Rootless Cones and Tree-Root Lava: Recognizing Lava-Water Interactions Remotely

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Abstract

Lava-water interactions (LWIs) are rarely considered in lava flow hazard assessments or emergency planning scenarios, though they can generate a range of secondary hazards, including tephra blasts, rootless eruptions, disruption to water supplies, and flooding. These hazards may endanger life, damage property, and hinder evacuation or rescue efforts, so identifying the signs of LWI in the products of past eruptions may help emergency planners identify potential hazards for future eruptions. The physical products of LWI, such as abundant hyaloclastite, high proportions of fine ash, lava pillows, and irregular columnar jointing, have long been recognized in the field. However, remote sensing offers the opportunity to assess whole lava fields relatively quickly and cheaply, and allows investigation of inaccessible lava fields and planetary volcanism. In addition, the large-scale view can reveal features that are not immediately visible in the field, and tools like LiDAR can be used to strip away vegetation to show hidden morphology and structure. We present features indicative of LWI that can be identified by remote sensing techniques and discuss what they can and can't tell us about LWI in past eruptions. We illustrate these with data from the well-documented 1783-84 Laki fissure eruption, supplemented with other case studies from Iceland, Hawai'i and the Pacific NW. In particular, the size, type and spacing of rootless cones can tell us about the availability of water and intensity of rootless eruptions. When examined in conjunction with lava flow morphology and local topography, we can learn about the local lava flux and the likely water sources and pre-eruptive landscape. In the absence of rootless cones, dendritic textures on the lava flow surface may indicate passive LWI. These textures are found across the Laki lava field, commonly in areas where the lava encountered rivers or floods, and match those at other lava basaltic flows known to have interacted with water, including the 2018 eruption of Kilauea. Together, these features are useful indicators for identifying and interpreting past LWIs, both as a complement to field observations and when field studies are not feasible.

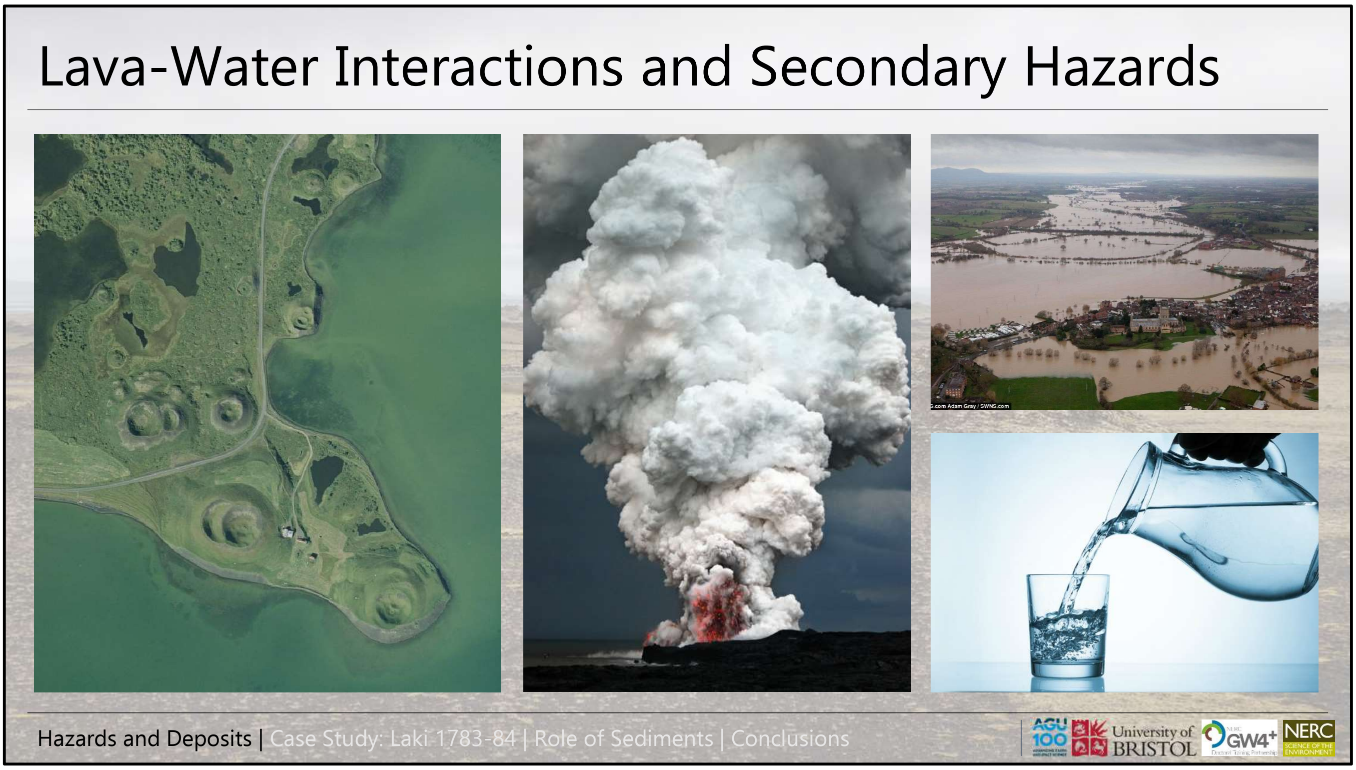
Good morning.

Today I'd like to speak to you about the secondary hazards generated by lava-water interaction (LWI) and how remote sensing can be a used to look at the deposits and guide further investigations.

The key take-away messages from this talk are

- That LWIs are dangerous, difficult to predict, and deserve to be considered in future hazard assessments
- Secondary explosions (or rootless eruptions) are much more likely to happen in regions with low-permeability sediments
- And that remote sensing is a valuable tool in assessing past lava-flows for LWI deposits

Before I begin, I'd like to thank my supervisors Kathy Cashman and Alison Rust for their support and guidance over the last four years of my PhD, and NERC for funding my research



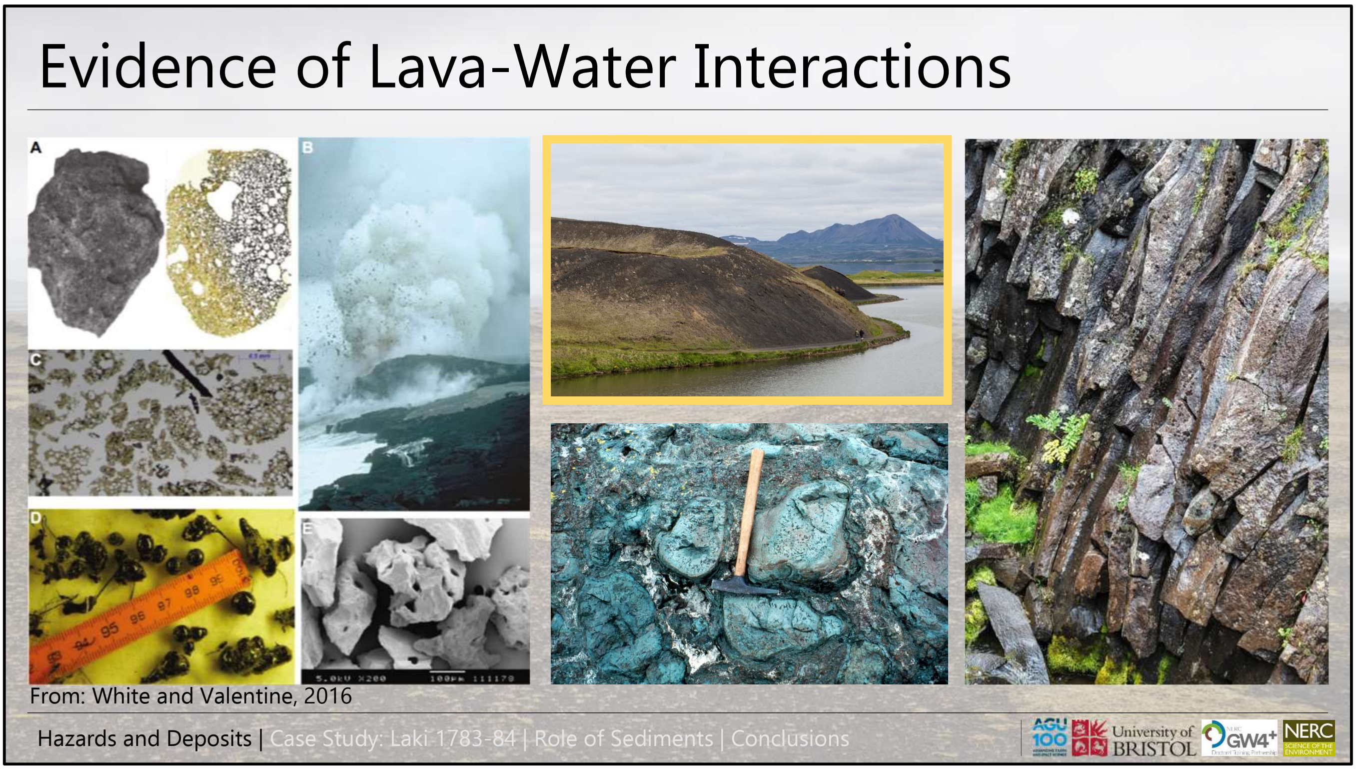
Let's start by considering the hazards.

LWIs generate a range of secondary hazards
They can start vigorous steam explosions that generated tephra blasts and rootless cones
Lava flows can also dam rivers, causing local floods, which can damage property, endanger life and hinder travel, evacuation or aid. Interaction with rivers may also disruption and pollute water supplies.

But these consequences are rarely considered when it comes to hazard assessments or emergency planning scenarios.

But there have been recent reminders of how dangerous and unpredictable these hazards are
A group of tourists and a BBC camera crew were caught in a steam explosion on Mount Etna March 2016 from lava flowing over snow
And in July 2018 a tourist boat in Hawai'i was damaged by a steam explosion from a submarine lava flow

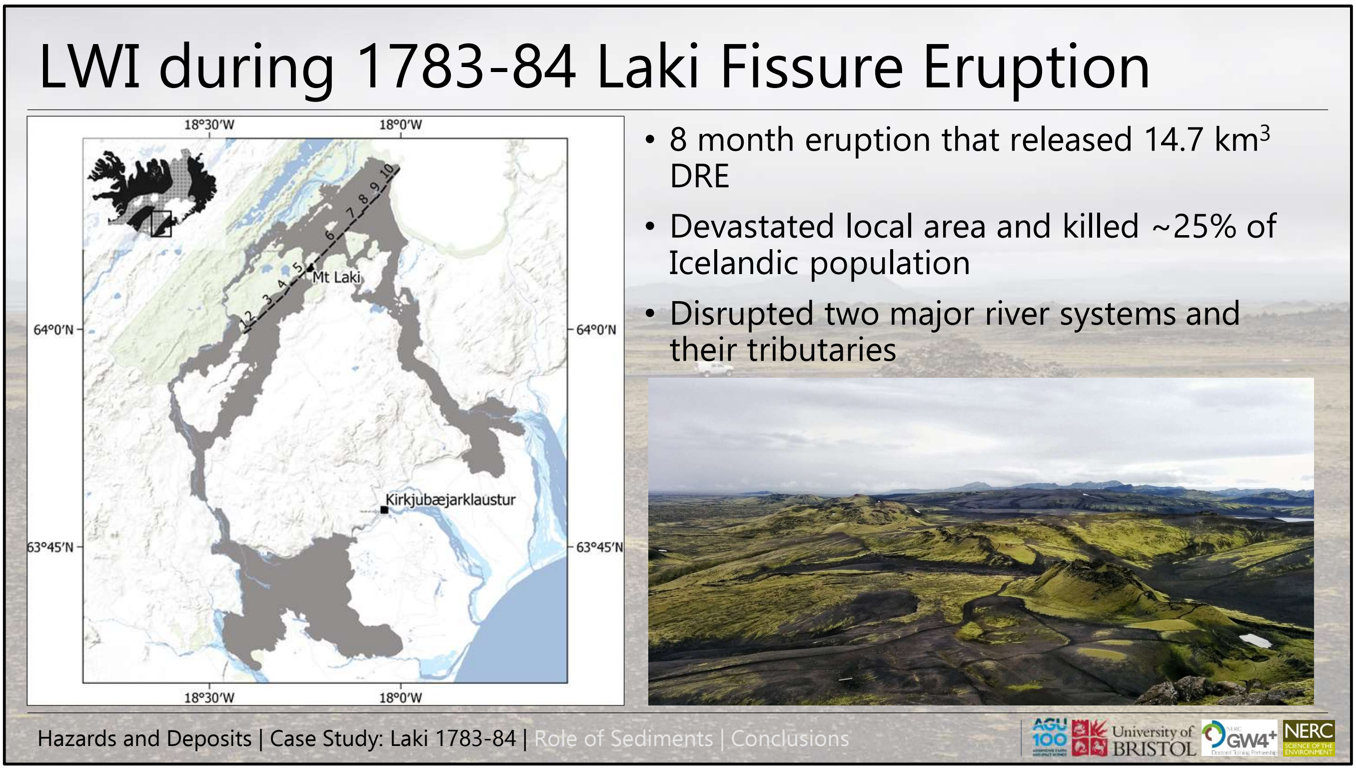
The key to planning for future hazards is understanding what has happened at past eruptions, and which environments or scenarios generation which hazards.



While the physical deposits of LWI (abundant hyaloclastite, high proportions of fine ash, lava pillows, irregular columnar joining etc.) are well recognised, these require intensive and expensive field campaigns to identify.

But if we can identify features of LWI that can be recognised through remote sensing, we have the potential to do quicker and cheaper assessments, help target and complement fieldwork, assess remote, inaccessible areas, and even strip away the disguising effects of vegetation.

Potential to rapidly assess lava flows and match LWI hazards with the environments they occur in



The 1783-84 Laki fissure eruption in southern Iceland provides an unique opportunity to link the secondary hazards of LWI to the physical deposits left behind

- It lasted 8 months: June 1783 – Feb 1784 and erupted 14.7 km^3 of lava
- It devastated local area and killed ~1/4 of Icelandic population

The details of the eruption were captured by the local pastor, Rev Jón Steingrímsson, (and others), which has have allowed volcanologists to reconstruct the events of the eruption.
Steingrimsson described the different interactions between the lava and local rivers in great detail, they've received little attention so far

LWI during the 1783-84 Laki Fissure Eruption II

Flooding: *"Liquid fire poured forth over the land so that everything became mixed together. It dammed up the river Holtsá, so that the valley filled with water, after which it crossed the river bed to burn down the Holt farmstead and continued east along the slopes and dammed up the river Fjaðará"*

Flooding and quicksand: *"When I reached the river [...] I first sank into quicksand [...] So much glacial silt and floodwater had collected on those alluvial flats that it took the boy and I from six o'clock one evening until around nine the next morning to cross"*

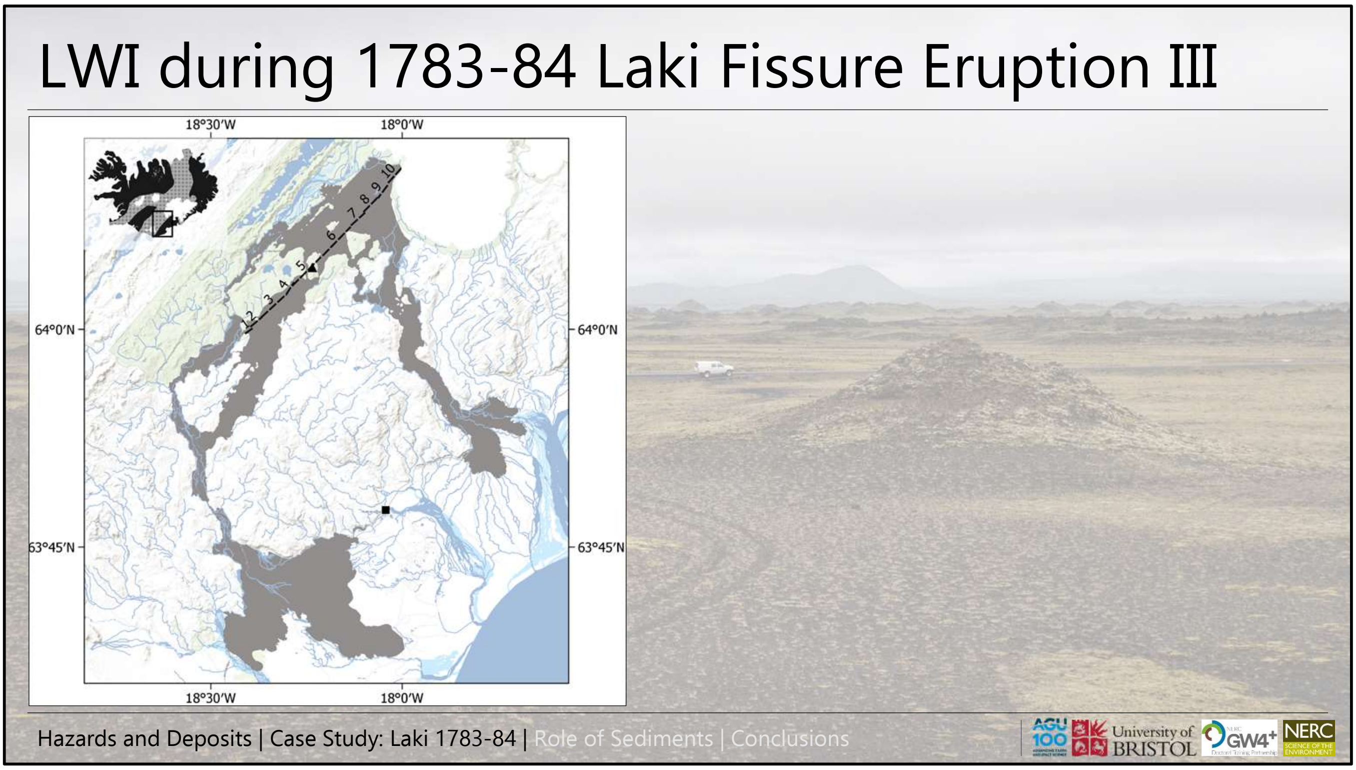
Tephra blasts / rootless eruptions: *"When the molten lava ran into wet-lands or streams of water, the explosions were as loud as if many cannon had fired"*

From *Fires of the Earth*, Jón Steingrímsson, trans. Keneva Kunz (1998)

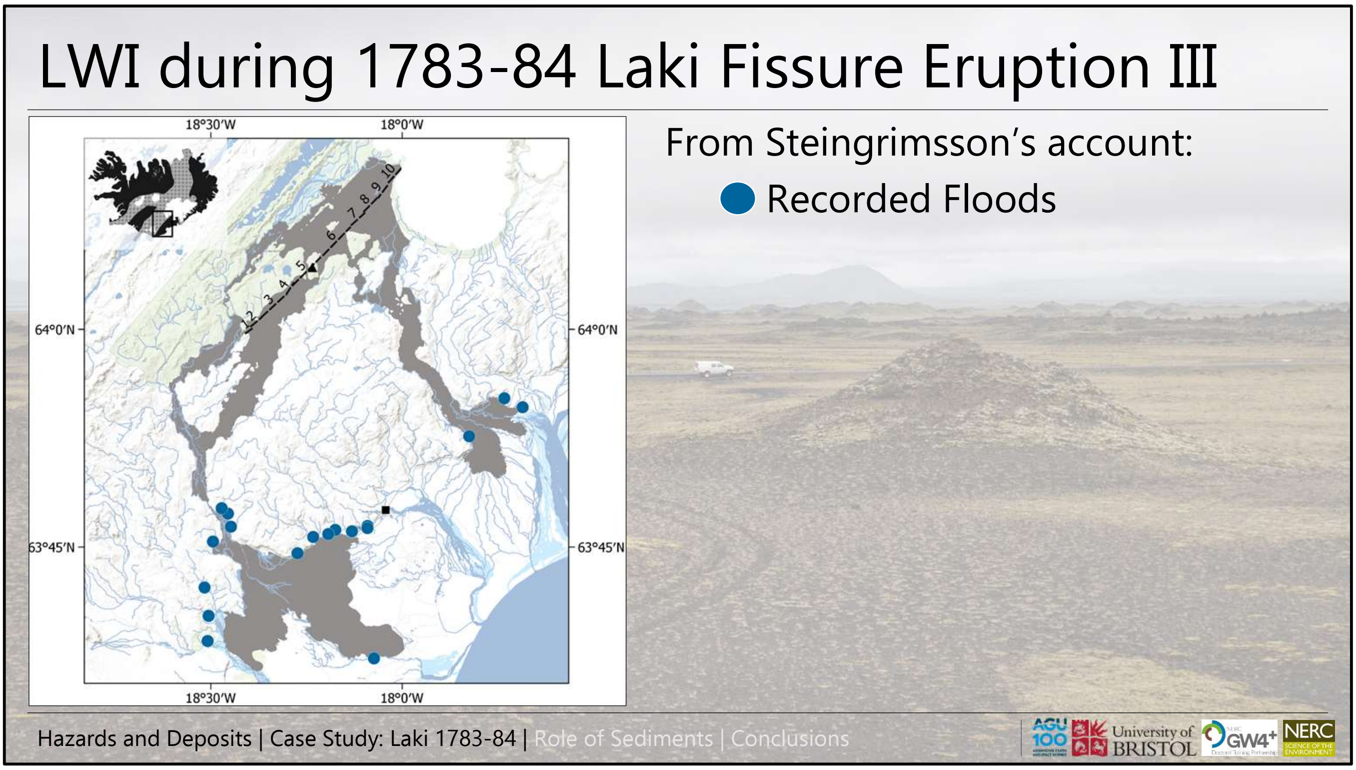
Hazards and Deposits | Case Study: Laki 1783-84 | Role of Sediments | Conclusions

The eruption disrupted two major river systems and their tributaries, causing rootless eruptions, flooding and pollution of drinking water

Selected descriptions from Steingrimsson's book, Fires of the Earth

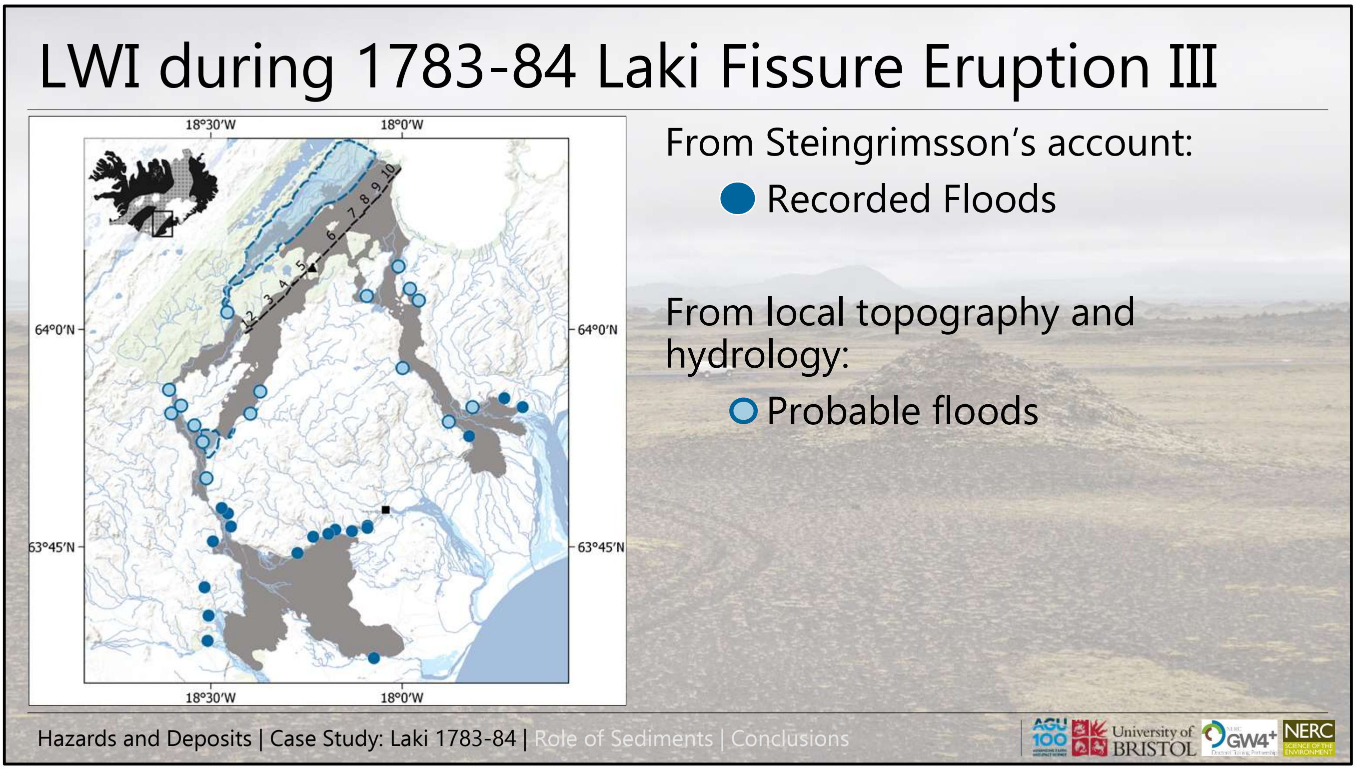


By mapping the events described by Steingrímsson on to the lava flow, we can see how the local topography and hydrology came together to cause hazardous LWI

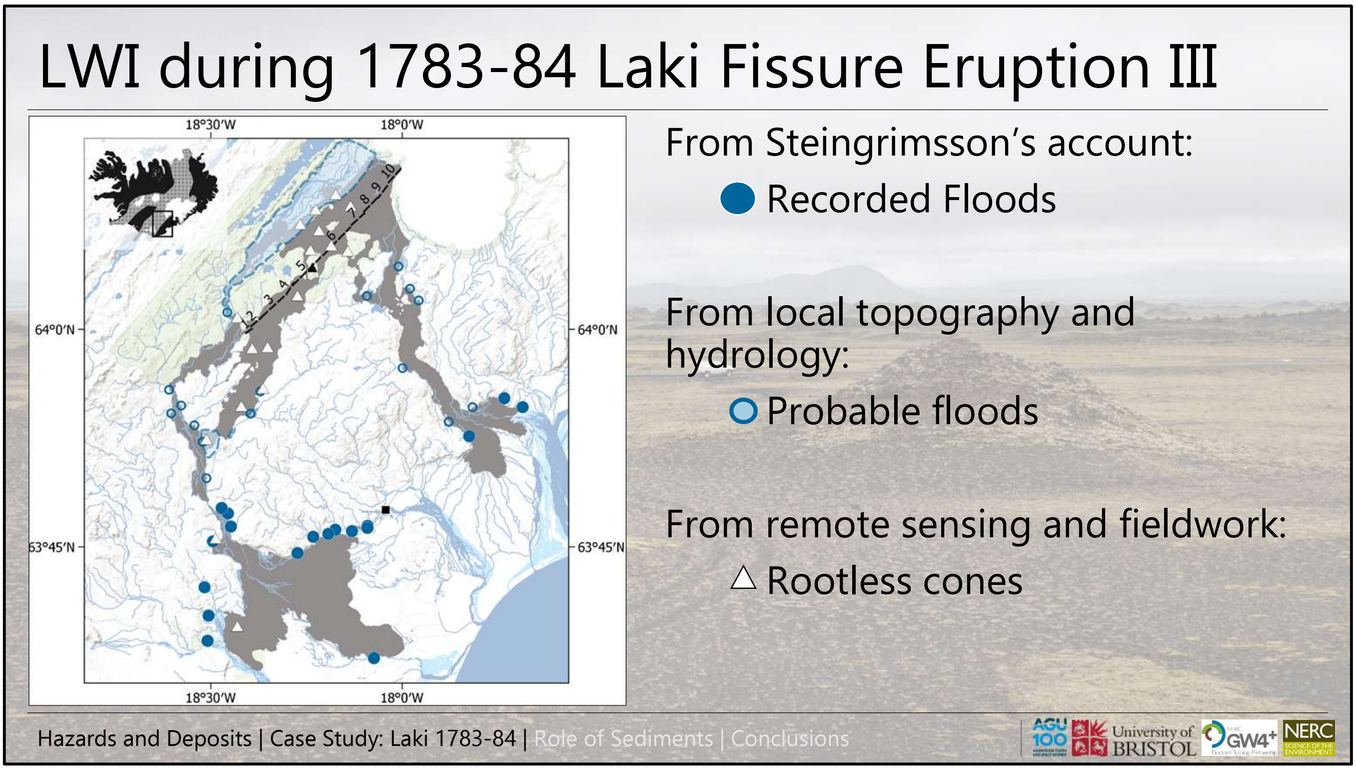


We can map the locations of farms or houses that flooded

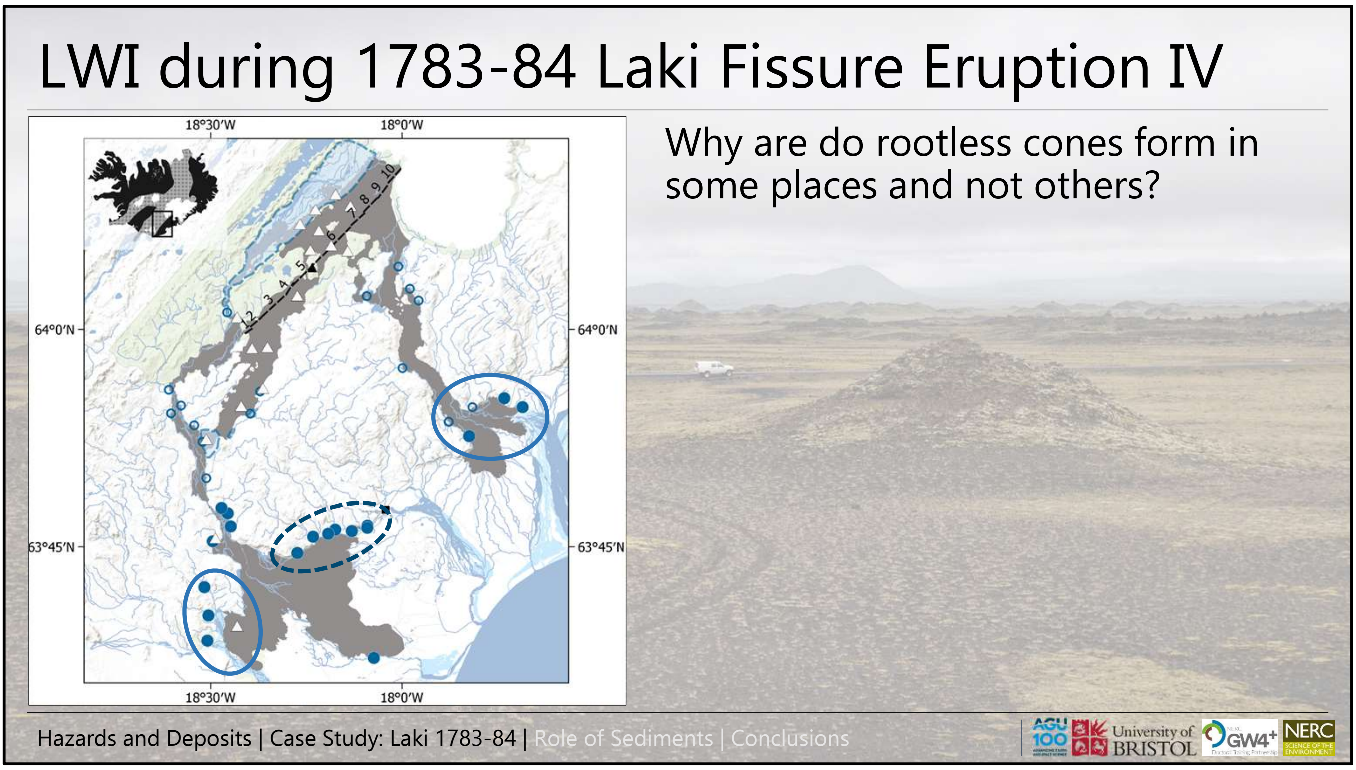
Primarily where the lava flow dammed tributaries in narrow, steep-sided valleys. While most of the flooding may have been local and contained in these small valleys, it was still devastating for the affected farms. And along the western edge of the flow the lava created a dammed lake that covered at possibly as much as 5km^2



And based on the local hydrology and topography, we can map places that probably flooded when lava dammed rivers, but where there were no eyewitnesses



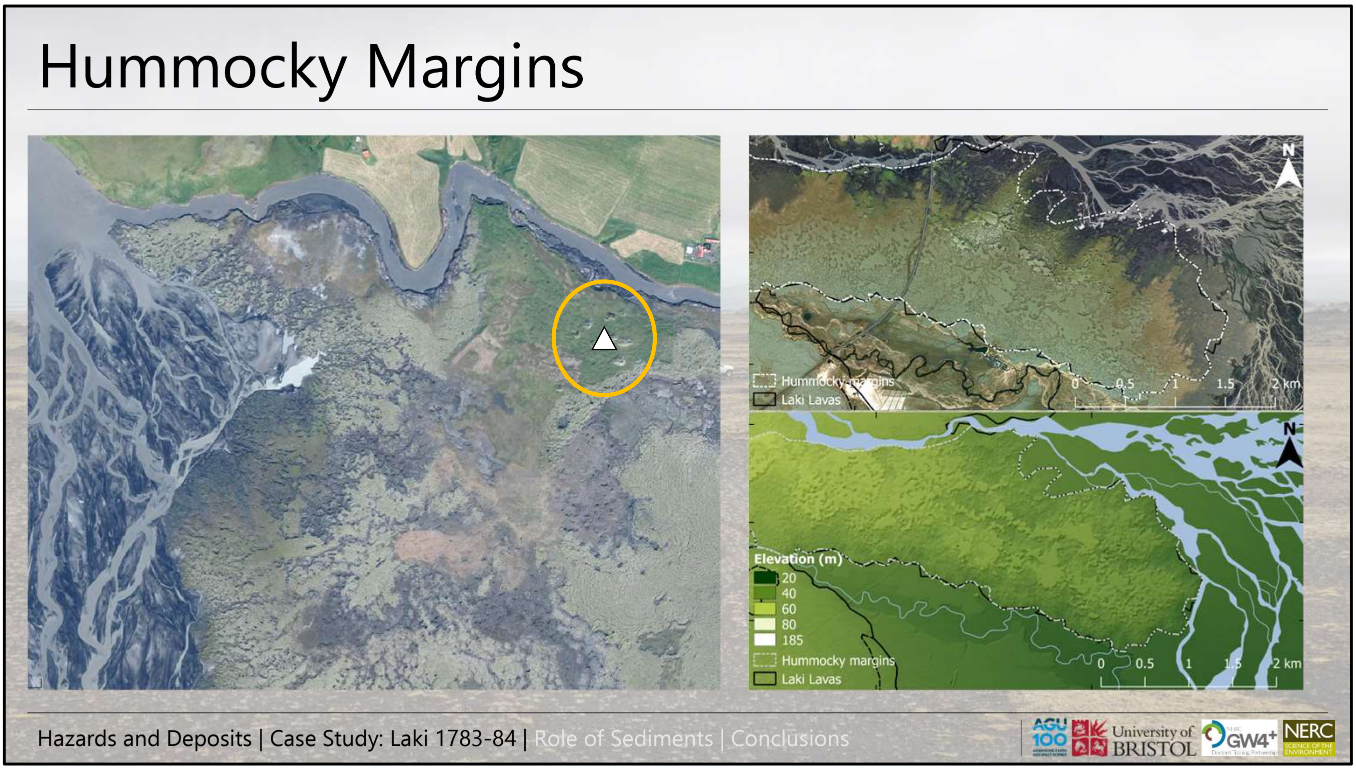
From satellite images, we can then add the rootless cone groups across the lava field



But we can also see that there are many instances of lava-water interaction that DIDN'T result in rootless cones – why? And are there any other indications of LWI?

In some areas, for example where lava dammed the mouth of steep-sided valleys, contact between fresh lava and water was cut of very quickly – limited heat transfer, no opportunity to trap water, low probability of explosive LWI

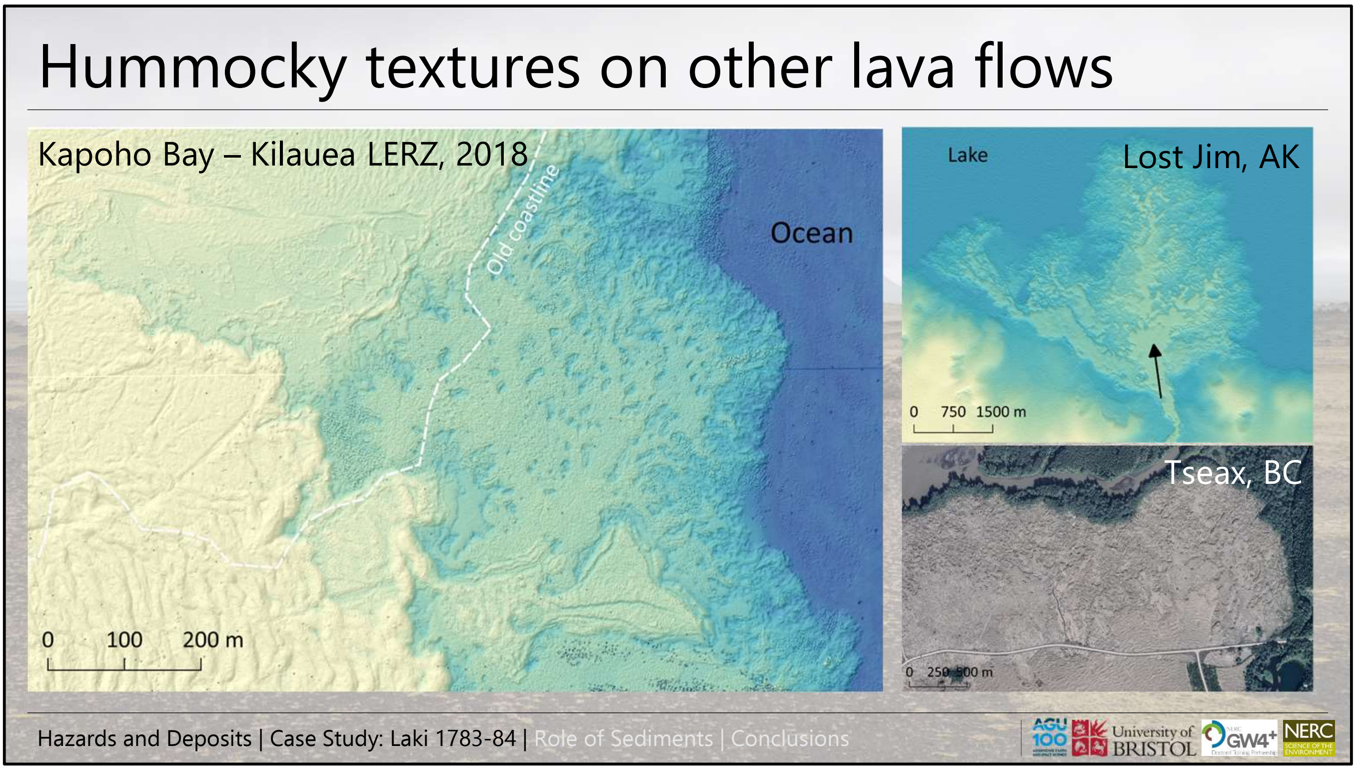
But what about large expanses of wet sediment, for example: flood deposits and riverbeds?



On the western edge of the flow, Steingrimsson described substantial flooding as the lava partially dammed three large rivers. Along this flow margin, the lava has a branching, pitted, hummocky texture. And on the boundary between the hummocky margin and the main flow, there is a group of rootless cones.

And on the eastern edge of the flow, where Steingrimsson recorded flooding and quicksand, and where the lava meet another large river, we have another extensive areas of hummocky, inflated flow.

These are clear and obvious in satellite imagery and also in satellite-derived DTMs, such as the 2m resolution ArcticDEM dataset



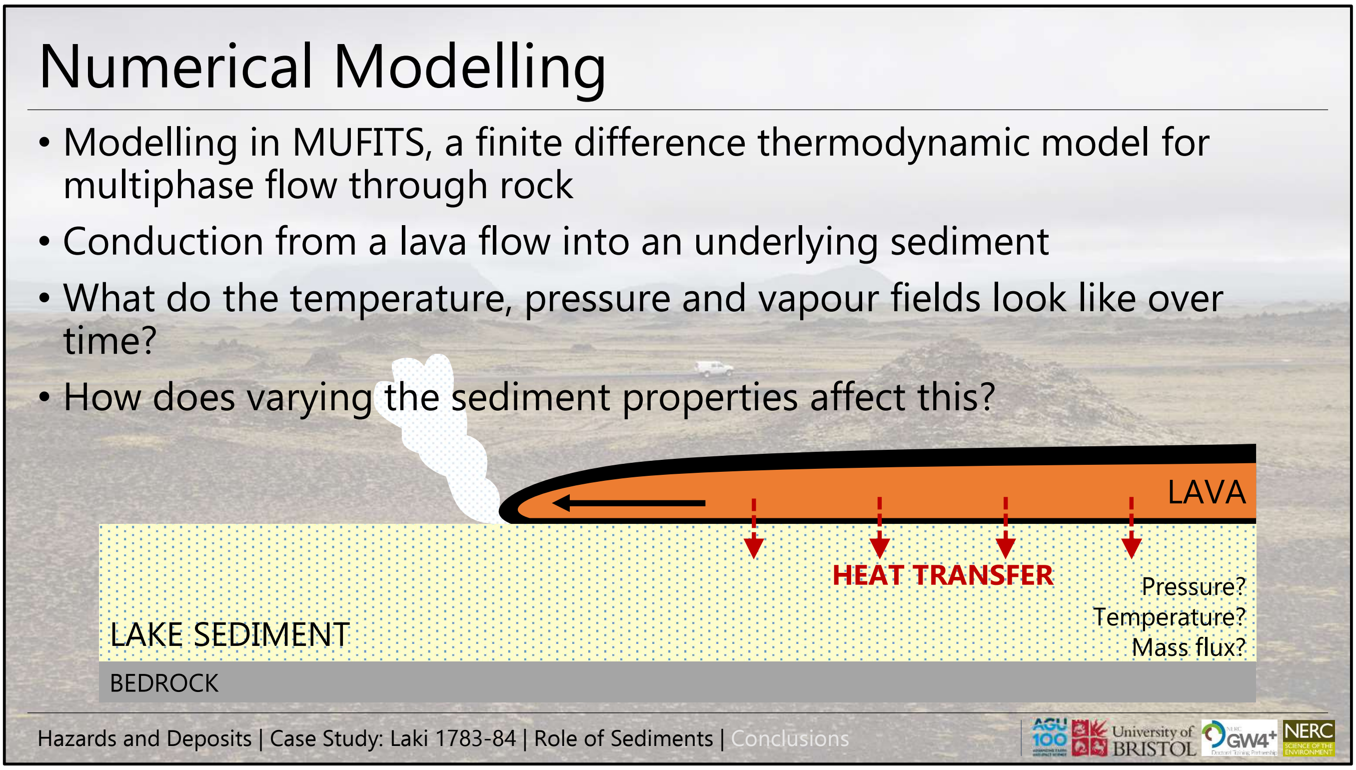
And we see these textures on other lava flows that interacted with water.

On the right, we have LiDAR data captured during the 2018 Kilauea Lower Easter Rift Zone eruption, as the lava entered the ocean at Kapoho Bay

Top left, we have part of the 1-2 thousand year old basaltic Lost Jim lava flow in Alaksa, as it enters Lake Imuruk.
Below that, the 1775 Tseax lava flow, which covers the Nass river floodplain. Again, basaltic.

It may be that the presence of water promotes flow inflation by increasing crustal cooling and thickness, and reduces the internal pressure needed for inflation through buoyancy. This mechanism was suggested by Deschamps et al (2012) for submarine and subaqueous lava flows, and we wonder whether it is contributing to inflation in lava flows that meet rivers or floodwater

So why do we get rootless cones in some areas and not in others? And can we use that to help future hazard assessments?

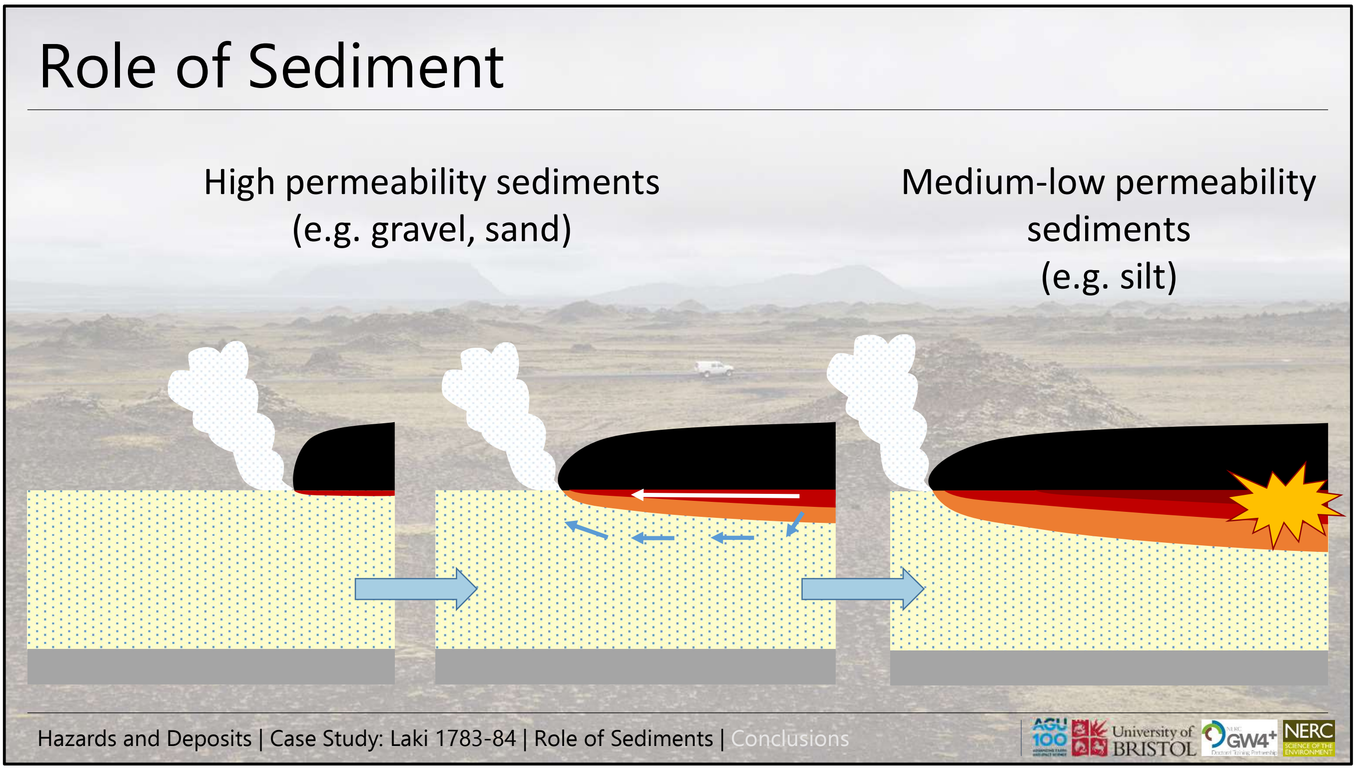


We looked a one end-member model for triggering rootless eruptions: conduction from a lava flow to an underlying saturated sediment

We use the code MUFITS (developed for modelling heat and mass transfer of multiphase fluids through rocks) to build a simple numerical model of heat transfer into fully saturated, homogeneous sediment

Particularly interested in the rates of heat transfer, steam generation and pressure build-up
Systematically varied sediment permeability and porosity to see what effect it had on pressure build-up and degassing

Crucially, does enough pressure build up to break through the lava flow initiate a rootless eruption? (combination of lava flow weight, crust strength and sediment cohesion – max ~1MPA)

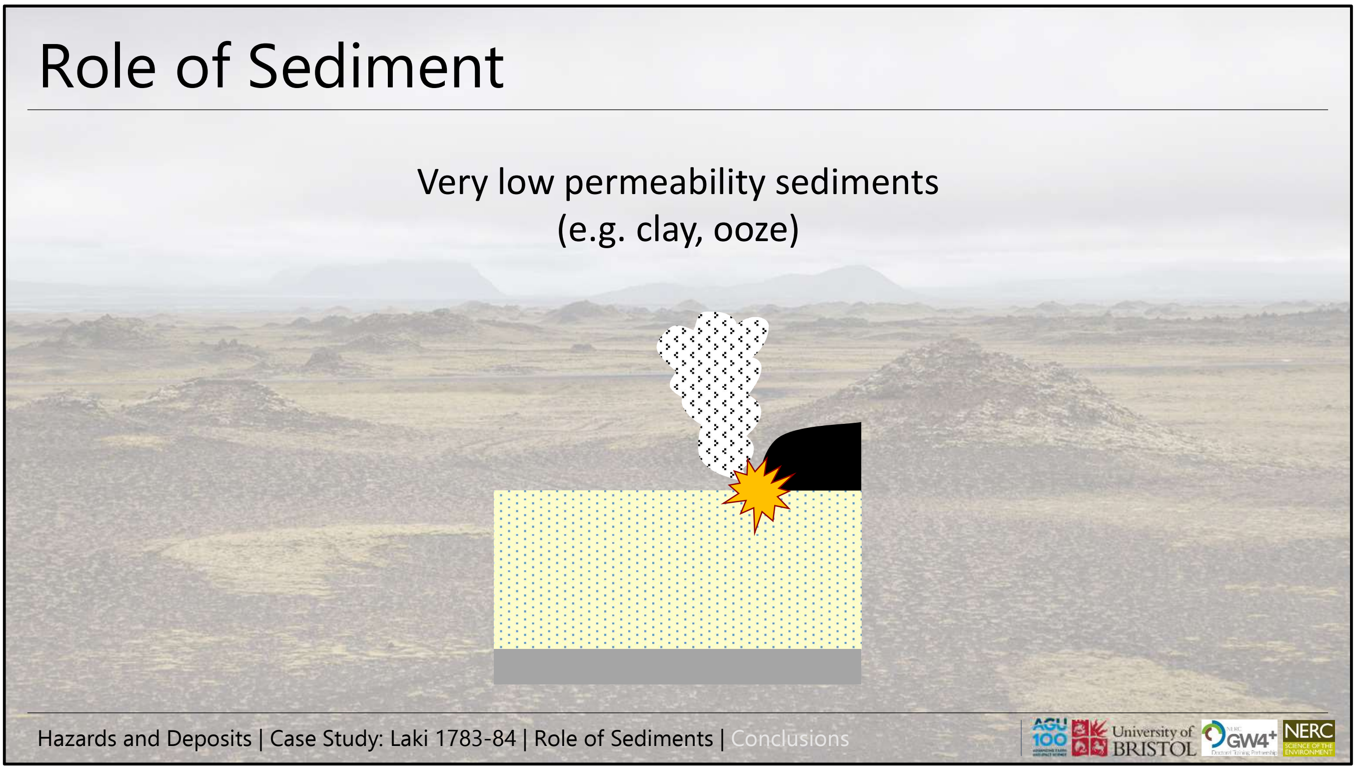


As lava advances, top layer of sediment heats and dries out, and we get steaming at lava front

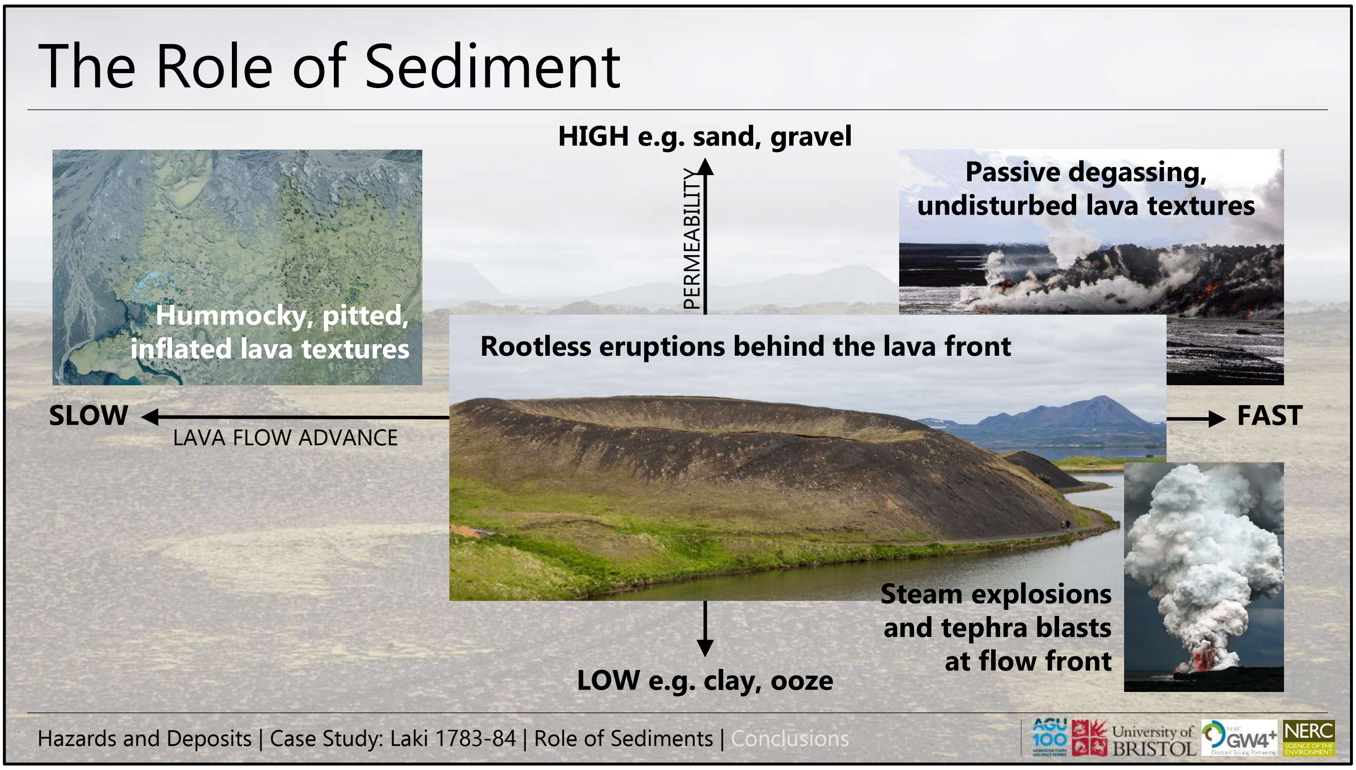
The lava flow continues to advance and subsurface continues to heat.
This generates steam deeper in the sediment behind the lava front. Pressure drives flow of water and gas towards lava front.
Dry top layer acts as steam-escape pathway

If the sediment is highly permeable, such as a gravel or sand, then this stable steam generation ad degassing continues as the flow advances, without significant pressure build up

HOWEVER, if the sediment is less permeable, e.g. silt, then there reaches a point where the pressure build-up behind the lava flow is sufficient to break through the overlying flow – triggering a secondary explosion



For very low permeability sediments, pore pressure in the top layer of sediment grows rapidly and instead of passive steaming at the lava front, we expect small explosions, disrupting the flow advance



The ultimate results will depend on the balance between the rate of lava flow advance and the rate of steam generation and escape.

Where there is a fast advancing lava over a highly permeable sediment, we expect passive steam escape, and undisturbed lava textures. For example, no rootless cones formed when the 2014 Holuhraun lava flow entered a river bed – the ground is highly permeable, allowing steam to easily escape.

Where the lava advance rate is slower, we expect to see hummocky pitted textures caused by flow inflation. Deschamps et al. suggested that inflation is aided by the presence of water because buoyancy reduces the force for inflation

However, where the sediment is less permeable, we would expect to see rootless cones forming

If the flow advance is sufficiently high and the permeability sufficiently low, we would get steam explosions at the flow front, as well as rootless cones further back. Akin to tephra blasts described by Steingrimsson and seen at lava flows advancing into water.

Implications for Future Hazard Assessments

- Lava-water interactions should be considered in hazard assessments for wet areas
- Floods caused by LWI can modify the environment to deposit low-perm sediments
- Remote analysis of past deposits, e.g. rootless cones and hummocky lava, give an indication of what happened in past eruptions
- Outcomes of LWI (explosive or passive) are affected by sediment permeability
- Rootless eruptions more likely on low permeability sediments than high

- Supervisors
- Andrey
- NERC and GW4+
- ArcticDEM
- OpenTopography
- Google Earth
- Map.is