2018 Graduate Student Showcase

Graduate Student Showcases

April 2018

Synthesizing Field and Experimental Observations to Investigate the Behavior of Pyroclastic Density Currents

Nicholas M. Pollock
Boise State University

Brittany D. Brand
Boise State University

Olivier Roche
Universite Clermont Auvergne

Peter J. Rowley
University of Hull

Damiano Sarocchi
Universidad Autónoma de San Luis Potosí

Synthesizing Field and Experimental Observations to Investigate the Behavior of Pyroclastic Density Currents

Abstract

One of the major hazards associated with volcanic eruptions are pyroclastic density currents (PDCs), which are fast-moving volcanic avalanches consisting of ash, boulders, and gas. Because of their unpredictability, studying PDCs in real time is dangerous and difficult. Therefore, we investigate the deposits produced by PDCs and use granular flow experiments to simulate PDCs in the laboratory. The experimental results allow us to understand sediment transport and erosional processes at small scales, and then we can extrapolate those results to natural PDCs. By better understanding what controls PDC behavior, we hope to ultimately improve risk assessment for these dangerous flows.

Synthesizing Field and Experimental Observations to Investigate the Behavior of Pyroclastic Density Currents

Nicholas M Pollock[1], Brittany D Brand[1], Olivier Roche[2], Peter J Rowley[3], Damiano Sarocchi[4]

1. Boise State University 2. Laboratoire Magmas et Volcans, France 3. University of Hull, United Kingdom 4. Universidad Autónoma de San Luis Potosí, Mexico

Take Home Message

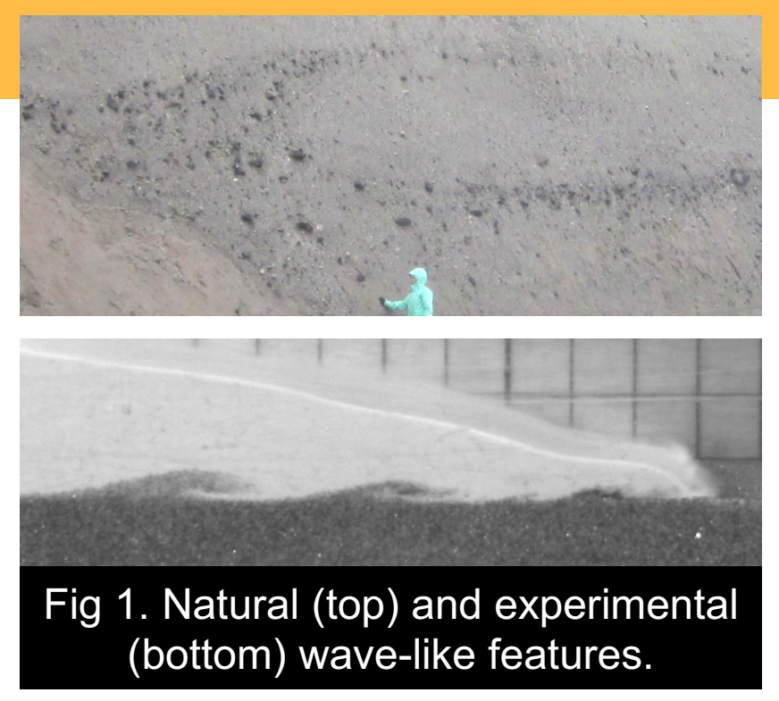


Fig 1. Natural (top) and experimental (bottom) wave-like features.

Wave-like features in the deposits of pyroclastic density currents result from granular shear instabilities formed at the flow-bed interface. The dimensions of wave-like features allow us to constrain important flow parameters including flow velocity and thickness.

Constraints on flow velocity and thickness are necessary to test the accuracy of numerical models, and ultimately improve risk assessments.

What is a pyroclastic density current?


Fig 2. PDC at Sinabung Volcano, Indonesia, 2015.
(Image from Volcano Discovery, Ingrid Smet)

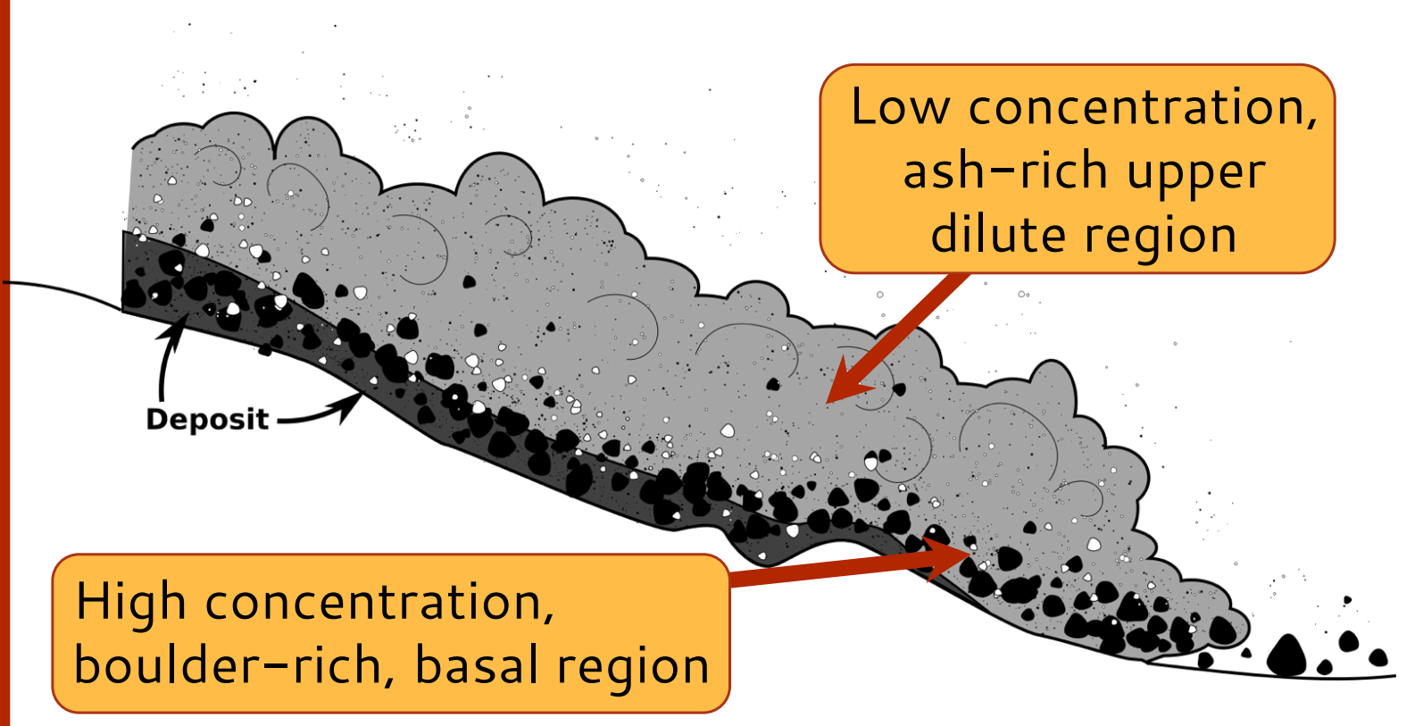


Fig 3. Sketch of general PDC structure.

Pyroclastic density currents (PDCs) are:

- Ground-hugging mixtures of volcanic gases and solid particles ranging in diameter from microns to meters
- Highly unpredictable and capable of traveling 10s of kilometers at 100s of degrees C, making direct observation difficult
- The most deadly phenomenon associated with explosive volcanic eruptions

PDCs consist of two main regions:

1. A dilute upper ash cloud that obscures the view of the interior
2. A dense basal portion that transports >95% of the flow mass and controls overall flow behavior

Eruption of Mount St Helens – May 18, 1980

Following months of precursory activity, the eruption of Mount St Helens began with the largest landslide in recorded history at 8:32 a.m. on May 18, 1980.

Soon after the landslide, the eruption transitioned to a typical eruption with large, sustained ash plume (at right). Later in the afternoon, the ash column began to collapse, producing at least three periods of PDC activity.


Fig 4. May 18 1980 eruption of Mount St Helens.
(Image from Universal History Archive/UIG via Getty Images)


Fig 5. PDC deposits at Mount St Helens.

The three periods of PDC production deposited five PDC units throughout the pumice plain (Figure 8; Brand et al., 2014).

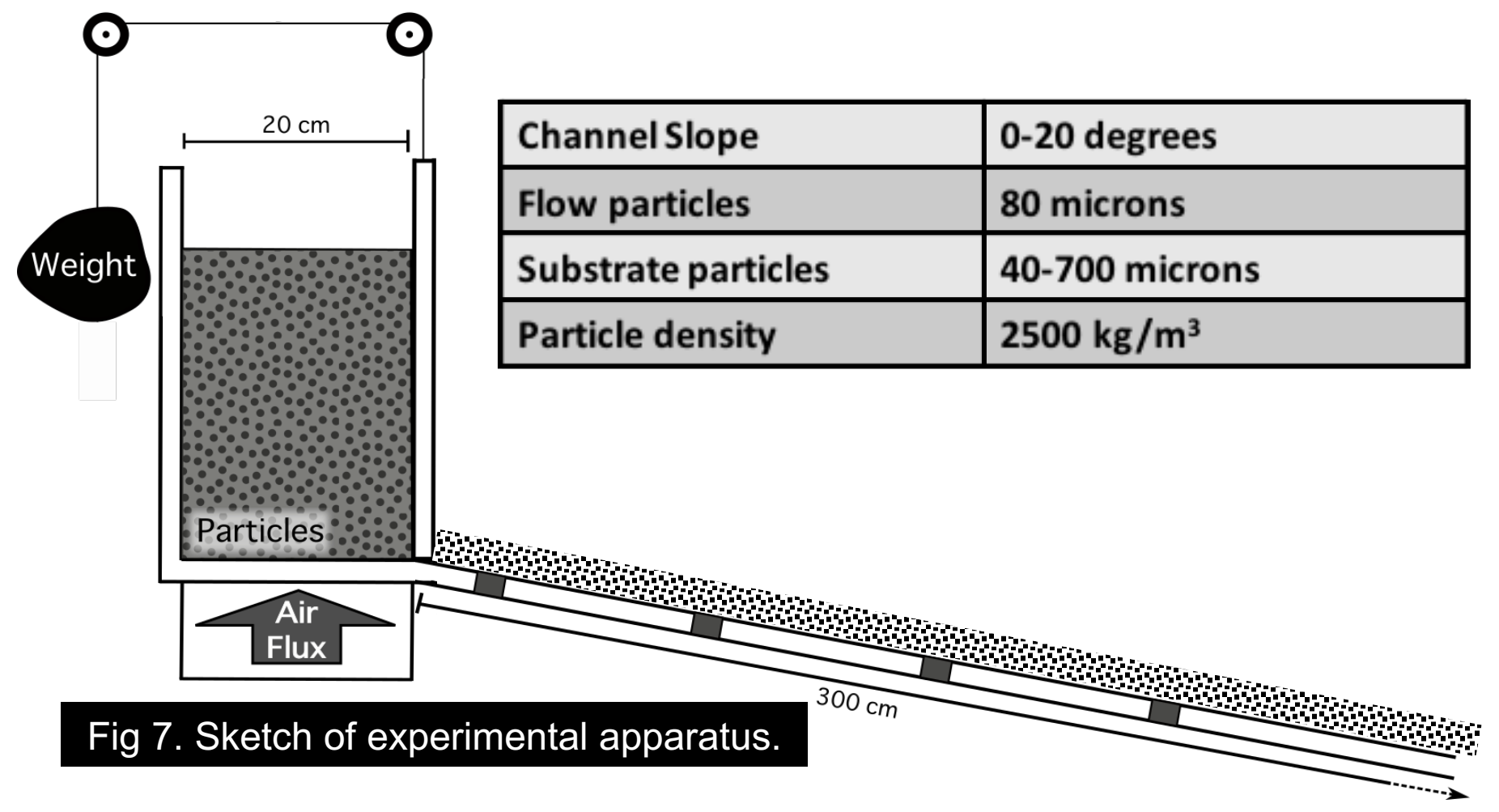
We investigate the deposits for evidence that the PDCs eroded into the bed during transport.

Scaled, analogue granular flow experiments

Through a series of over 120 scaled, granular flow experiments we investigate:

- How does fluidization (i.e. internal gas) affect the flow?
- What controls the initiation of erosion and by what processes does the flow erode?
- How does the nature of the bed (angle, size of particles) affect flow behavior?

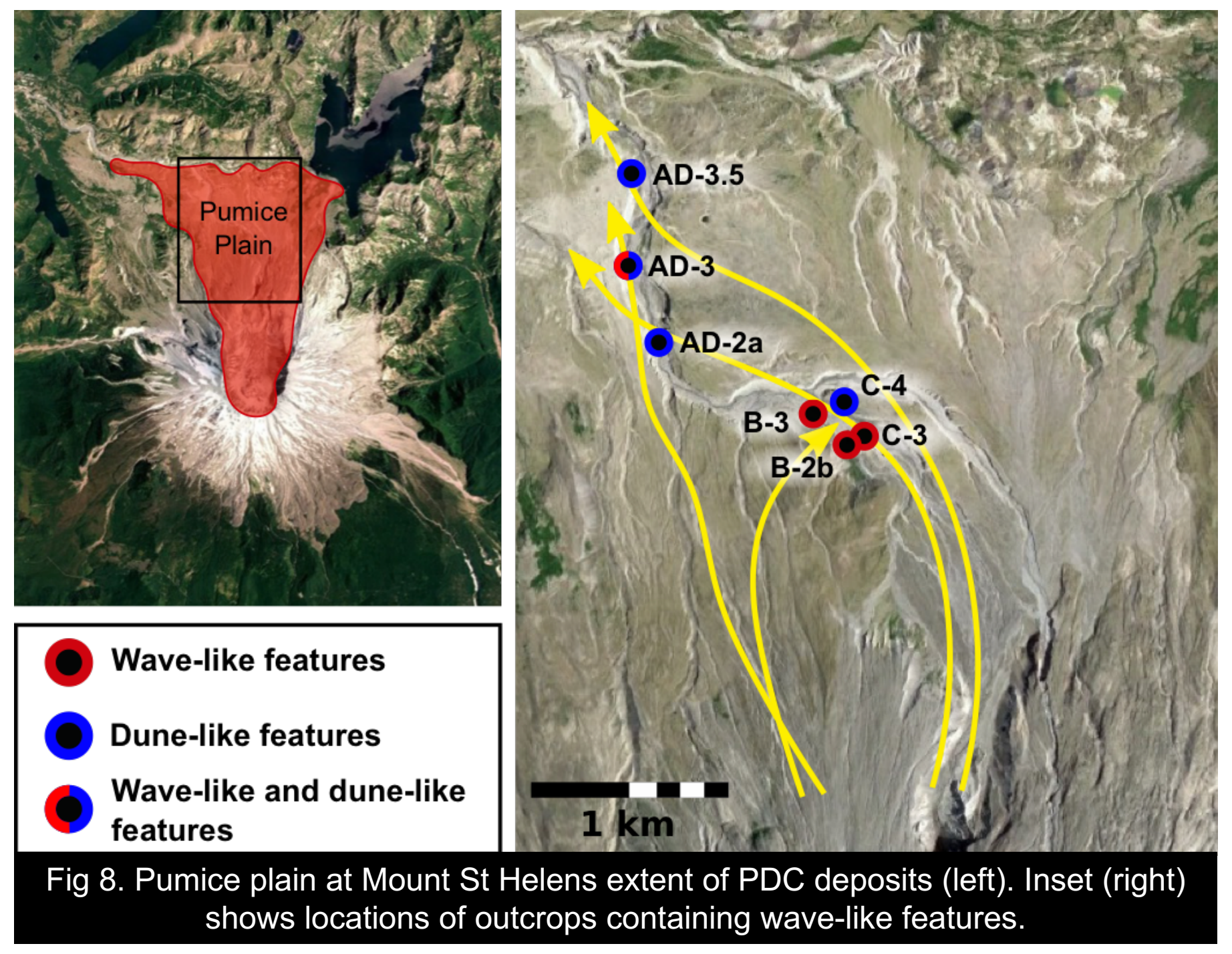

Fig 6. Lab facility at LMV.



Channel Slope	0-20 degrees
Flow particles	80 microns
Substrate particles	40-700 microns
Particle density	2500 kg/m³

Fig 7. Sketch of experimental apparatus.

Field observations – Wave-like features



- ● Wave-like features
- ● Dune-like features
- ● Wave-like and dune-like features

Fig 8. Pumice plain at Mount St Helens extent of PDC deposits (left). Inset (right) shows locations of outcrops containing wave-like features.

We observe wave-like mixing features throughout the PDC deposits at Mount St Helens.

The wave-like features are:

- Self-similar in form
- Varied in size by over two orders of magnitude
- Found both at unit contacts and within individual units
- Most commonly formed on top of earlier PDC deposits

Examples of wave-like features

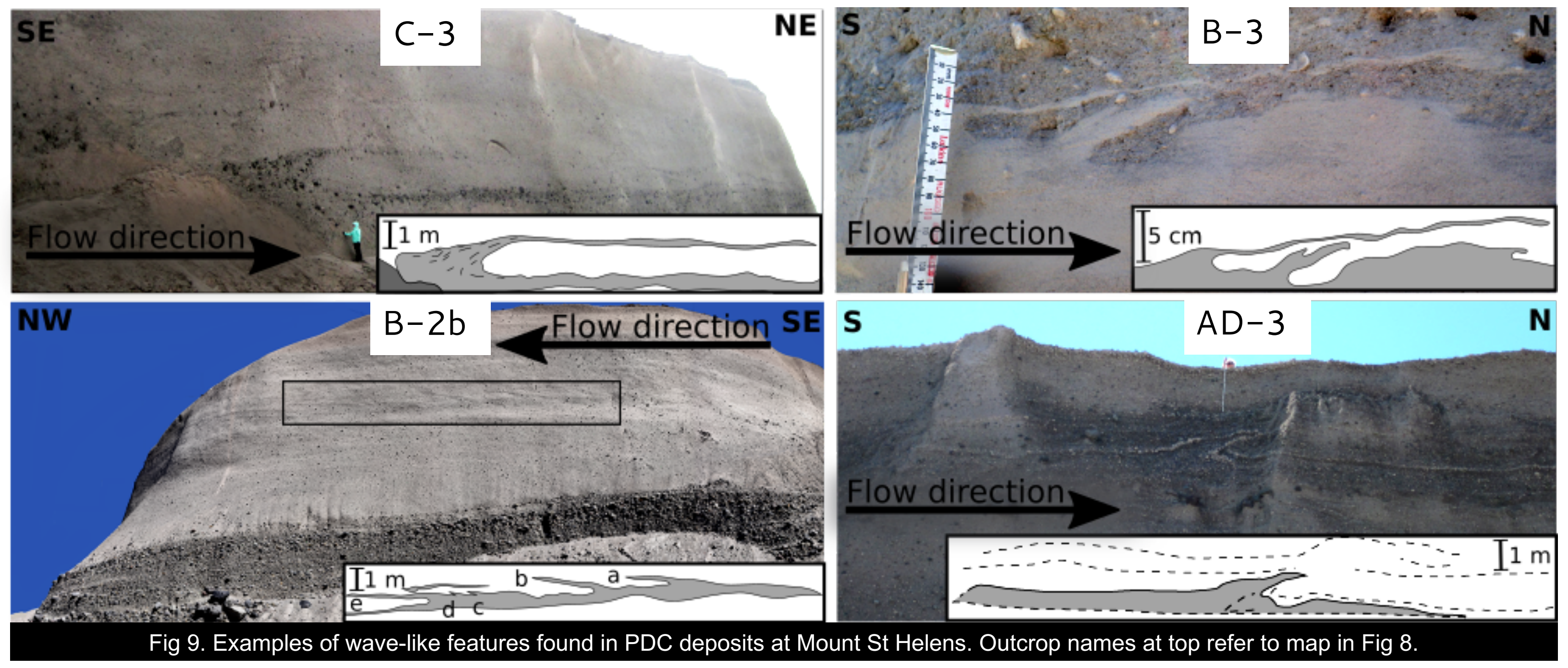


Fig 9. Examples of wave-like features found in PDC deposits at Mount St Helens. Outcrop names at top refer to map in Fig 8.

Measuring wave-like features

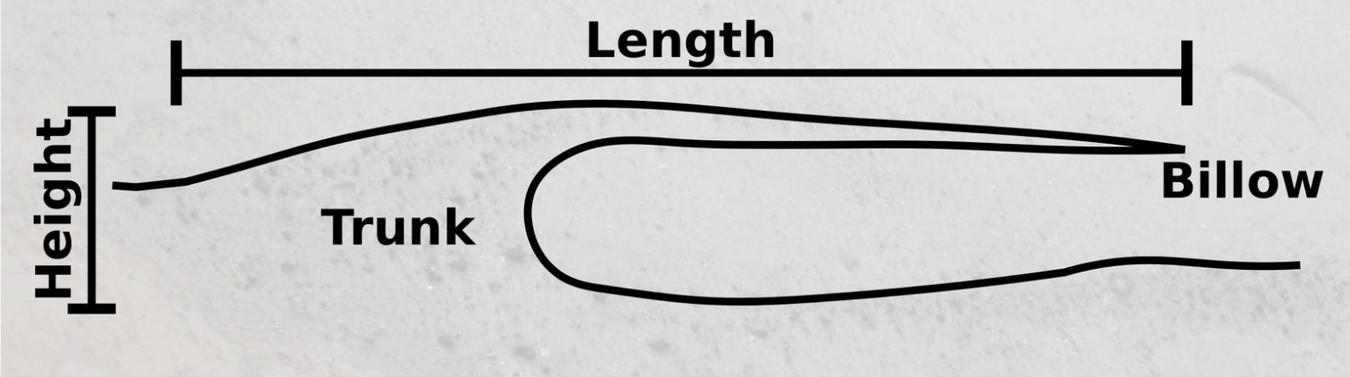


Fig 10. General structure of wave-like feature

Length of the billow scales closely with height.

Self-similarity suggests that a similar mechanism of formation acts across scales.

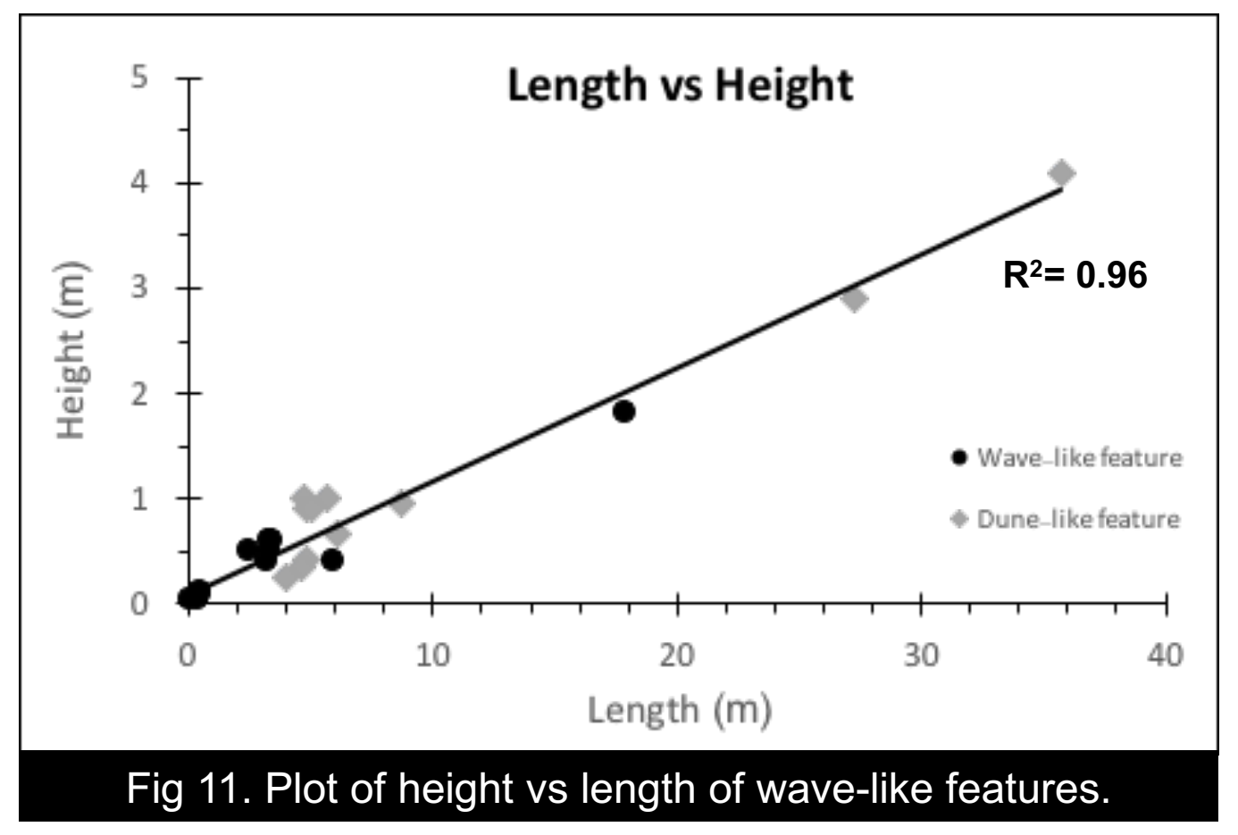


Fig 11. Plot of height vs length of wave-like features.

Experimental observations – Wave-like features

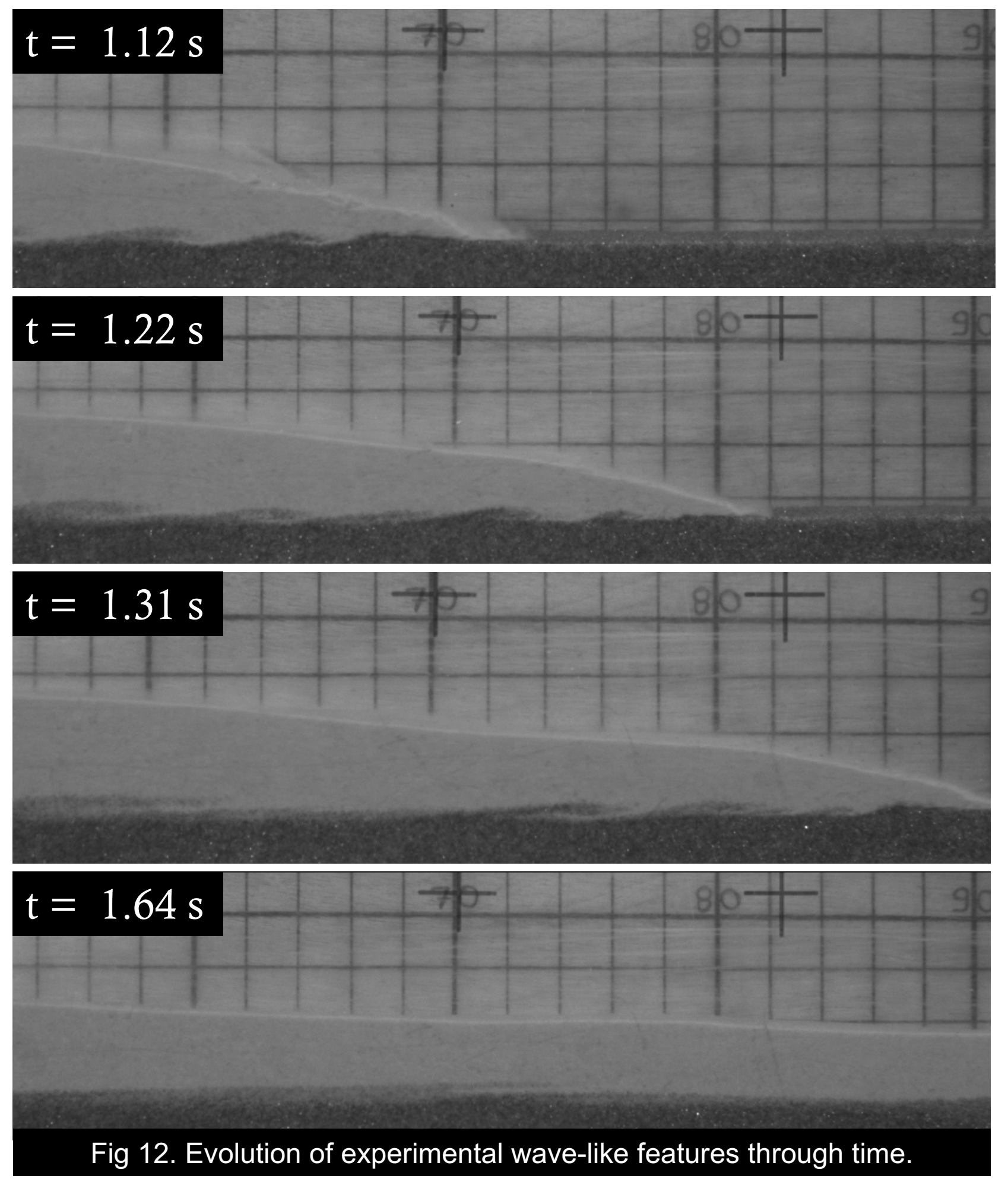
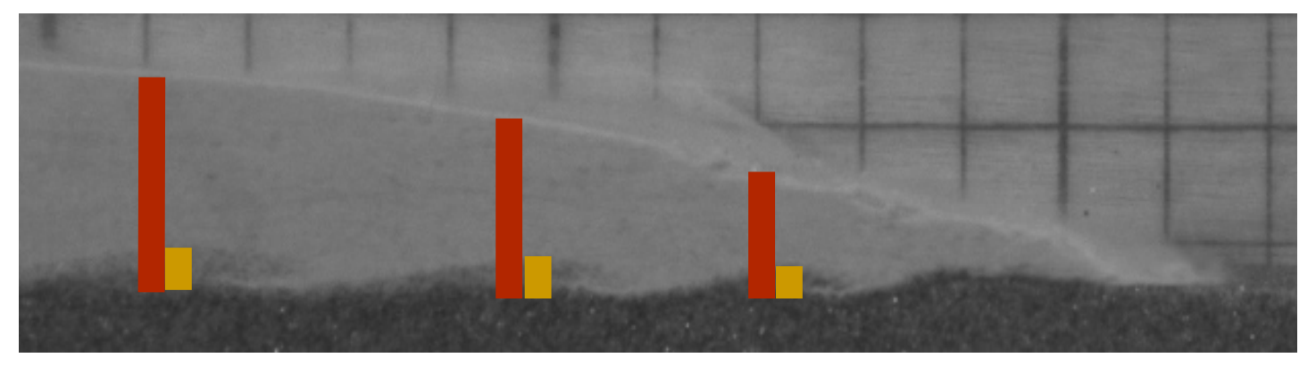


Fig 12. Evolution of experimental wave-like features through time.

What controls wave height?



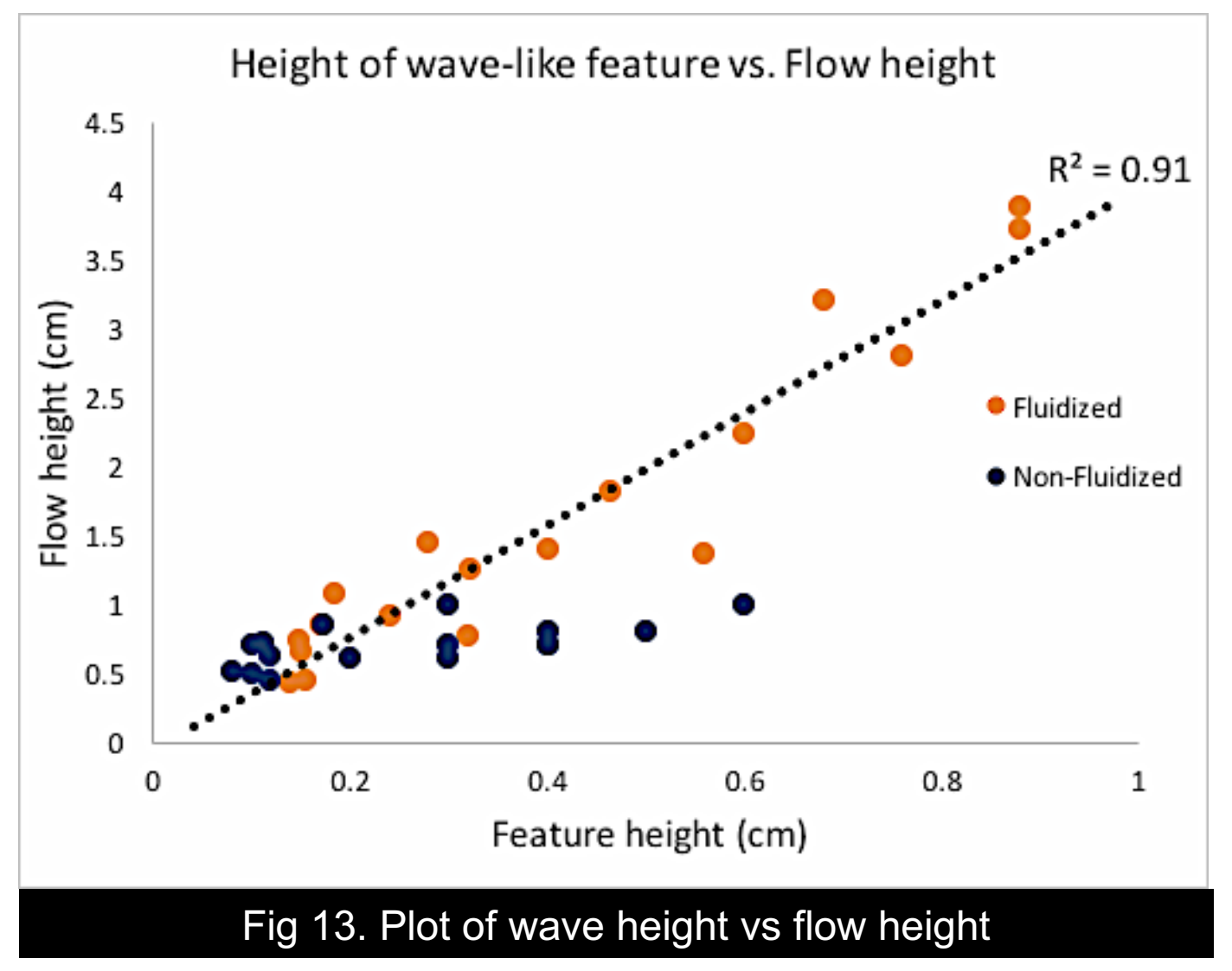


Fig 13. Plot of wave height vs flow height

Height of waves formed in fluidized flows are ~1/4 the total flow height.

Effect of bed characteristics on flow behavior

What causes flow to travel further?

- Higher slope (light to dark)
- Fluidization (blue vs orange)

How does the diameter of particles in the bed affect flow behavior?

- No significant change except for when particles are 80 microns

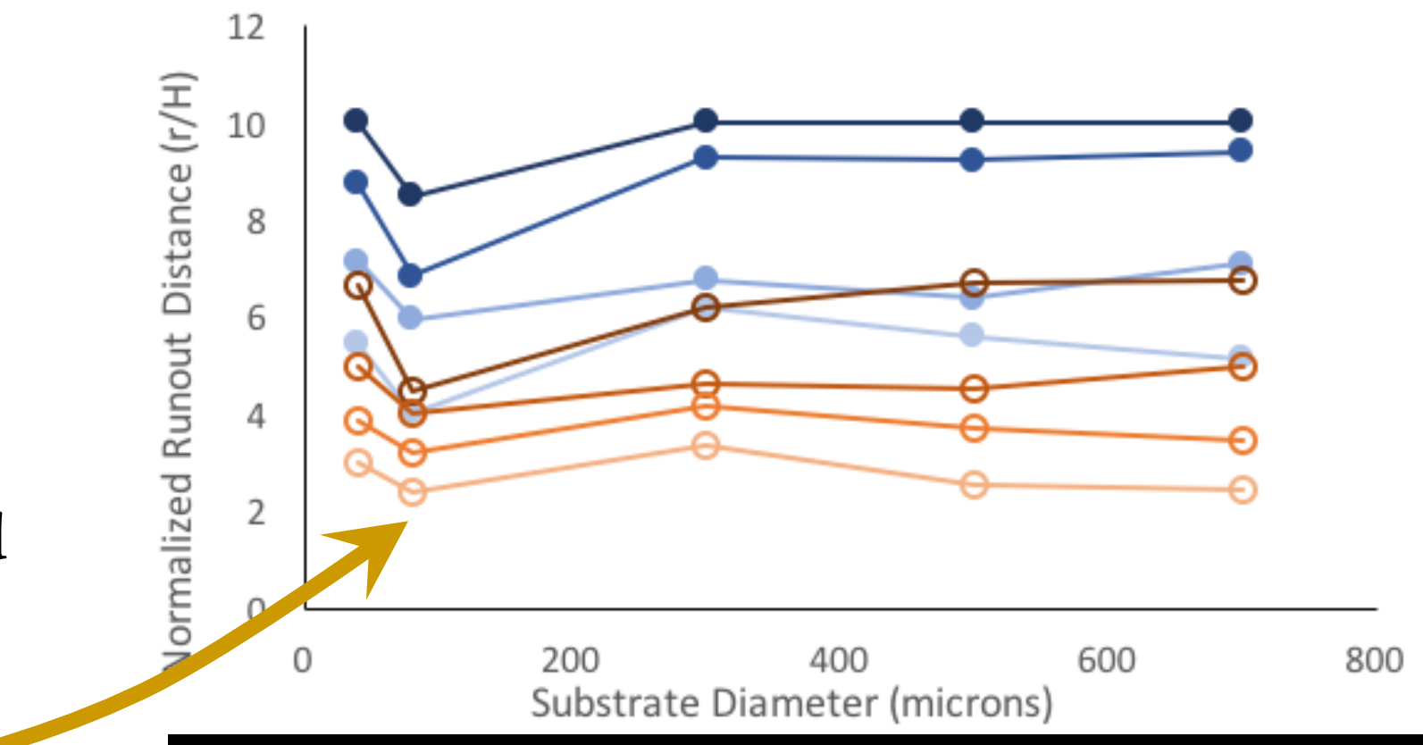
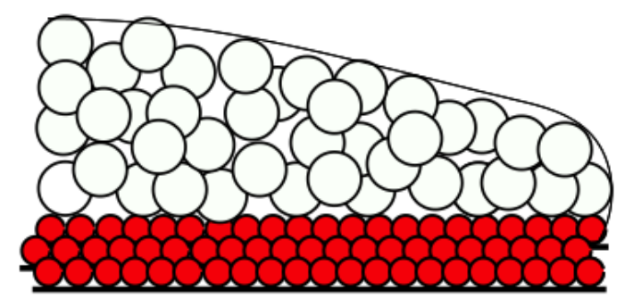
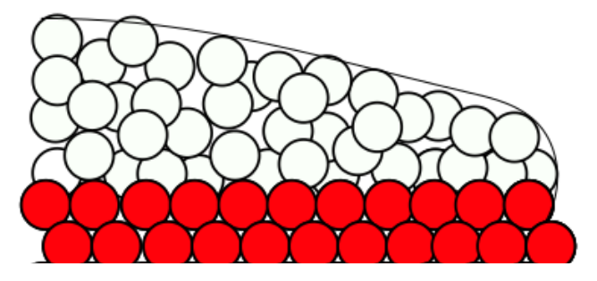


Fig 14. Normalized flow runout distance vs size of particles in the bed. Darker colors indicate higher slopes and blue is fluidized and orange is non-fluidized.



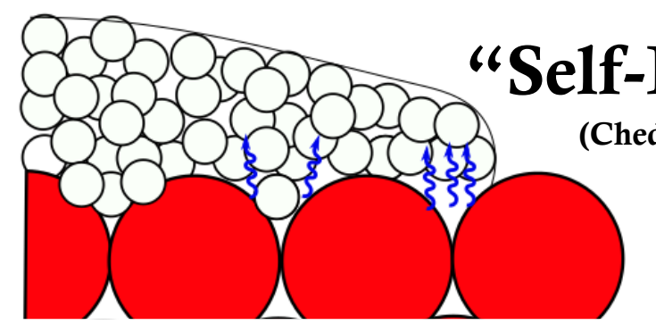
$d_{flow} > d_{bed}$

Flow slides over bed with low friction



$d_{flow} = d_{bed}$

Higher friction, decreased runout



"Self-Fluidization"

(Chedeville and Roche 2014, 2015)

$d_{flow} < d_{bed}$

Highest friction, but flow particles fall into interstices and ejected air that fluidizes flow

Synthesizing field and experimental observations

Estimating flow thickness using experimental results:

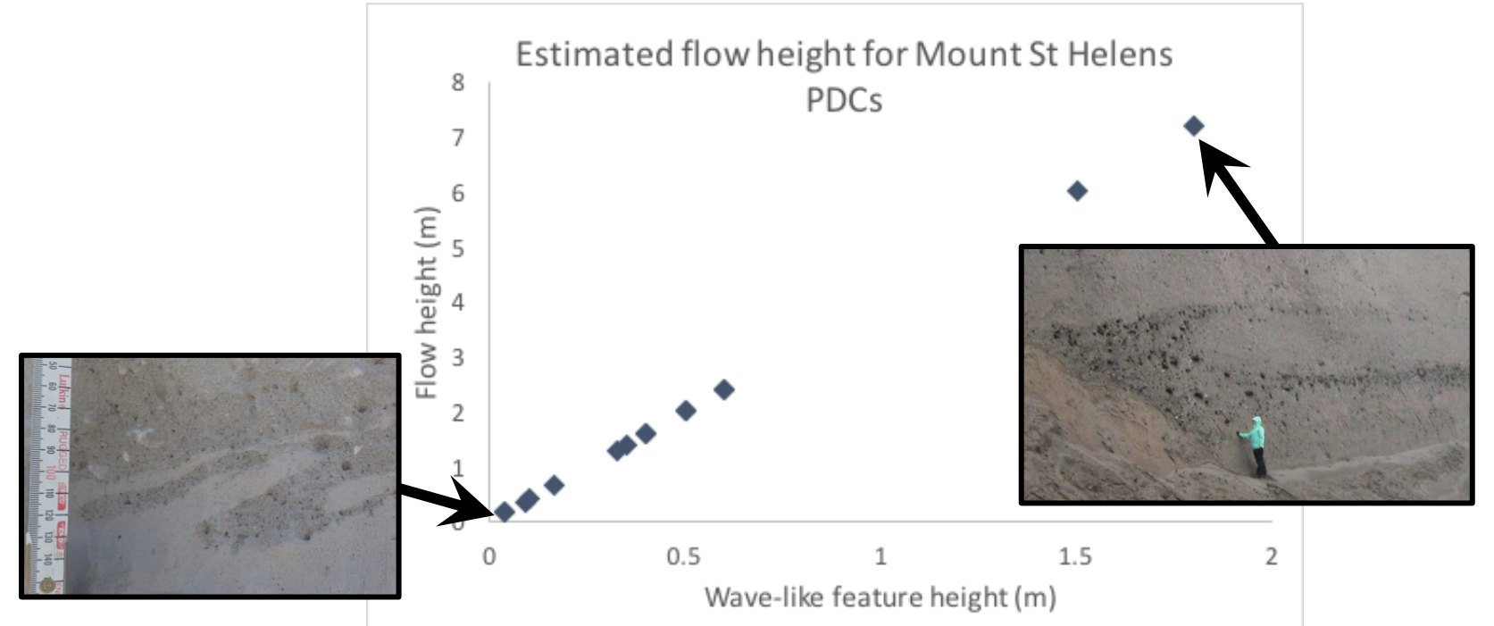


Fig 15. Estimated flow height based on wave-like feature height.

Using relationships derived from experiments, we can constrain the PDC thickness based on the height of wave-like features observed in the field.

Estimates for flow thickness:

- Tallest waves: ~8 m
- Shortest waves: ~0.15 m

Wave-like features form due to granular shear instabilities:

Previous numerical and experimental studies attribute the formation of similar wave-like features to **granular shear instabilities**.

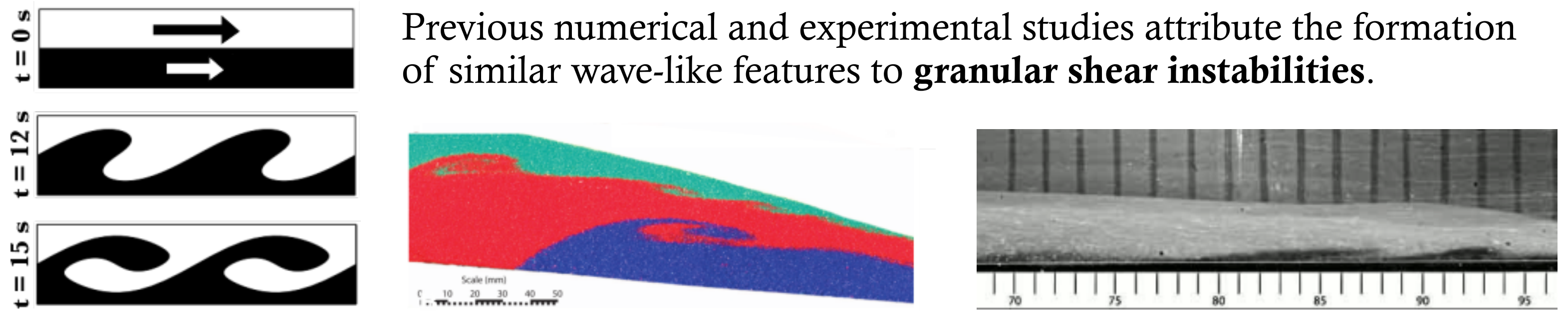


Fig 16. Wave-like features produced numerically (left, Ciamarra et al. 2005) and experimentally (center, Rowley et al. 2011; right, Farin et al. 2014).

Estimating flow velocity using instability growth criteria:

$$v_1 - v_2 \geq \sqrt{\frac{g\lambda}{2\pi}\left(\frac{\phi_2}{\phi_1} - \frac{\phi_1}{\phi_2}\right)}$$

(Kundu and Cohen 2004; Rowley et al. 2011)

v_1, v_2	Velocity of flow, bed
g	Gravity
λ	Wavelength
ϕ_1, ϕ_2	Particle concentration of flow, bed

The PDC wave-like features record granular shear instabilities at the flow-bed interface. The dimensions of the wave-like features allow us to constrain PDC flow velocity using the Instability Growth Criterion.

Estimates for flow velocity:

- Longest waves: 1-6 m/s
- Shortest waves: 0.1-0.4 m/s

Future Work

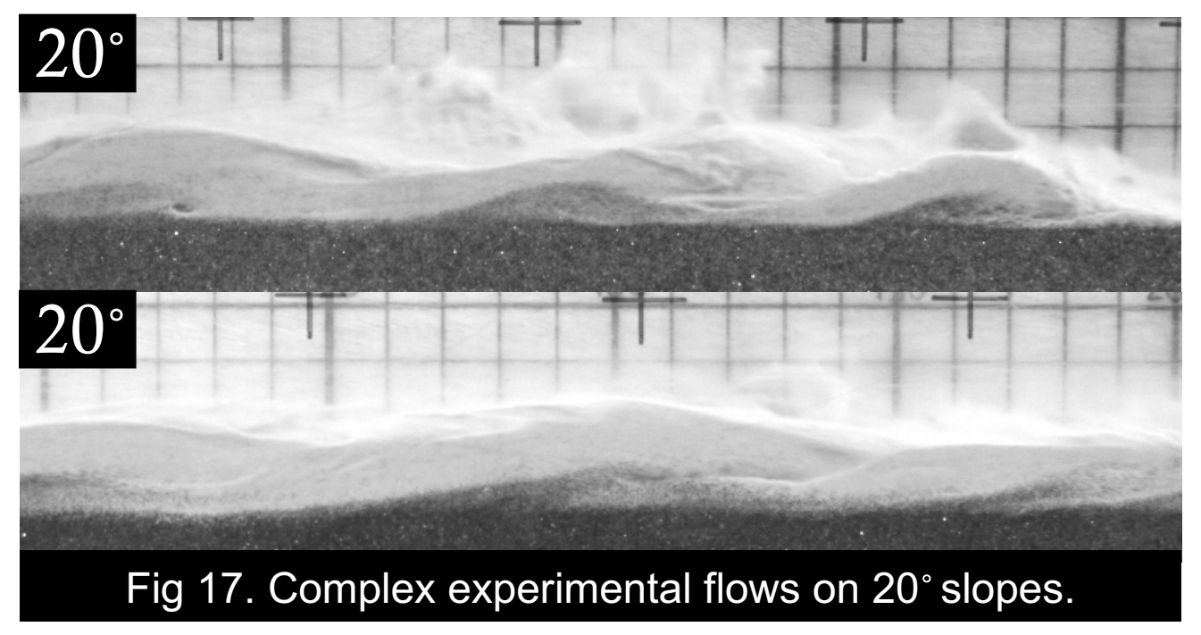


Fig 17. Complex experimental flows on 20° slopes.

In future work we will:

- Investigate applicability of the Instability Growth Criterion to experimental flows
- Use experimental results to decrease error on velocity estimates
- Explore what affects extreme behavior at high slopes

References and Acknowledgements

Funding for this work provided by NSF Award #1347385 and a Geological Society of America Graduate Student Research Grant.

- Brand, B.D., Mackaman-Lofland, C., Pollock, N.M., Bendana, S., Dawson, B., and Wichgers, P., 2014, Dynamics of pyroclastic density currents: Conditions that promote substrate erosion and self-channelization - Mount St Helens, Washington (USA): Journal of Volcanology and Geothermal Research (JVGR).
- Ciamarra, M.P., Coniglio, A., and Nicodemi, M., 2005, Shear instabilities in granular mixtures: Physical Review Letters, v. 94, no. 18, p. 1–4.
- Farin, M., Mangeney, A., and Roche, O., 2014, Fundamental changes of granular flow dynamics, deposition, and erosion processes at high slope angles: Insights from laboratory experiments: JVGR, v. 119.
- Kundu, P.K., and Cohen, I.M., 2004, Fluid Mechanics: Elsevier Academic Press, California.
- Rowley, P.J., Kokelaar, P., Menzies, M., and Waltham, D., 2011, Shear-Derived Mixing In Dense Granular Flows: Journal of Sedimentary Research, v. 81, no. 12, p. 874–884.