of the field area.

Blue-green tuff - vent material?

The window of bedrock, seen in the Svínafell glacier ice fall (Figure 2), is intriguing. It is entirely inaccessible, though material from the bedrock is eroded by the ice and can be found scattered over the glacier close to the ice fall. The rock is greenish, indicative of chlorite and epidote hydrothermal alteration caused by fluids circulating in the bedrock, and comprises an ash tuff matrix with larger lapilli sized clasts of pumice and lithics. Rocks scattered across the glacier display varying amounts of the lithic to pumice ratios, some being predominantly lithic breccias and others being more pumice dominated.

Along the same stratigraphic level as the green tuff is a silicic intrusion (Figures 2 and 3). Due to the ice, no contacts between these 2 units can be established, though due to the presence of the intrusion both sides of the ice fall, it appears that the tuff could be younger than the intrusion. As such, the tuff must crosscut the intrusion, suggesting this may be vent agglomerate material. The proximity of the green tuff close to the current caldera rim of Öræfajökull makes this suggestion plausible, as explosive silicic eruptions do occur here and would preferentially fill in pre-existing topographic lows in the area.

Hrútfjall

Aerial imagery taken in this project shows a complex geological record on the face of Hrútfjall (Figures 1, 2, and 3). Without access to direct contacts, a true history is impossible to gather, but the high-quality imagery coupled with 3D relationships using photogrammetric modelling allows some piecing together of a 'most-likely' scenario.

The base of Hrútfjall is Matuyama age lavas of basaltic composition. These are subaerially erupted, often displaying red-bed paleosols between lavas, though in this area the alteration is most pervasive through these more permeable rocks. There is a rough continuity across the glacier to the south, where Matuyama age lavas are present. A good section is easily accessible at this location, lavas are overlain by a thick, columnar silicic body. In this location the silicic rock is massive, and the contact between lavas unconformable and sharp. The silicic body is a thick intrusion that appears to link further south to a steep wall on Skarðatindur.

Silicic rocks are exposed unconformably above the Matuyama age lavas on Hrútfjall, however, image analysis reveals that the rocks display tuffaceous features, including layering and clasts. The layering is horizontal to sub-horizontal. This is therefore not thought to be the same body as the silicic intrusion.

The entire cliff face displays complex erosional and in-filling geology. Silicic rocks are a dominant feature of the cliff face, a major silicic tuff and lava is visible at 1000 m elevation to a thickness of 770 m. This was probably erupted in a subglacial effusive eruption, as it displays features similar to those found in subglacial silicic eruptions in Kerlingarfjöll (Stevenson, 2006). A clear erosional unconformity cuts the silicic body on the eastern side of the south face, this has a lens of breccia-like material between the silicic body and the brownish tuff and basaltic lava which is exposed above the unconformity. The tuff and lavas grade up into subaerial basaltic lavas, which form the highest points of the mountain. This sequence is interpreted to have been formed through a silicic eruption, which produced the silicic lavas and tufts, this was then partially eroded. The ice may have been retreating or thin at this point, the presence of a breccia suggests the area became ice-free though the basaltic tuff above must have been formed underwater, be that ice or a pro-glacial lake.

Slope instability

There does not appear to be a significant fissure or cracking of the face of Hrútfjallstindar. Figure 4 shows a close up of an area indicated by a black line in figure 2. This is a detached block, that is likely to collapse and form some sort of mass movement deposit on the glacier below. However, this block is 300 m in length, by 200 m high, which would not cause a significant disturbance to the glacier or a wide-spread hazard as is expected from the instability below Svínafellsheiði on the other side of the valley. Another possible crack is visible slightly east of this block, though it is difficult to assess as it is snow and ice covered. This second may not be a fracture but cannot be reliably assessed. Our findings do not preclude the possibility that a significant (i.e., would affect the local population or infrastructure) landslide hazard is present but not visible in this study's model.

Discussion and Conclusions

This study was a preliminary investigation to test the warrants and limits to a remote-sensing based mapping project on Hrútfjallstindar. Our results show that this is entirely possible, though some further ground-truthing would be preferred, but is nevertheless a difficult or dangerous undertaking.

We show that Hrútfjalls south face displays a complex geology. We propose that the majority of the mountain consists of Brunhes age rocks, predominantly formed on the flanks of the Öræfajökull stratovolcano. The entire face displays at least three periods of ice-free eruptive environments. The first is the older Matuyama age rocks that are pre-glacial, a small section of subaerial basalts, sediments, and scoria halfway up the mountain face indicates a second ice-free phase or first interglacial period, the last is seen in the uppermost sequences of the mountain comprising the summit peaks.

A significant proportion of the rocks on the face are silicic, including a thick sequence thought to be from a single eruption. The silicic rocks show typical morphologies of silicic subglacial eruptions such as tuffs, and fine columnar jointing (e.g., Stevenson et al. 2006). These were probably erupted in an ice filled valley, when the ice retreated, the valley was filled with diamictites (glacial or fluvial breccias), lake or river sediments, and basaltic lava flows.

A shallow intrusion is also seen on the southern side of the glacier of Svínafell, this must have intruded at less than 1 km depth and would have caused significant deformation and tectonic activity in the area. A significant intrusion such as this could cause some ground deformation and further increase slope instabilities on the slopes of the volcano.

We do not see any significant, i.e., non-localised, landslide hazards in the models produced in this study (crack shown in Figures 2 and 4; such as seen on Svínafell), this does not rule out the possibility of a hazard forming in the future. The geology of the cliff face is such that there is a low risk of a fracture forming through a significant portion of the face.

We hope this preliminary study can be used to further investigate the edifice building processes that formed the Öræfajökull stratovolcano, and the complex glacial and interglacial morphologies and interactions seen within it. Further work is needed, with more time required in the field in order to safely reach areas that are accessible, including accessing from the upper areas of Hrútfjallstindar.

Figures

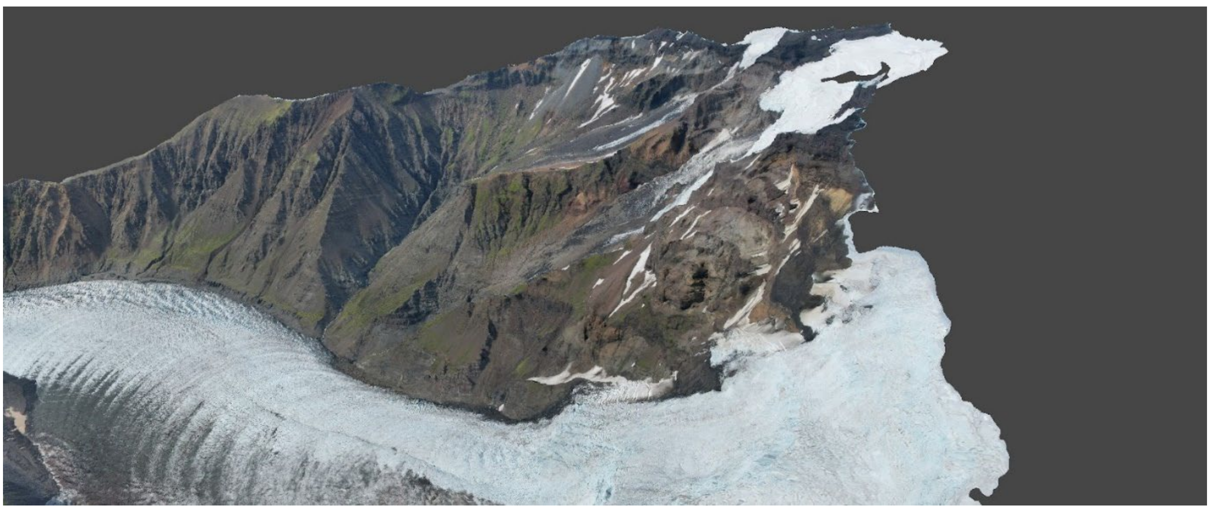

Figure 1: Agisoft generated 3D model of Hrútfjall

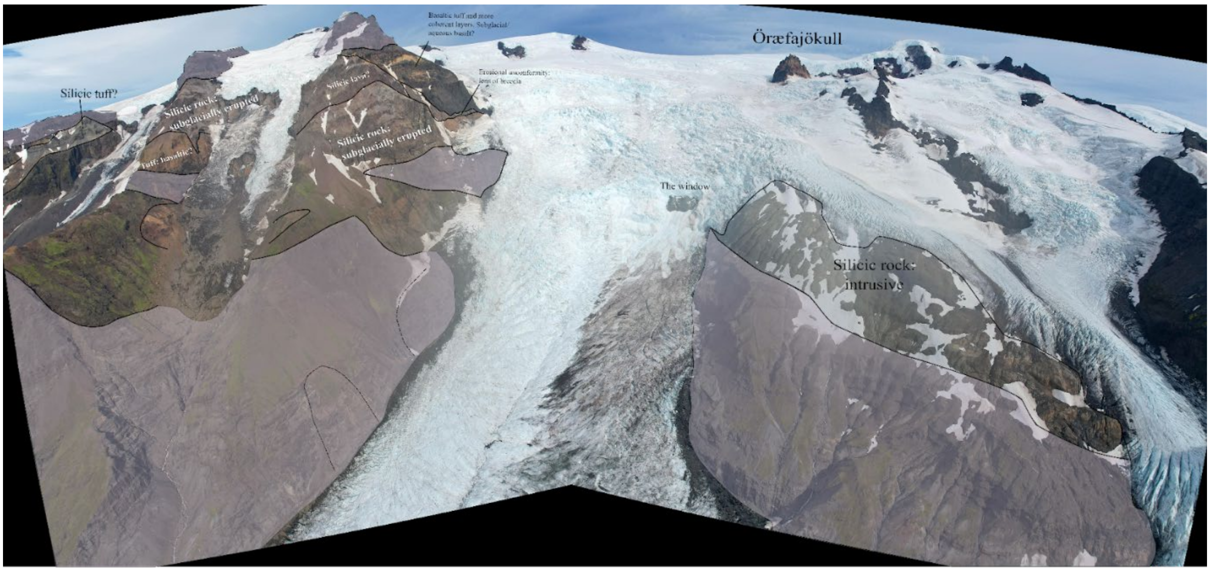

Figure 2: Hrútfjallstindar and Öræfajökull with major geological boundaries indicated. Grey shading indicates subaerially erupted lavas, black dashed lines indicate visible cracks. Image width is approximately 2.5 km.

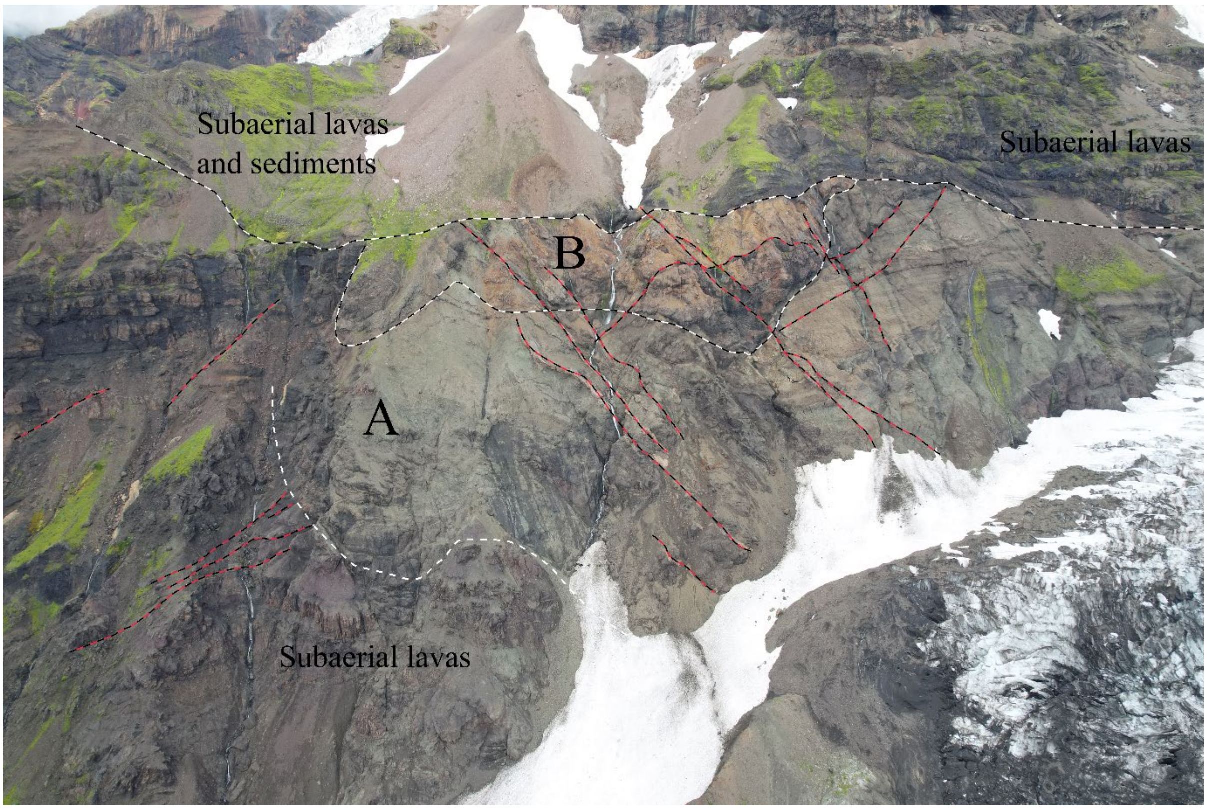

Figure 3: Drone image of Hrútfjall. Subaerial lavas are indicated, dykes and sheets are shown as red lines (where they are visible). A) is a tuffaceous-like material, it appears layered and blur-green-grey in colour. It is unconformably overlying the subaerial lavas below, it's layered, and tuffaceous, appearance leads one to suggest it is extrusive though no ground-truthing is possible (it could be related to the "window" rocks found on the glacier). B is a silicic, orange-black brecciated rock, it appears to infill a small section of the blue-green tuffaceous rock. It is possible this rock is a brecciated lava. Thin subaerial lavas and sediments overlie these units. The image shows an area of approx. 700 m wide by 800 m high.

Figure 4: An unstable block in basement lavas, detached from the main cliff, the block is relatively small, close to the glacier surface and is unlikely to be a significant hazard. The block is 300 m wide (approx. visible extent on this image) by 200 m high. The instability follows a weakness provided by a pale coloured dyke diagonally cross-cutting the sequence. The glacier can be seen in the bottom left of the image.

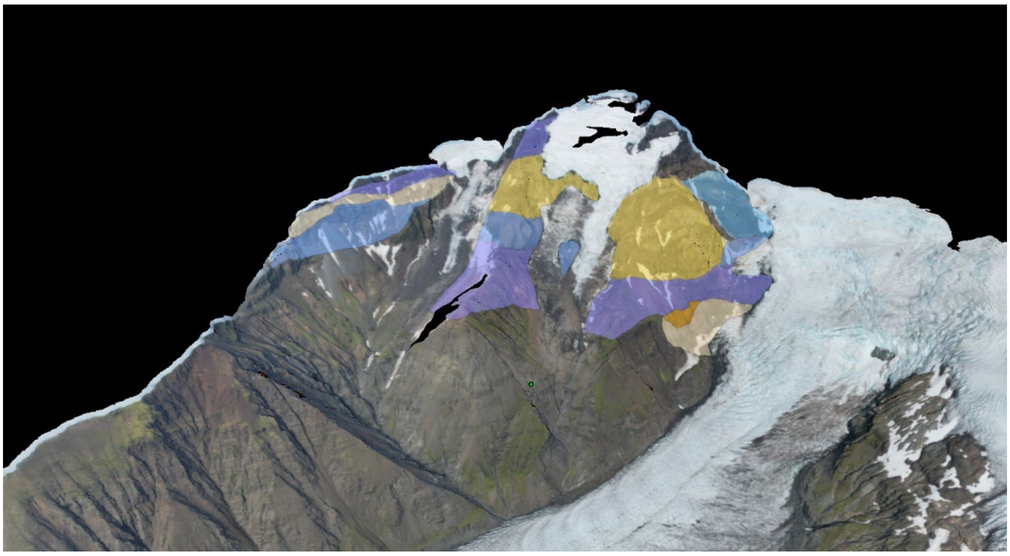

Figure 5: Geological mapping utilising a 3D mapping program. Yellow: silicic sib-glacial lava; Purple: Sub-aerial lava displaying some evidence of water interaction in the stratigraphy, younger than Matuyama; Blue: Sub-glacially erupted tuff; light yellow/cream: Silicic tuff; Orange: silicic rock unknown origin; No colour: Older sub-aerial basalts and red-beds.

References

Helgason, J. and Duncan, RA., 2001. Glacial-interglacial history of the Skaftafell region, southeast Iceland, 0–5 Ma. *Geology* 29(2):179–182.

Helgason, J. and Duncan, R.A., 2013. Stratigraphy, 40Ar-39Ar dating and erosional history of Svínafell, SE-Iceland. *Jökull*, *63*, pp.33-56.

Helgason, J. and Duncan, RA., 2014. Magnetostratigraphy, K-Ar dating and erosion history of the Hafrafell volcanics, SE–Iceland. *Jökull*. 64, pp 41–60.

Loughlin, S.C., 2002. Facies analysis of proximal subglacial and proglacial volcaniclastic successions at the Eyjafjallajökull central volcano, southern Iceland. *Geological Society, London, Special Publications*, *202*(1), pp.149-178.

Prestvik, T., 1979. Geology of the Öræfi district, S.E. Iceland. *Nordic Volcanological Institute Report* 79-01, Reykjavík.

Stevenson, JA., 2005. Volcano-ice interaction at Öræfajökull and Kerlingarfjöll, Iceland. *PhD Thesis*, Open University, Milton Keynes.

Stevenson, J.A., McGarvie, D.W., Smellie, J.L. and Gilbert, J.S., 2006. Subglacial and ice-contact volcanism at the Öræfajökull stratovolcano, Iceland. *Bulletin of volcanology*, *68*(7), pp.737-752.

Thorarinsson, S., 1958. The Öræfajökull eruption of 1362. *Acta Naturalia Islandica* 2:1–100.

Walker, G.P.L., 1963. The Breiddalur central volcano, eastern Iceland. *Quarterly Journal of the Geological Society*, *119*(1-4), pp.29-63.