Determining the rheology of active lava flows from photogrammetric image sequence processing

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Paper: IN33B-1305

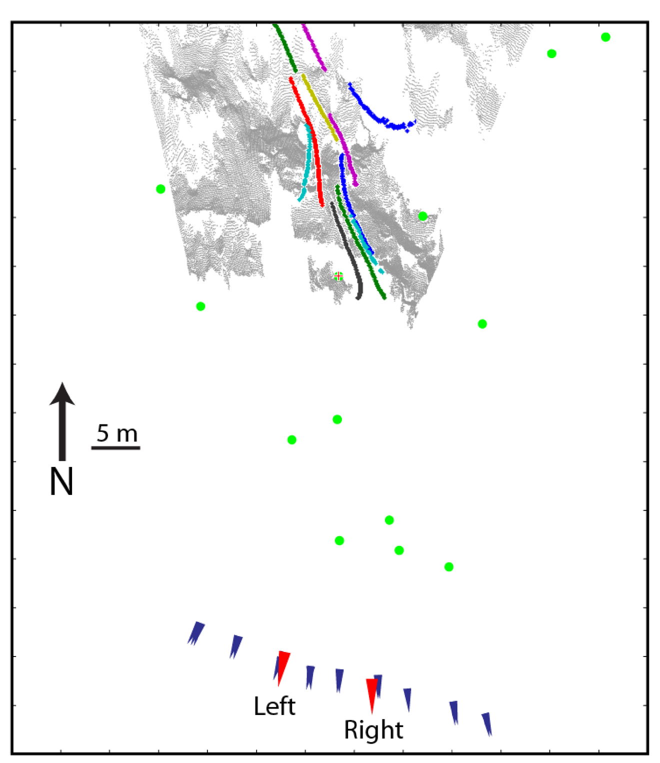
1. Introduction

Parameterisations of lava rheology form an important part of lava flow models, but are difficult to validate. We investigate the use of time-lapse digital photography and close range photogrammetric techniques to record the advance of a lava flow front, from which slope, velocity, volumetric flow rate and flow depth can be ascertained. Digital elevation models (DEMs) are calculated from pseudo-stereo image pairs, using an automated processing pipeline. The results allow the bulk rheology of the lava to be assessed.

2. Location and cameras

Images of an active 'a'ā lava flow lobe were collected during the 2008-9 eruption of Mt. Etna, Sicily.

- 2 tripod-mounted Canon EOS 300D digital SLR cameras
- 13 control targets, coordinates determined by dGPS
- image capture (every minute) synchronised by cable and controlled by external interval timer
- pseudo-stereo image pairs collected over 220 minutes



Site map

Green circles – control targets

Blue triangles – initial multi-view camera positions

Red triangles – time-lapse cameras

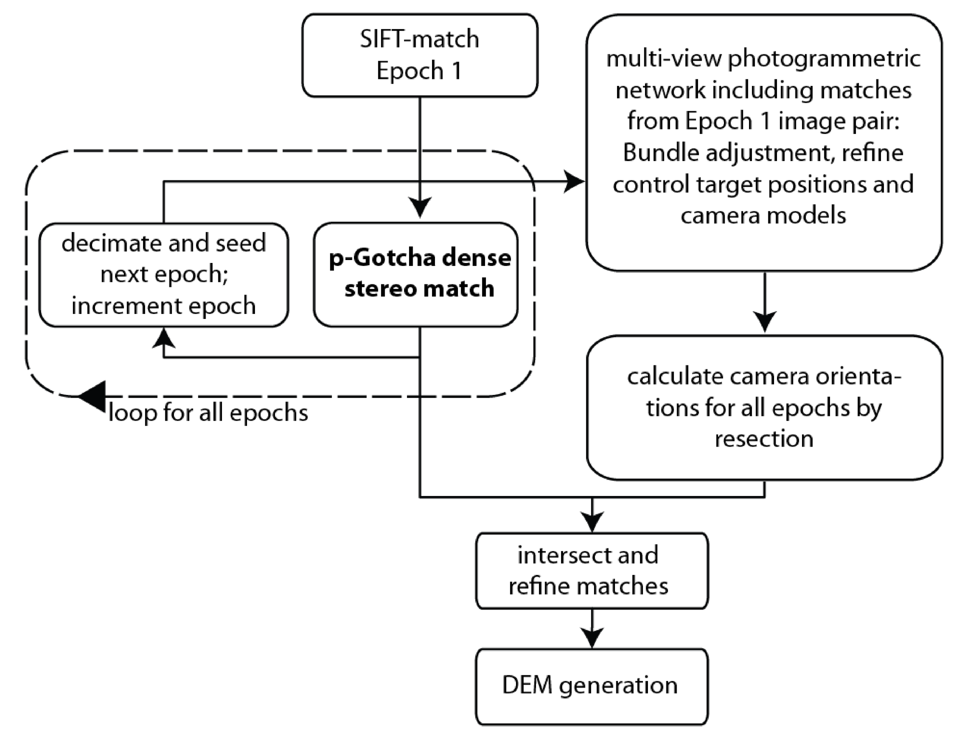
Grey dots – reconstructed point cloud of lava surface, t = 0 min.

coloured tracks – features tracked on flow surface

Time-lapse pseudo-stereo pair

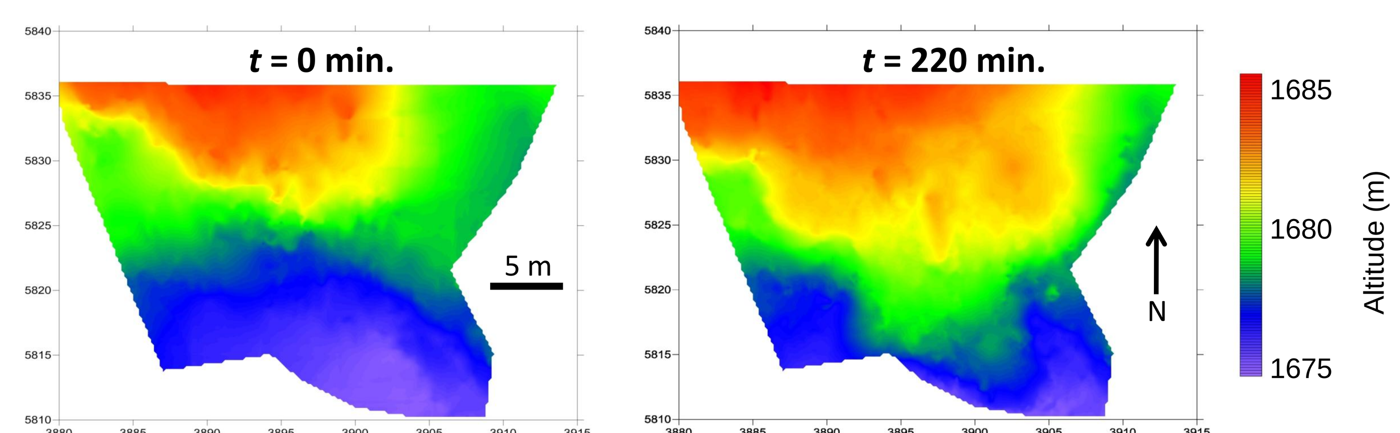
3. DEM processing pipeline

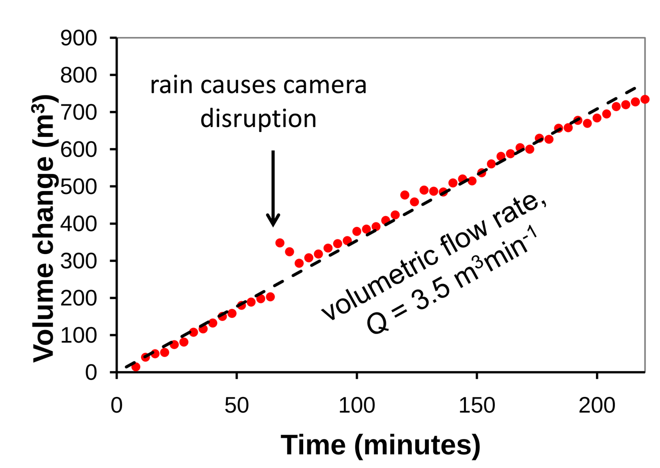
- camera models and control target locations initially refined by multi-view bundle adjustment using VMS software[1]
- for each epoch, image orientations calculated by resection[1]
- SIFT-features[2] used to seed sequence matching
- matching uses a pyramidal dense matcher, p-GOTCHA[3-5]
- following epochs seeded from previous epoch results



4. Results: DEMs

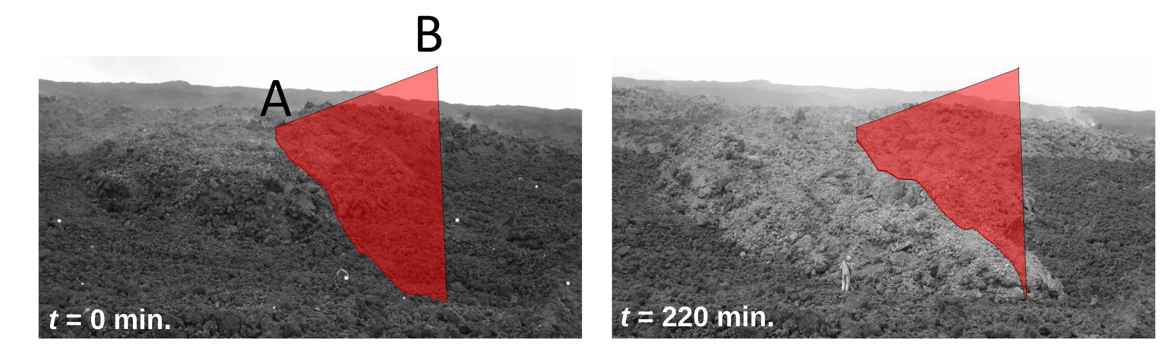
- 56 DEMs generated (at 4-minute intervals), covering the advancing flow front lobe



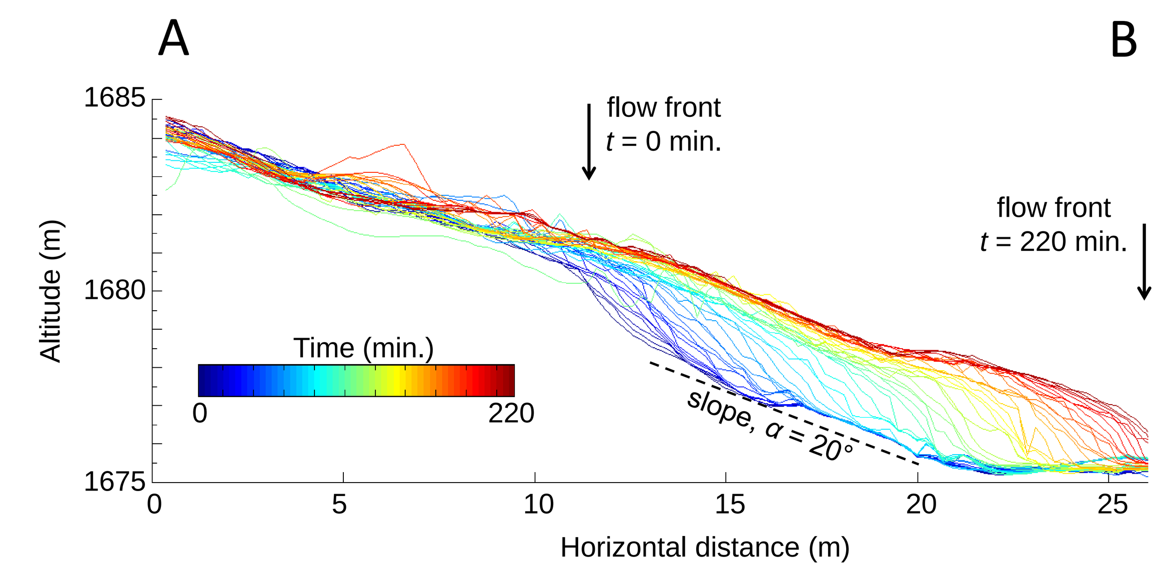


DEM subtraction demonstrates a near-constant volumetric flow rate

5. Flow cross sections and surface velocity

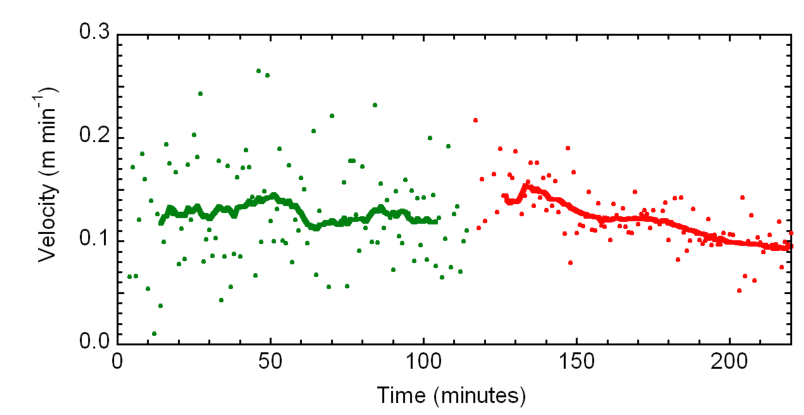


Plane of cross sections shown in red (line A-B is horizontal)



On initial slope, front advances at 0.094 m min^{-1}.

Flow slows and thickens on reaching flat ground.



Surface velocities calculated from tracking features on the flow surface (lines are 20-point running averages)

(Colours correspond to the upper green and red tracks in Panel 2)

6. Flow viscosity

Jeffery's equation for Newtonian flow in a wide channel can now be used with either the surface velocity measurements or the volumetric flux, to estimate the apparent viscosity, μ:

$$\mu = \frac{g h^2 \rho \sin}{2v} = 7.8 \text{ MPa s}$$

$$\mu = \frac{g h^3 w \rho \sin\alpha}{3Q} = 3.4 \text{ MPa s}$$

g = gravity (9.8 m s^{-2})
h = flow thickness (2.0 m)
ρ = fluid density (2500 kg m^{-3})
v = surface velocity (0.13 m min^{-1})
α = slope (20°)
w = flow width (9 m)
Q = volumetric flow rate (3.5 m^{3}min^{-1})

7. Conclusions and further work

- DEM sequences can deliver flow depth and volume flux data to enable robust bulk rheological measurements of active lavas
- longer duration occupations, over a range of slopes, will permit non-Newtonian flow models to be assessed

References: (1) VMS, Robson & Shortis, http://www.geomsoft.com/ **(2)** Lowe (2004), *Int. J. Comp. Vis.*, 60, 91-110. **(3)** Day & Muller (1989), *Image Vis. Comp.*, 7, 95-101. **(4)** Gruen (1985), *S. Afr. J. Photogramm. Remote Sens. Cartogr.*, 14, 175-187. **(5)** Otto & Chau (1989), *Image Vision Comp.*, 7, 83-94.