Structural mapping and analysis of rifting events using UAVs in the North Volcanic Zone (Iceland)

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Where will magma erupt?

- Understanding how magma propagates in the crust and eventually erupts is one of the key points in volcanology research.

- In this project we investigate the role of pre-existing structures and their reactivation during magma propagation in extensional tectonic environments.

- Iceland lies on both a spreading plate boundary and a mantle plume ⇒ occurrence of volcano-tectonic events

- Natural laboratory to examine the interaction of structures and propagating magma

- Scarcity of vegetation ⇒ terrain suitable for UAV surveys

- Historical reports of volcanic events since the first settlements (~ 870 AD)

Fig. 1 The Mid-Atlantic Ridge (black line) cutting through Iceland and the current position of the Icelandic mantle plume (red dot). Modified after Thordarson and Larsen (2007).
Icelandic *Fires:* historically recorded volcano-tectonic events

Icelandic *Fires* involve:
- **transport of magma** in the crust
- Eruptions
- Formation of graben structures
- Often **reactivation** of pre-existing structures.

<table>
<thead>
<tr>
<th>Event #</th>
<th>Volcanic system</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>Krafla</td>
<td>ca. 550 BC</td>
</tr>
<tr>
<td>②</td>
<td>Peistareykir/Krafla</td>
<td>1618</td>
</tr>
<tr>
<td>③</td>
<td>Krafla</td>
<td>1724-1729</td>
</tr>
<tr>
<td>④</td>
<td>Askja</td>
<td>1875</td>
</tr>
<tr>
<td>⑤</td>
<td>Krafla</td>
<td>1975-1984</td>
</tr>
<tr>
<td>⑥</td>
<td>Barðarbunga-Veidivötn</td>
<td>ca. 150</td>
</tr>
<tr>
<td>⑦</td>
<td>Bárðarbunga</td>
<td>ca. 870</td>
</tr>
<tr>
<td>⑧</td>
<td>Katla/Bardarbunga</td>
<td>ca. 934-940</td>
</tr>
<tr>
<td>⑨</td>
<td>Barðarbunga-Veidivötn</td>
<td>1480</td>
</tr>
<tr>
<td>⑩</td>
<td>Grímsvötn</td>
<td>1783-1785</td>
</tr>
<tr>
<td>⑪</td>
<td>Barðarbunga</td>
<td>1797</td>
</tr>
<tr>
<td>⑫</td>
<td>Bárðarbunga</td>
<td>1862-1864</td>
</tr>
<tr>
<td>⑬</td>
<td>Bárðarbunga</td>
<td>2014-2015</td>
</tr>
<tr>
<td>⑭</td>
<td>Hengill (West Volcanic Zone)</td>
<td>1789</td>
</tr>
</tbody>
</table>

Fig. 2 DEM (ArcticDEM) overlaid by the principal volcanic systems, composed by a central volcano (in brown) and a fissure swarm (outlined in black), and the locations of the historical volcano-tectonic events (in red). The numbers correspond to the events listed in the table. The two black arrows are the rift opening rate obtained by geodetic studies (e.g. DeMets et al., 2010).
• A UAV survey has been carried out in **Fjallagjá**, structurally relevant and logistically accessible area in the Askja volcanic system.

• Fjallagjá is a graben ~15-20 m deep and ~1 km wide that extends parallel to **Sveinagjá** graben for ~18 km.

• Sveinagjá graben was activated and it subsided 3 to 6 m during the 1875 volcano-tectonic event (Gudmundsson and Bäckström, 1991).

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**Fieldwork August 2019**

- 21 flights
- 13.5 km² coverage
- 31865 total images
- 540 Gb total images data
- 1.0 – 1.5 cm/px GSD @ ~100 m

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Fig. 3 DEM (ArcticDEM) of the field area, with the outline of the 21 drone flights and the location of the GNSS base. The yellow rectangle in the inset shows the field location.
At 120 m altitude (in optimal conditions):
- 50 min maximum flight time
- 1.5 cm/px GSD
- 2,1 km² coverage

Compared to other UAVs:
- broader coverage at high resolution ⇒ less flights needed
- high resolution provided by the 42 MP Sony RX1RII camera
- PPK precise positioning ⇒ in case of an event, it is possible to carry out a second survey and perform detailed studies of the changes occurred in between

### UAV
- **WingtraOne PPK (fixed-wing)**
- Drone type: Tailsitter VTOL (Vertical take-off and landing)
- Weight (empty): 3.7 kg
- Wingspan: 125 cm
- Max. payload weight: 800 g
- Radio link: 8 km (optimal conditions)
- Flight planning software: WingtraPilot
- Camera: Sony RX1RII / 35 mm, full-frame, 42 MP

### WingtraOne PPK Antenna Module (onboard)
- Constellations: GPS, Glonass
- Logging frequency: 10 Hz
- Mapping accuracy with PPK (w/o GCPs): Horizontal: down to 1 cm; vertical: down to 2 cm

### Operation
- Cruise speed: ~ 57 km/h
- Wind resistance: Up to 8 m/s on the ground
- Temperature: -10 to +40 °C
- Max. altitude (a.m.s.l.): 3000 m
- Weather: No precipitation, resists light rain
- Auto-Landing accuracy: < 5 m
GNSS base station and geotagging

Now need for GCPs (no communication needed between the UAV and the base station)

During the survey:
- The Trimble GNSS base station acquires data logged into "Receiver Independent Exchange Format (RINEX)" files.
- The UAV, with a PPK (Post Processing Kinematics) antenna on board, acquires images and georeferencing data, stored in the camera SD card.
- The base station and the UAV do not need to be connected to each other during the flights.
- For best results, the base station should be placed within a 10 km radius from the flight area.

After the survey:
- Geotagging process in within the Windows WingtraHub software, which compares the UAV PPK raw measurements of satellite locations and the raw measurements obtained through the base station.

### GNSS base station and geotagging

<table>
<thead>
<tr>
<th>Trimble R2 GNSS receiver as base station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position update rate</td>
</tr>
<tr>
<td>GNSS channels</td>
</tr>
<tr>
<td>SBAS channels</td>
</tr>
<tr>
<td>Horizontal accuracy</td>
</tr>
<tr>
<td>Vertical accuracy</td>
</tr>
<tr>
<td>Operating temperature</td>
</tr>
</tbody>
</table>
Preliminary results

High resolution DEM processing and structures mapping

Fig. 8 DEM (2.2 cm/pix) obtained from the drone photos of the northernmost flight of the field area. The red horizontal line defines the location of the profiles in fig. 10. The location of this DEM is indicated in fig. 3.

In red, preliminary mapping of structures based on the orthomosaic. The white line indicates a trend in the morphology of the vent, suggesting an intrusion oblique to the graben shoulders. It would not be possible to do the mapping at the Google Earth resolution (visible in the background of the image).

Measuring structures on the orthomosaic

Fig. 10 In red, profile obtained from the 2.2 cm/pix DEM, built on drone images acquired during fieldwork. In grey, same profile based on the 2 m/px ArcticDEM, the highest available resolution so far. Both profiles have a 5X vertical exaggeration.


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