



# Precursory seismic signals before two catastrophic landslides at Irazú Volcano, Costa Rica

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Noah Finnegan<sup>2</sup> and Bretwood Higman<sup>3</sup>

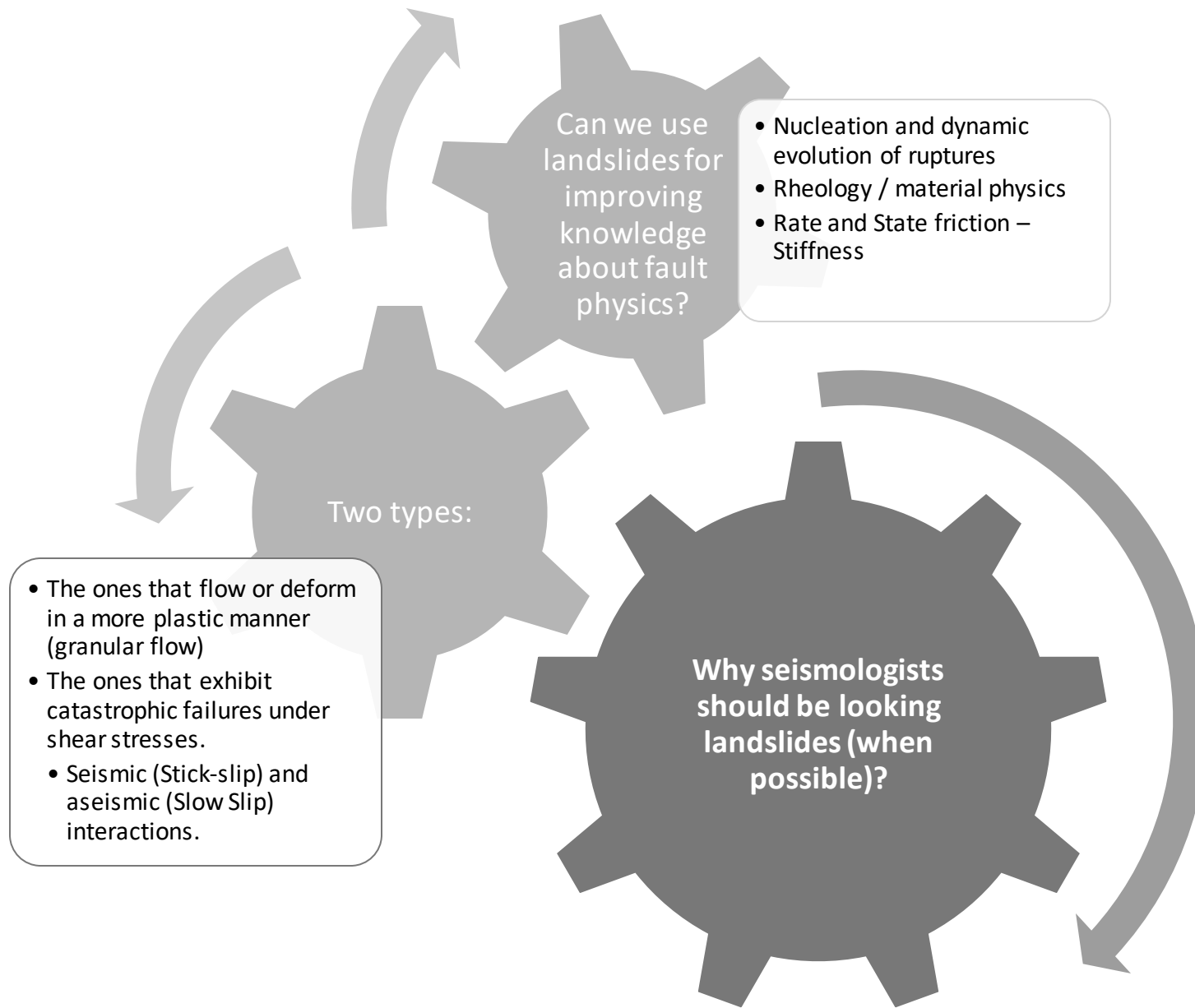
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<sup>2</sup> *Department of Earth and Planetary Sciences, University of California Santa Cruz, 95064, Santa Cruz, California, United States*

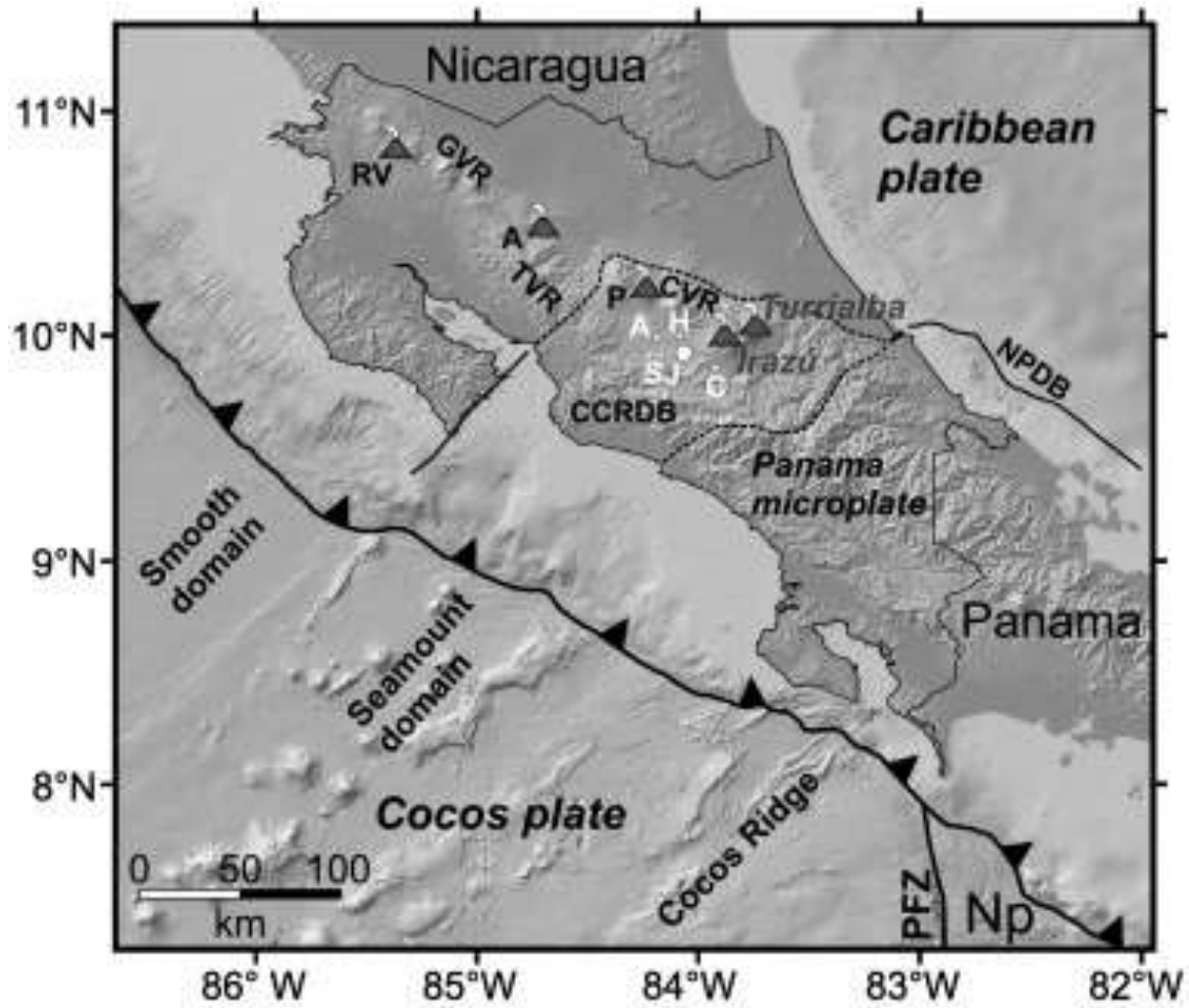
<sup>3</sup> *Grond Truth Alaska*

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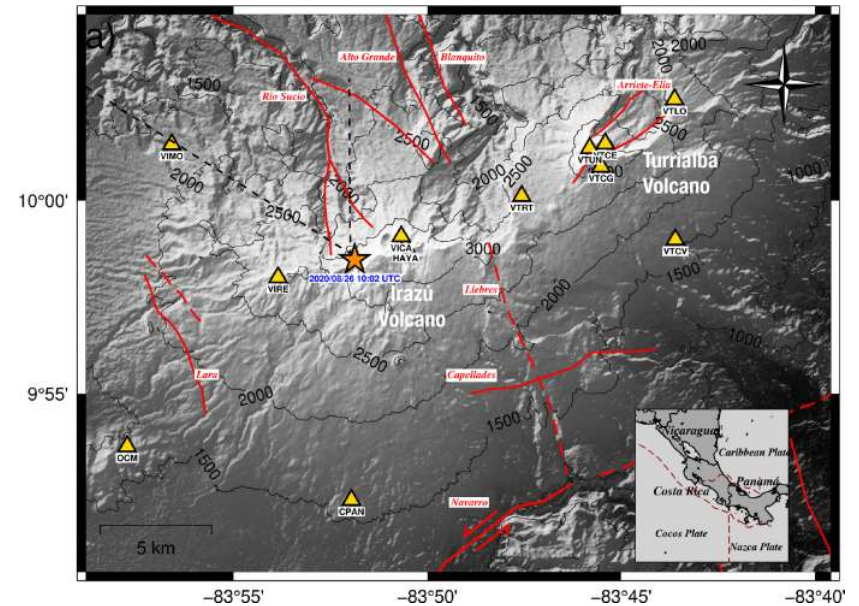




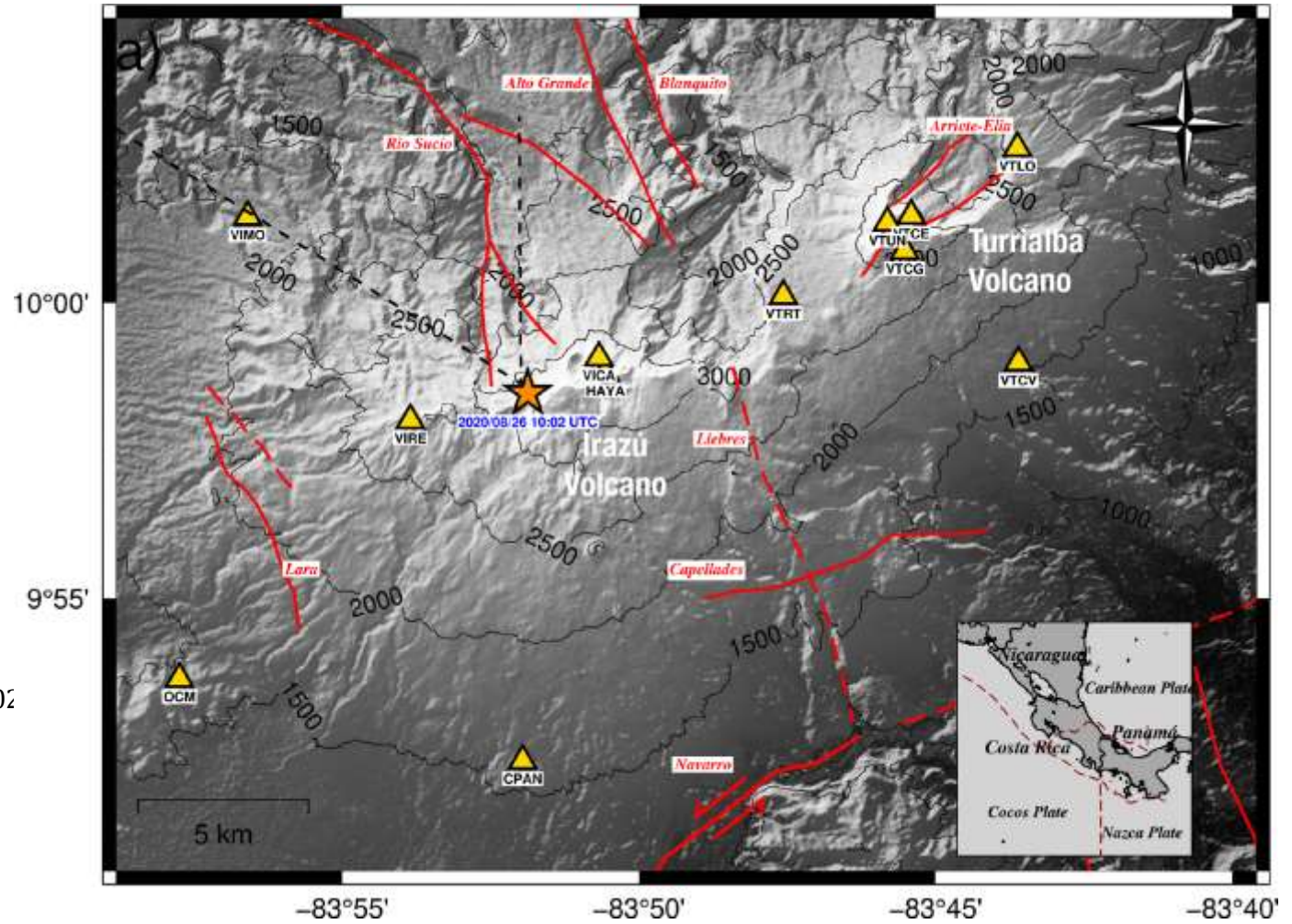
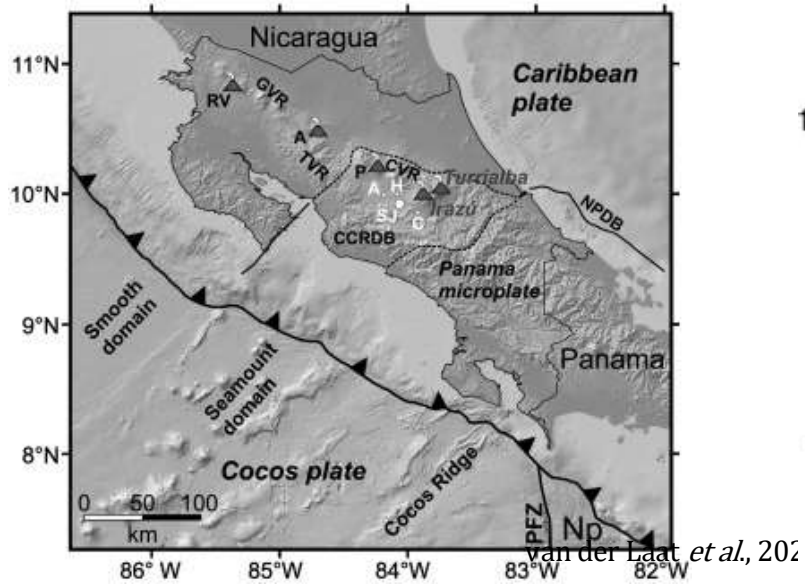
# Tectonic frame



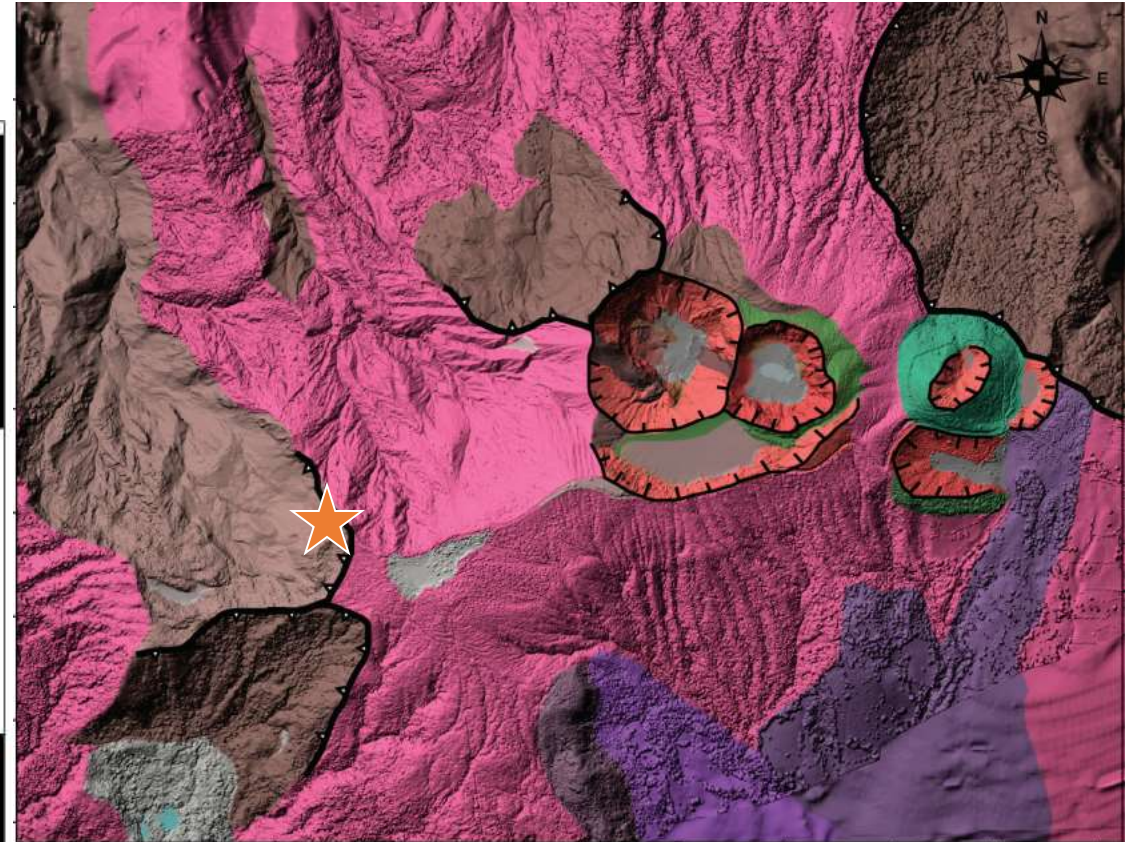
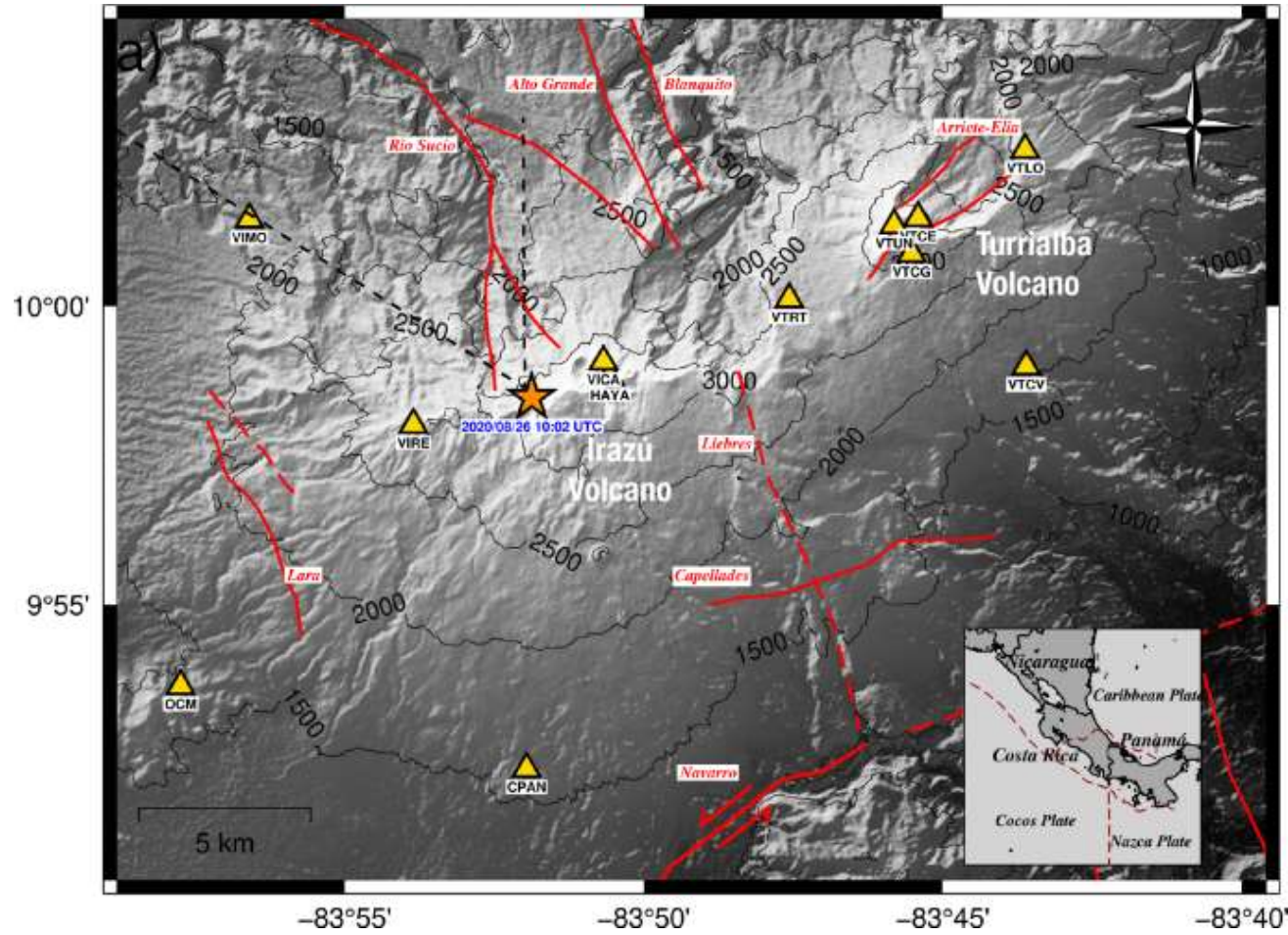
van der Laat *et al.*, 2022



# Tectonic frame



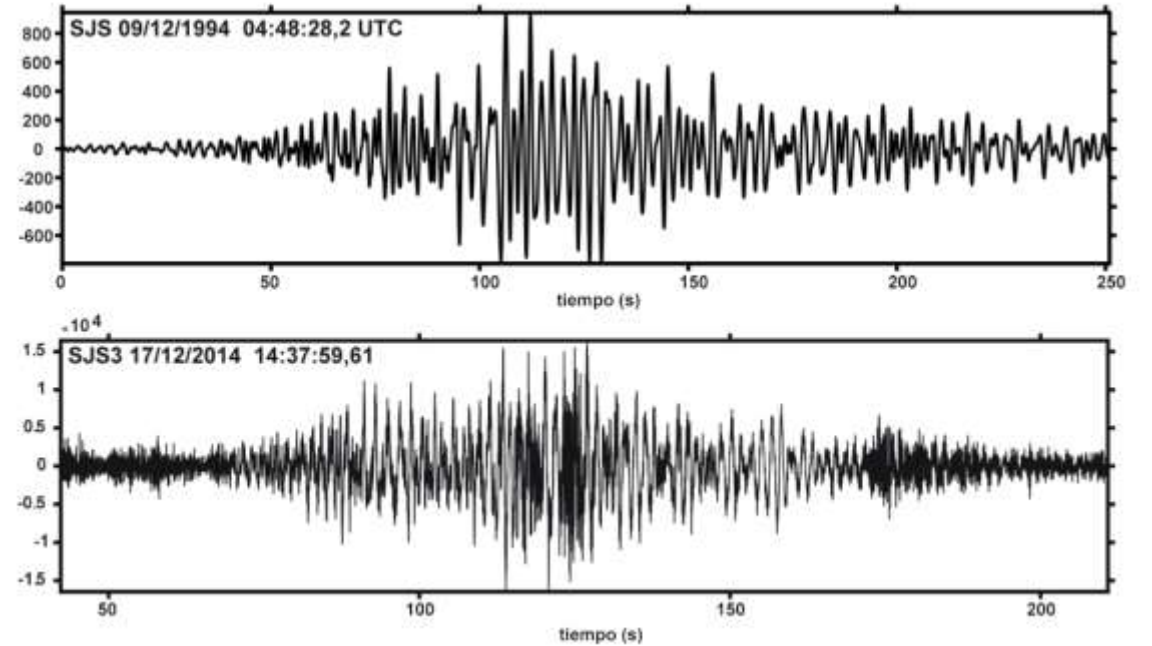
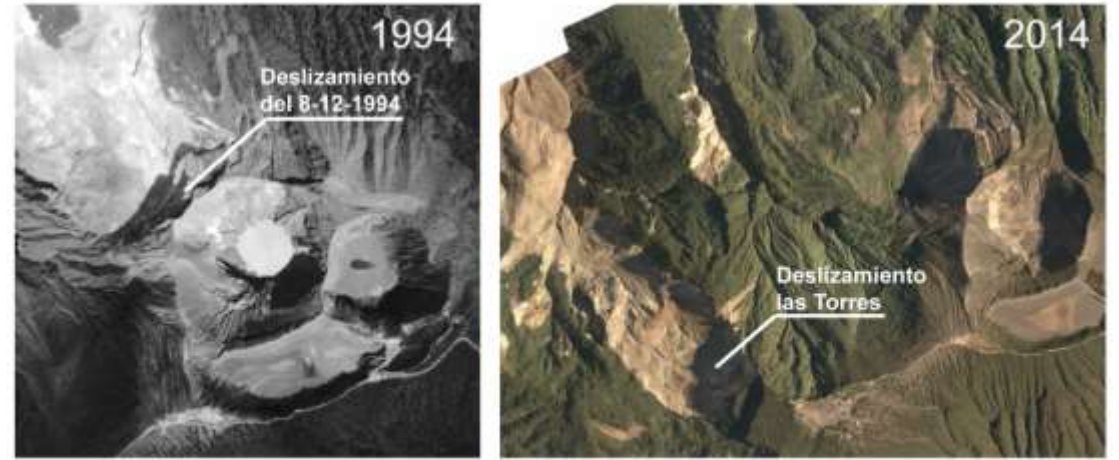
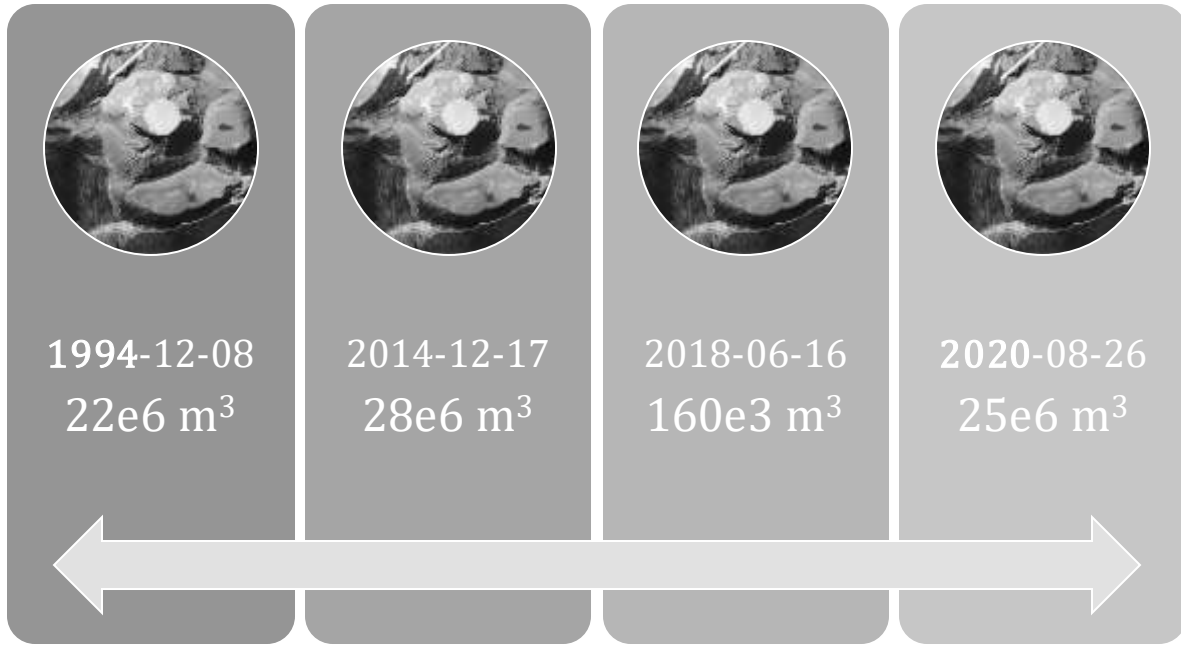
# Tectonic frame



- |   |                           |
|---|---------------------------|
| Laderas disectadas por erosión fluvial          | Escarpe de deslizamientos |
| Laderas afectadas por movimientos de masa       | Borde de cráter           |
| Laderas muy poco disectadas por erosión fluvial | Cráteres                  |
| Zonas con muy poca erosión                      | Borde externo de cráteres |
|   | Cono                      |

Fallas *et al.*, 2015

# Multi-episodic processes



Fallas *et al.*, 2015



**Fuente:** Umaña, P. (2020). Universidad Nacional anima en 3D el antes y el después del deslizamiento en el volcán Irazú. *El Observador*. <https://observador.cr/universidad-nacional-anima-en-3d-el-antes-y-el-despues-del-deslizamiento-en-el-volcan-irazu/>

# Landslide in 2014

## *Seismic evolution*

Days before collapse, discrete low frequency (LFe) and repeating earthquakes appear.

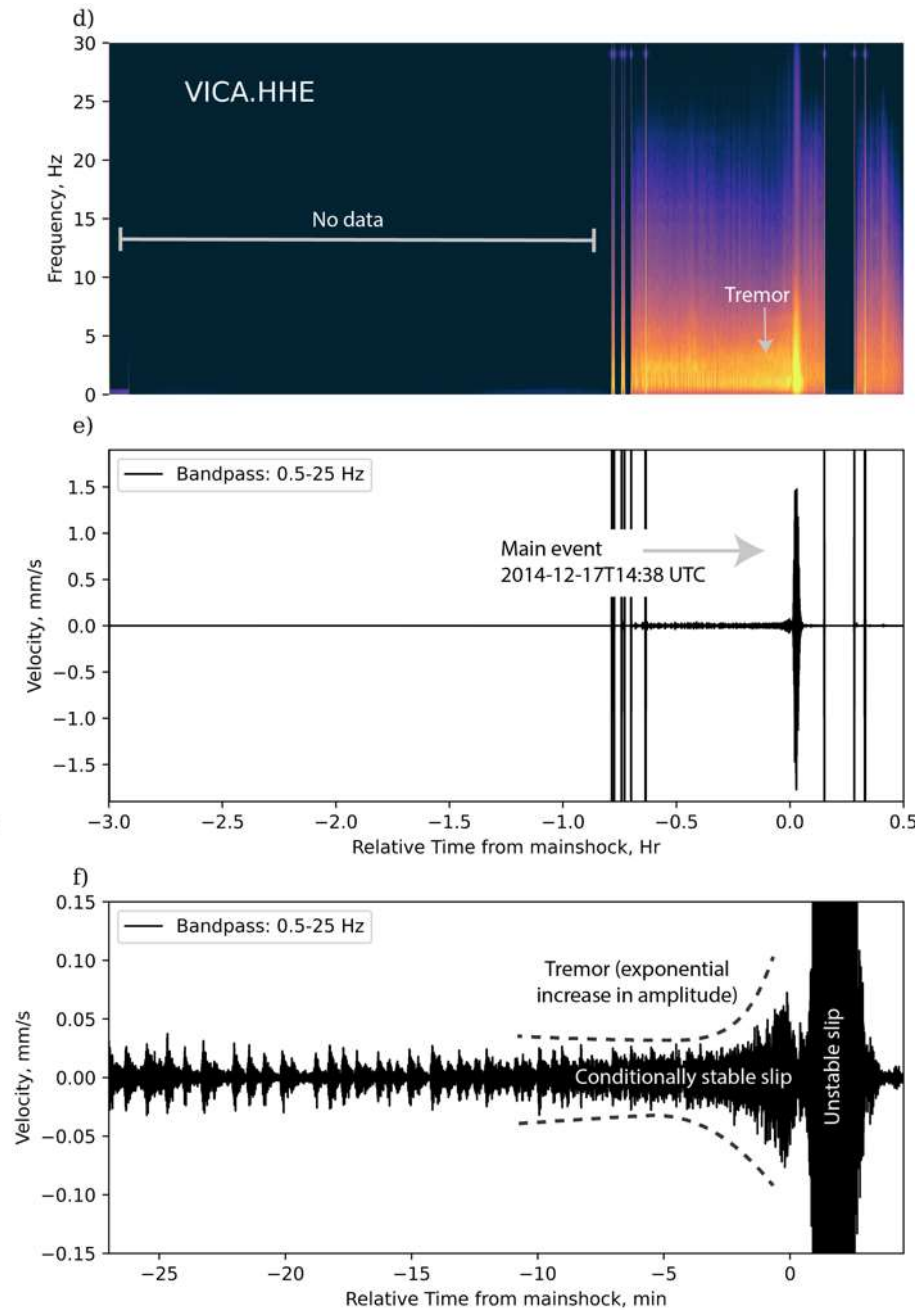
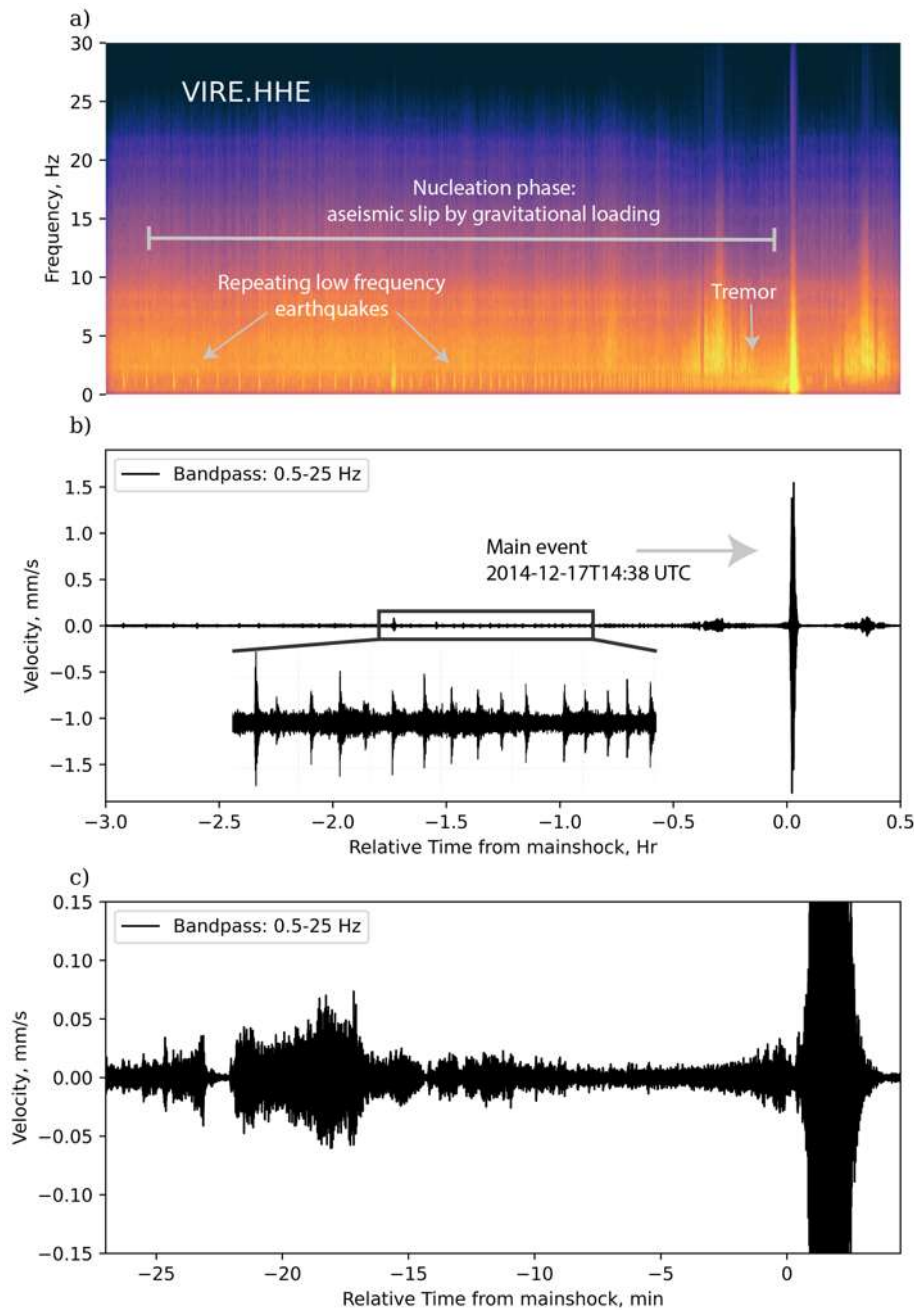


30 min before the catastrophic collapse, the repeating earthquakes merged forming a tremor signal.



The amplitude of the tremor increases exponentially, then reduces dramatically for ~20 seconds

Chaves et al., 2022 (in progress)





# Landslide in 2020

## Seismic evolution

Days before collapse, discrete low frequency (LF) and repeating earthquakes appear.

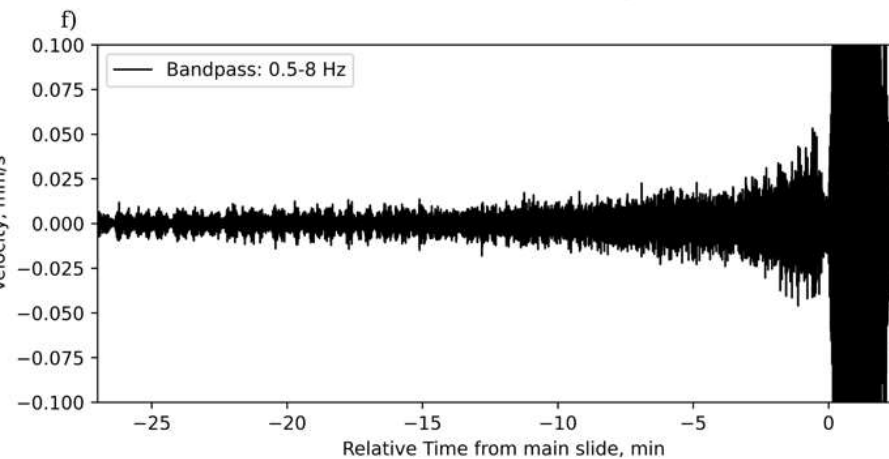
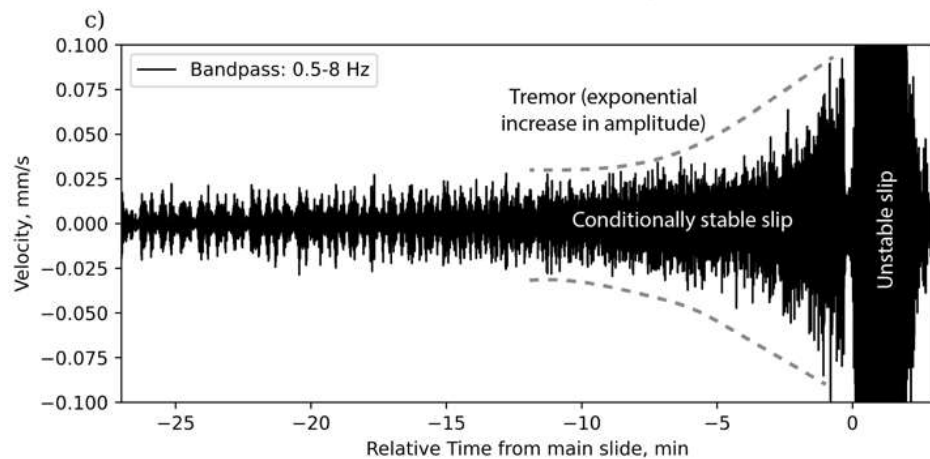
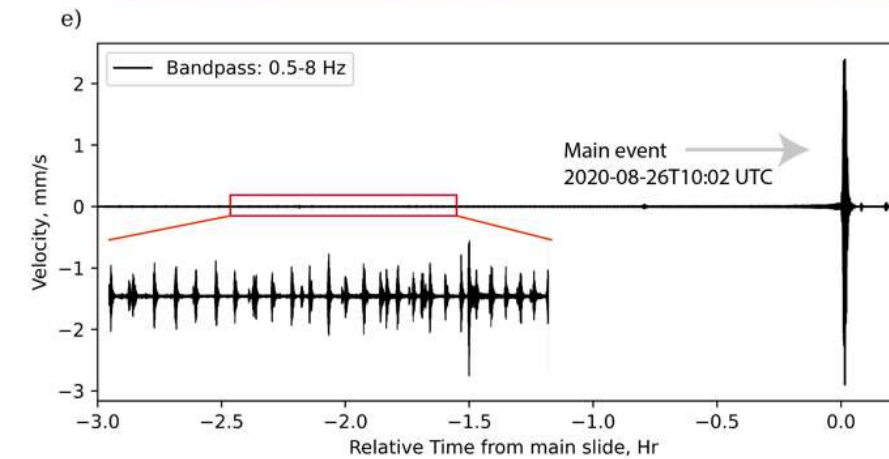
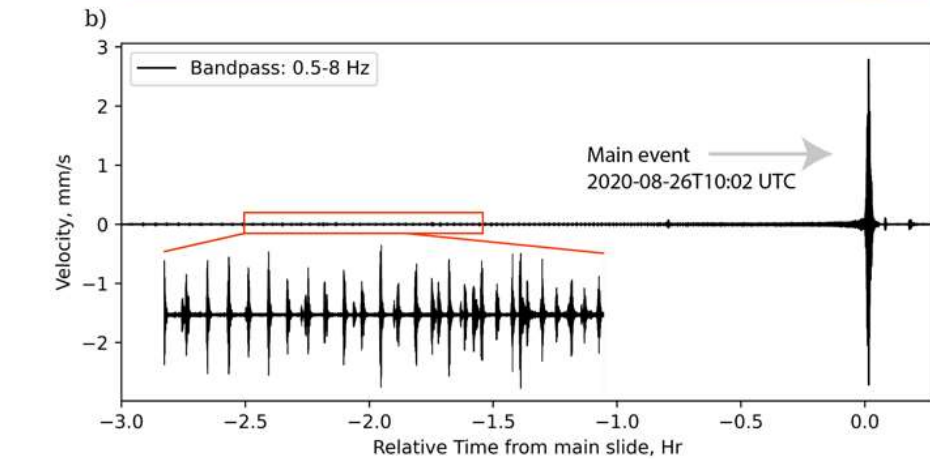
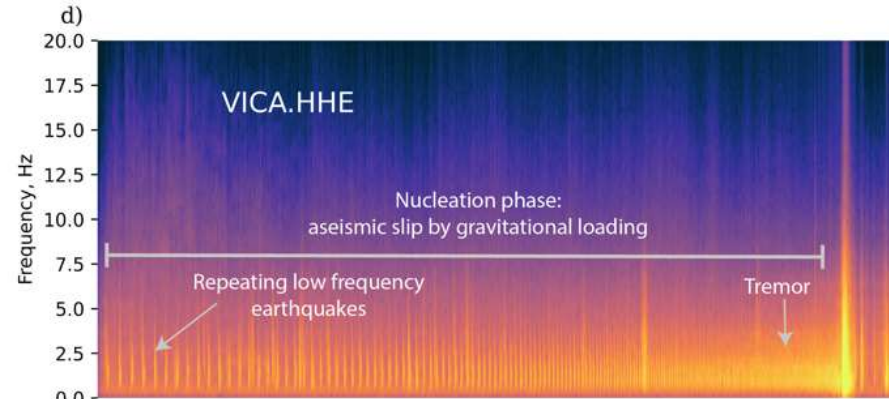
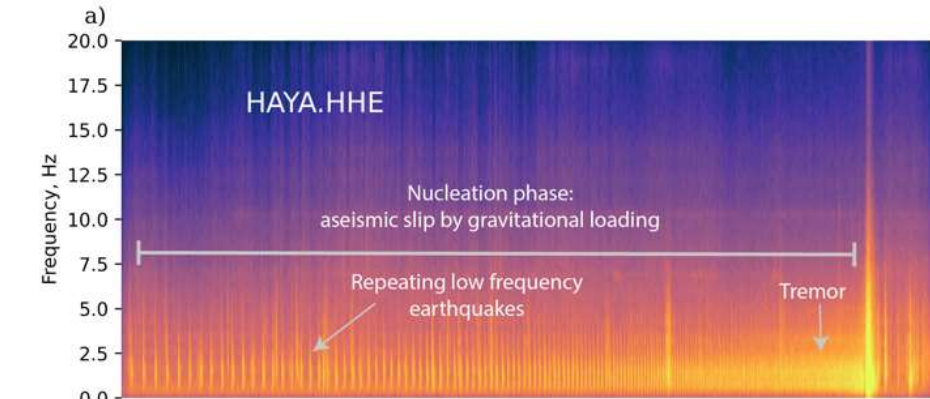


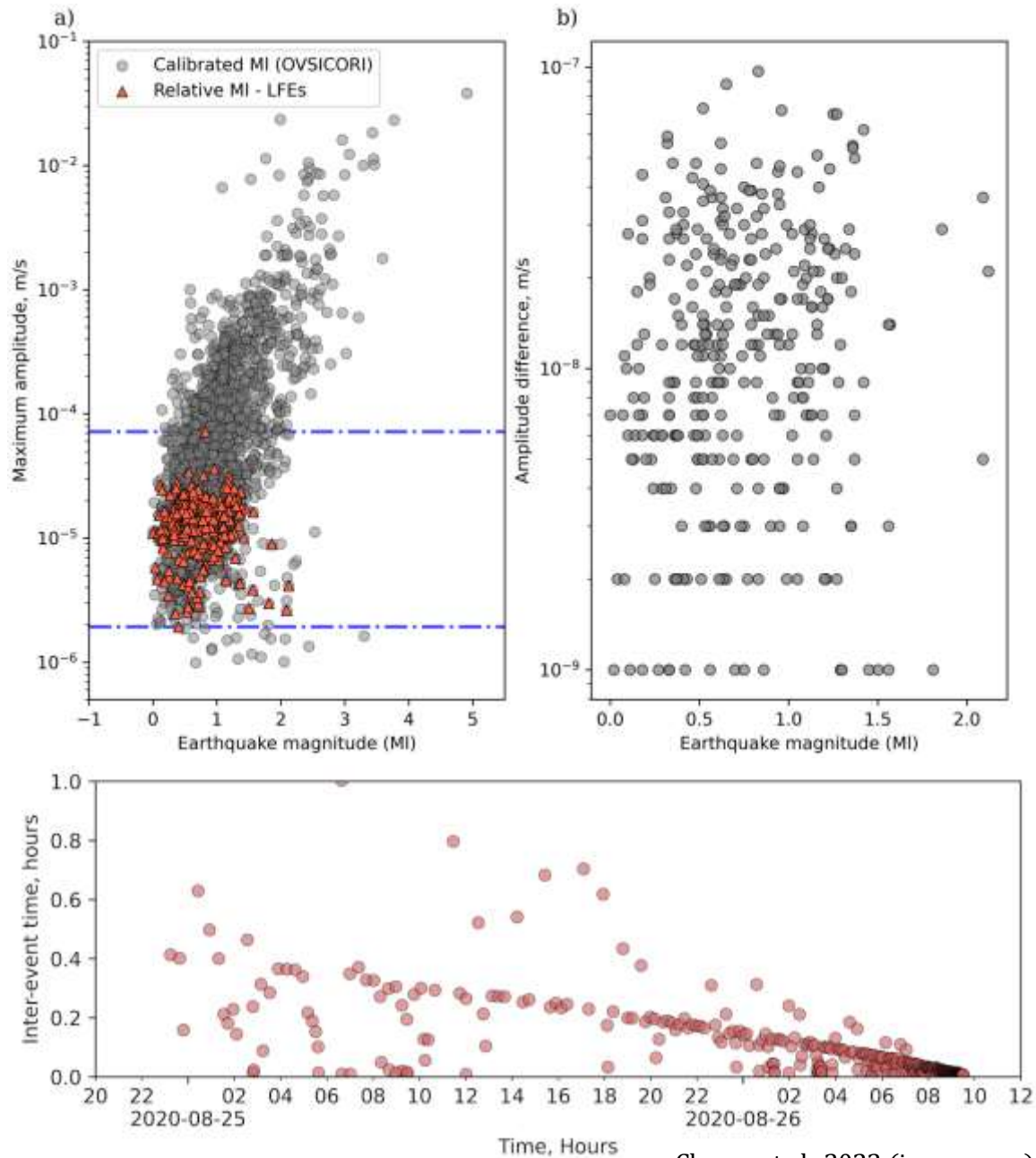
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Chaves et al., 2022 (in progress)



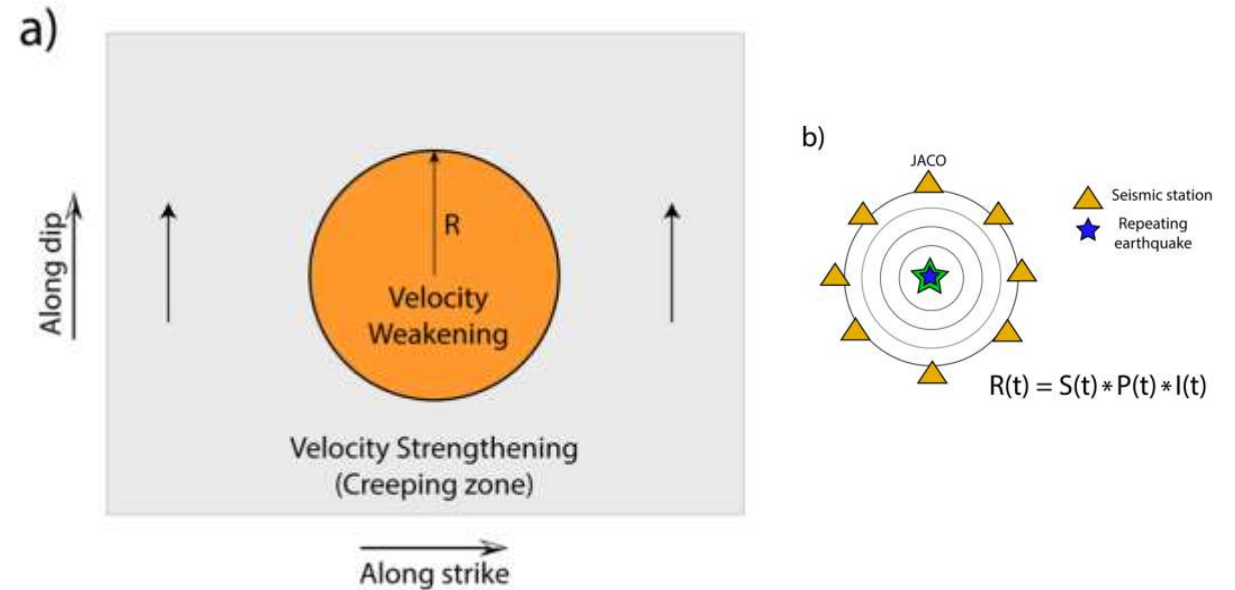


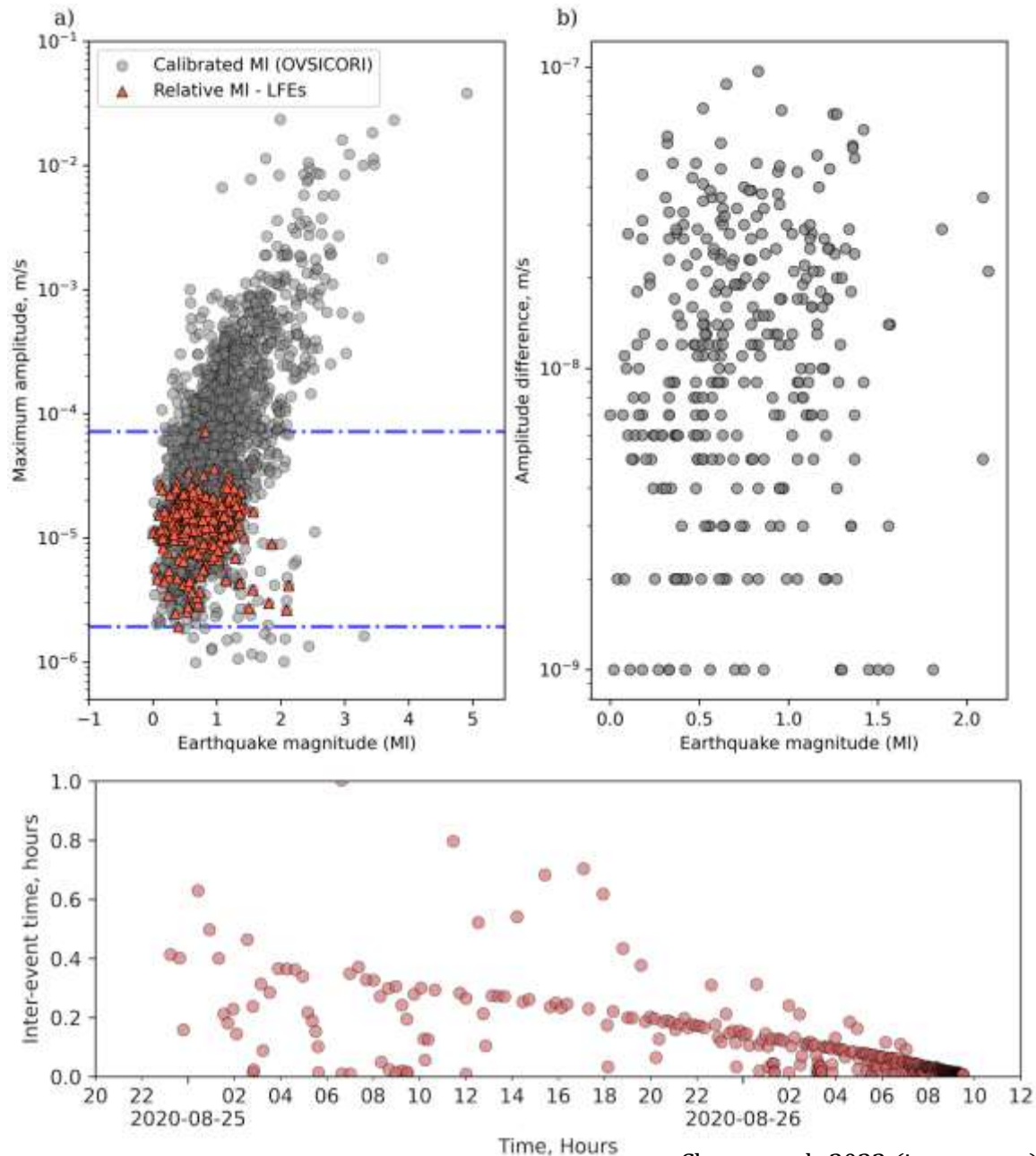
Chaves et al., 2022 (in progress)

## Precursory seismic signals before the 2020 Irazú landslide

- Magnitude calibration: MI between 0 and 2
- Inter-event time reduces linearly before collapse
- Presence of 10 families with repeating earthquakes confirming slow slip driving the process.

But... What is a repeating earthquake?



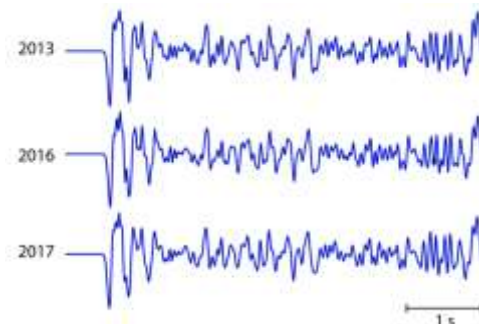
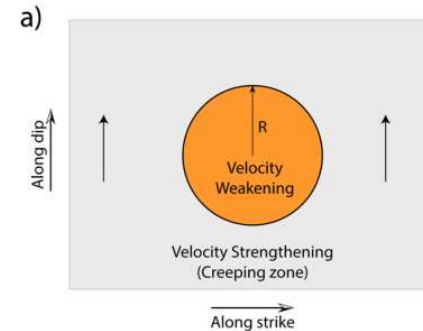
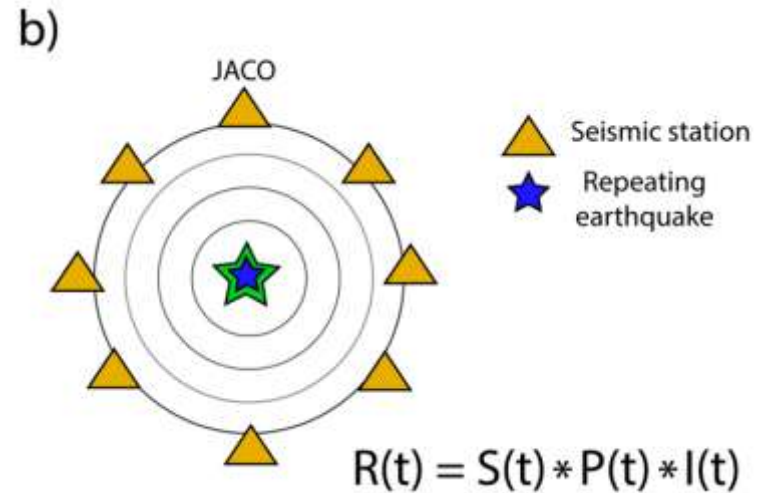


Chaves et al., 2022 (in progress)

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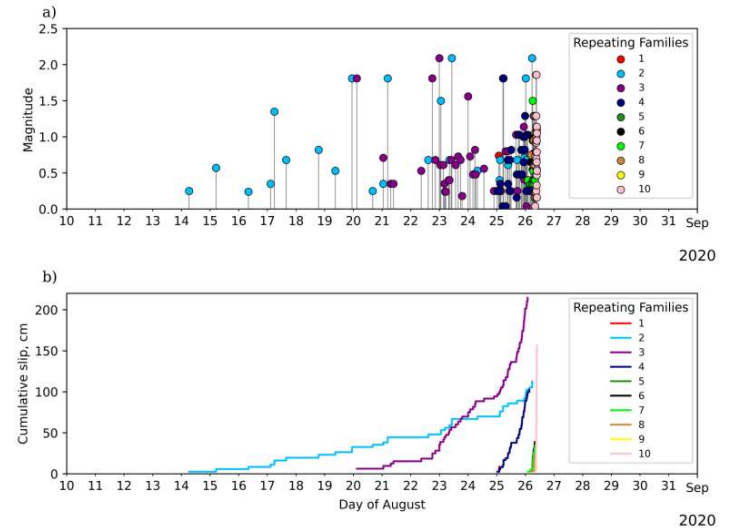
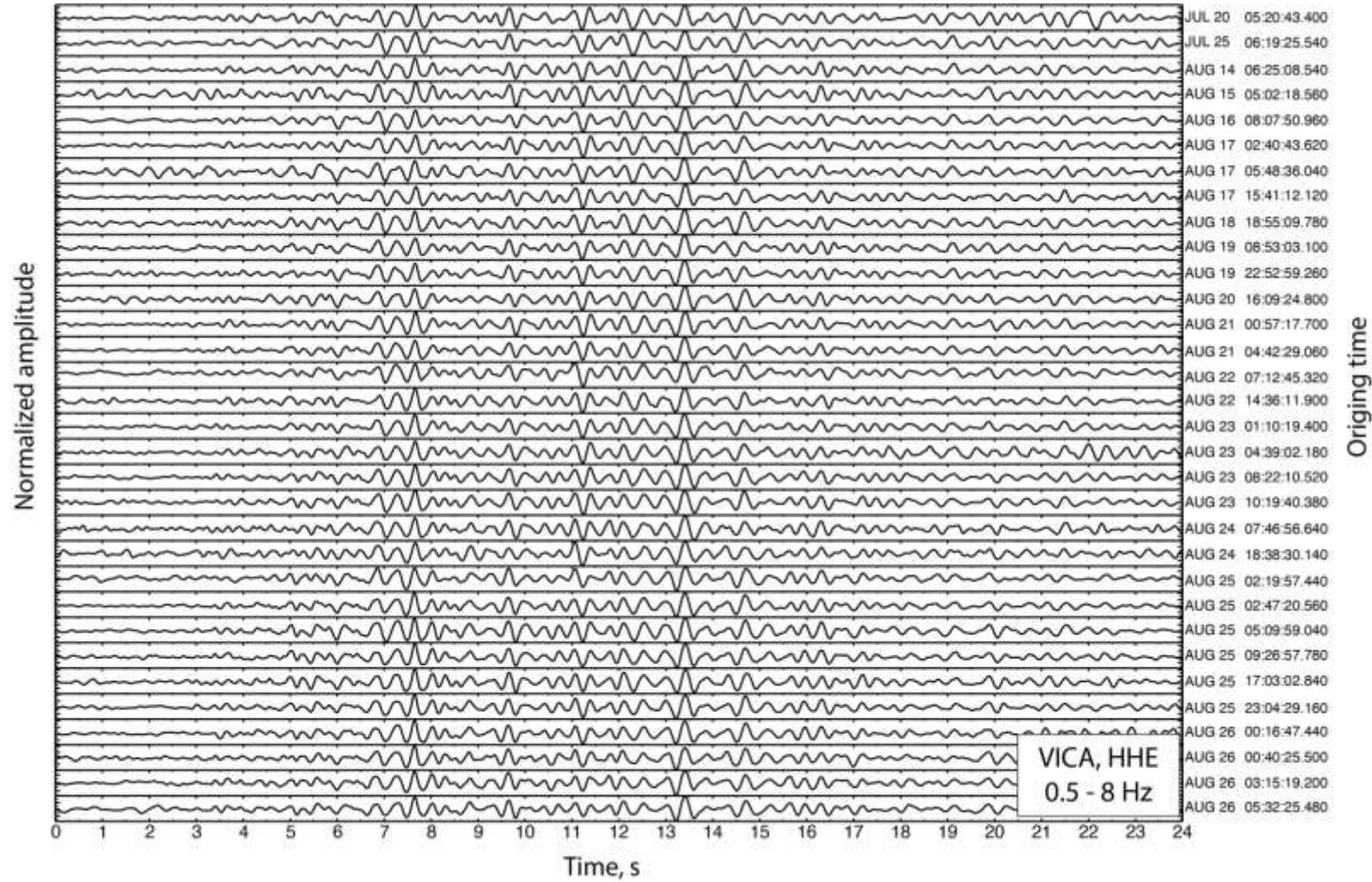
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# Precursory seismic signals before the 2020 Irazú landslide: Repeating Earthquakes

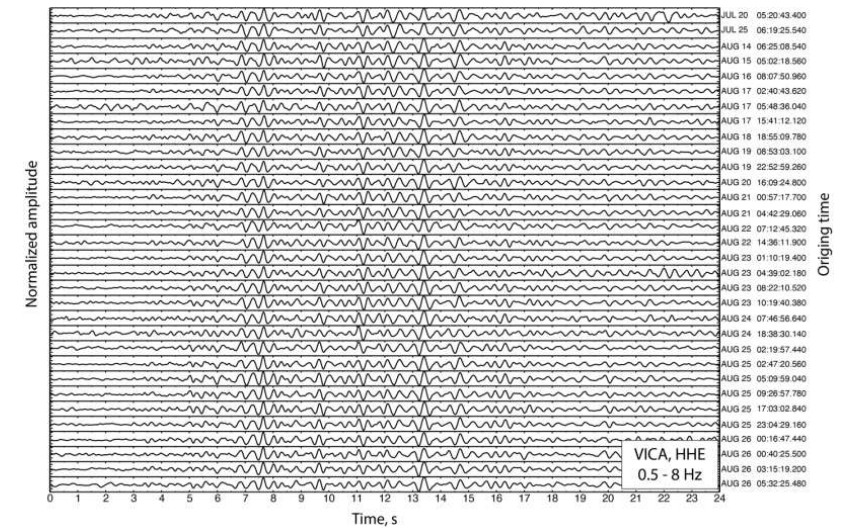
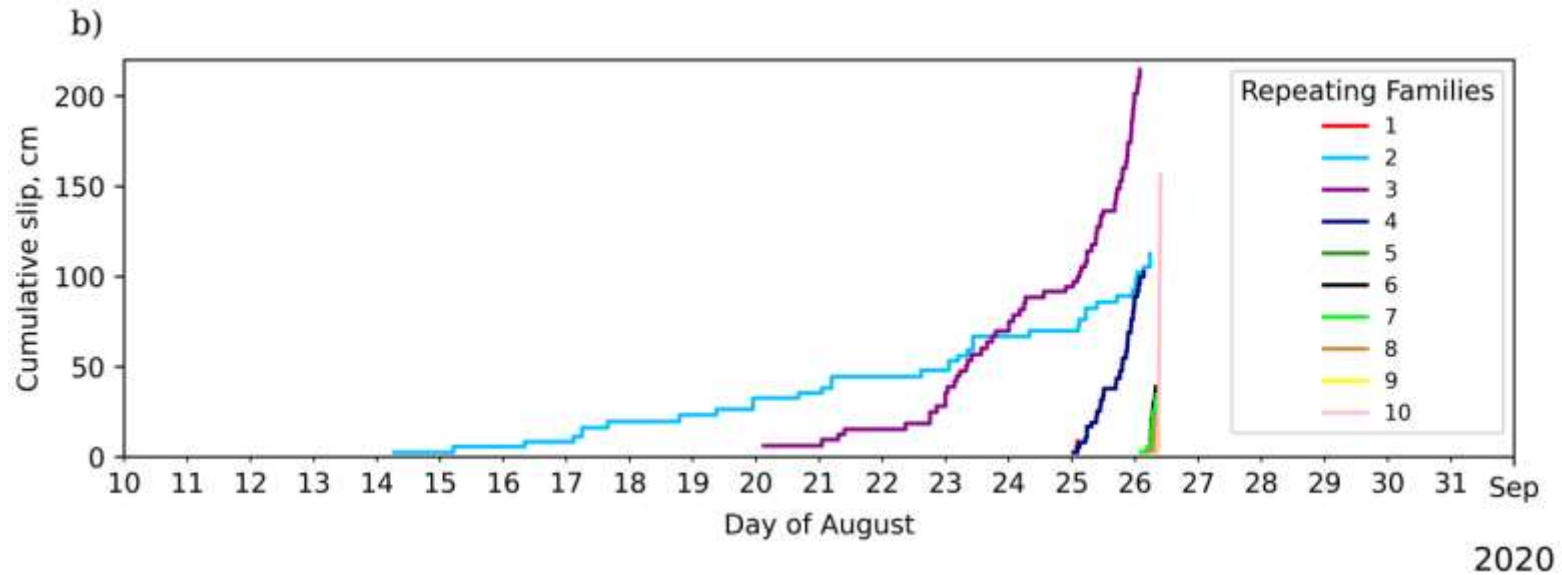
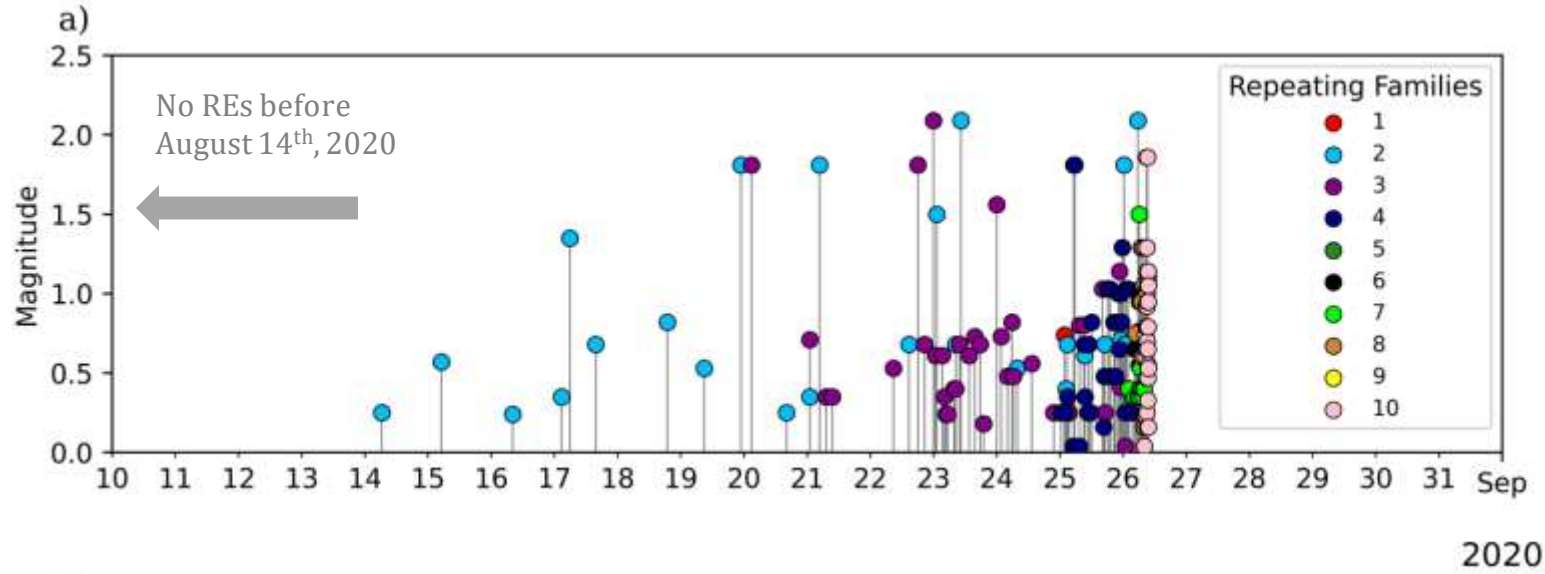
## Waveforms for the RE Family 2



Chaves et al., 2022 (in progress)

# Precursory seismic signals before the 2020 Irazú landslide: Repeating Earthquakes

*RE time evolution*



# Landslide in 2020

## Seismic evolution

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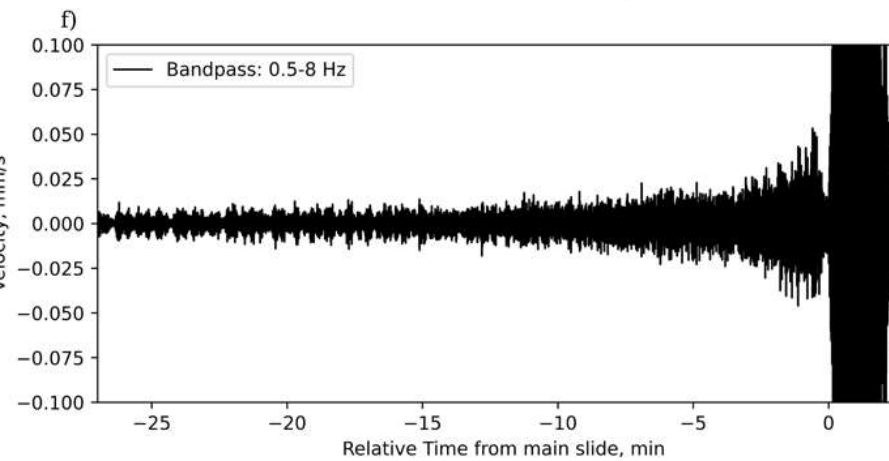
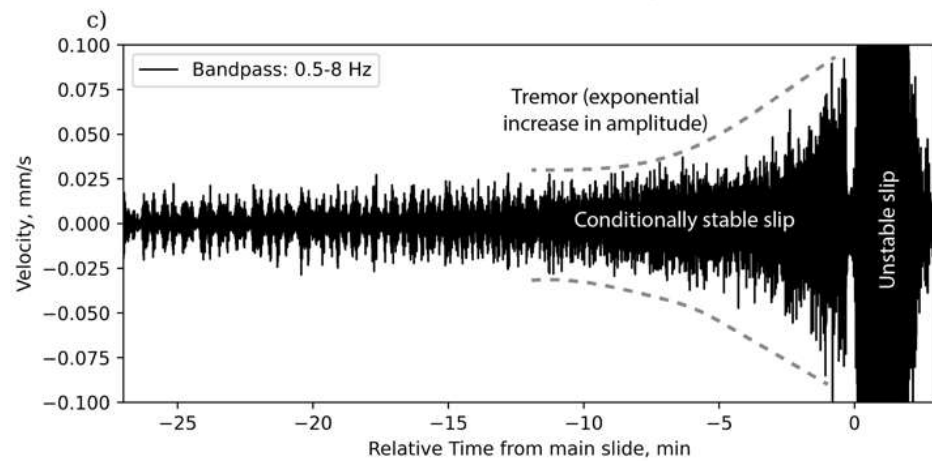
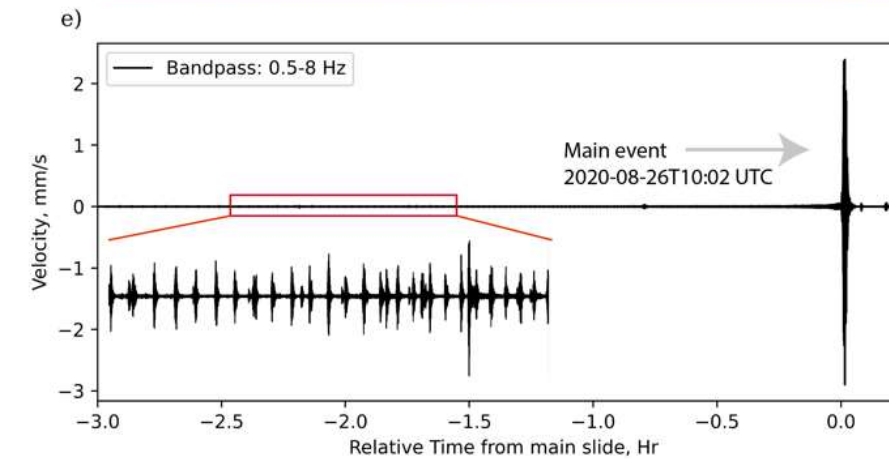
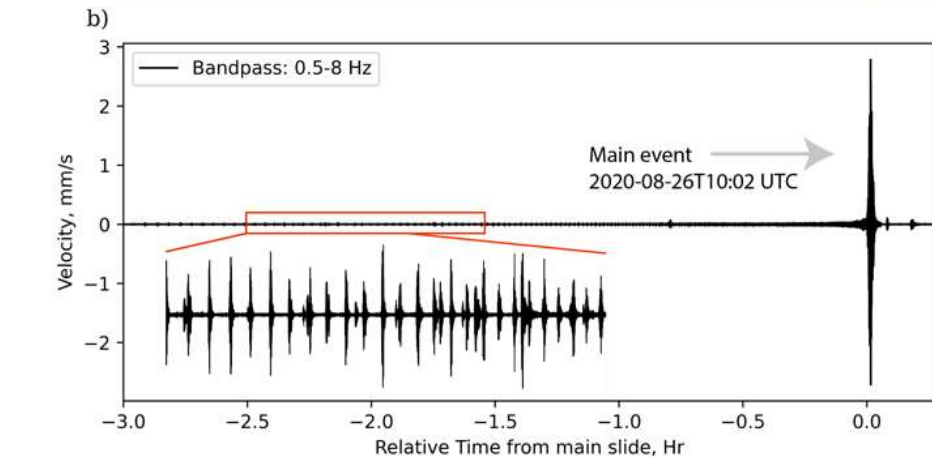
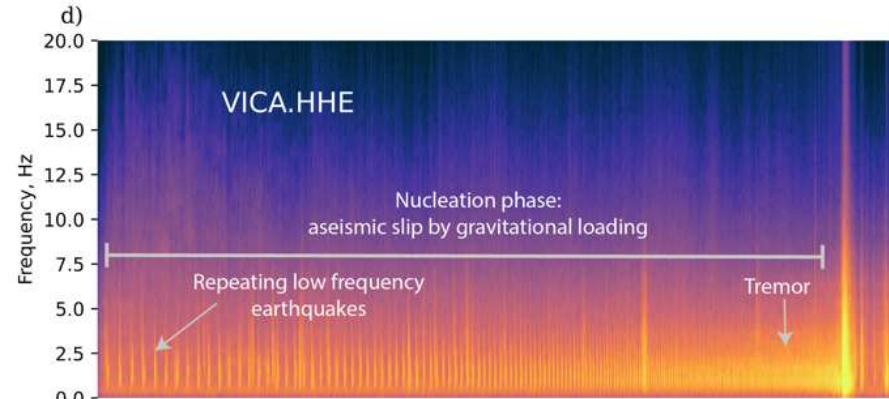
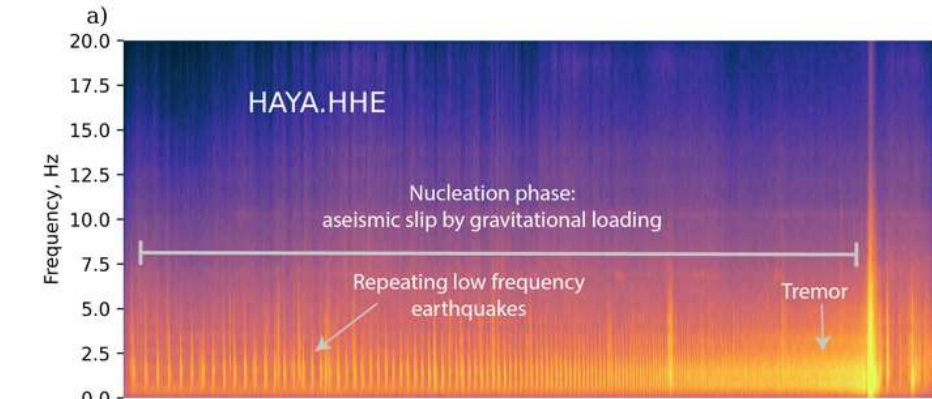


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Chaves et al., 2022 (in progress)



# Landslide in 2020

## *Seismic evolution*

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Chaves et al., 2022 (in progress)

$$M_o = \mu \cdot A \cdot \bar{D}$$

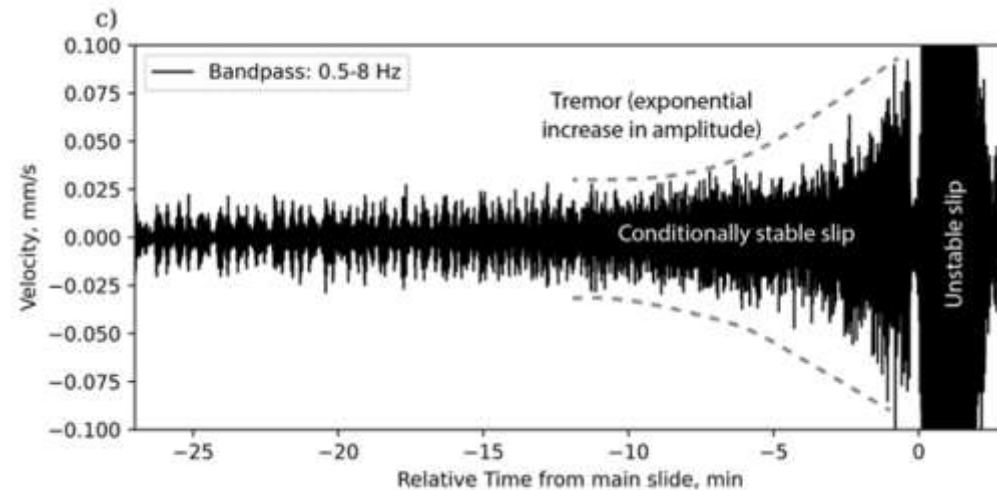
$M_o$  = Seismic moment

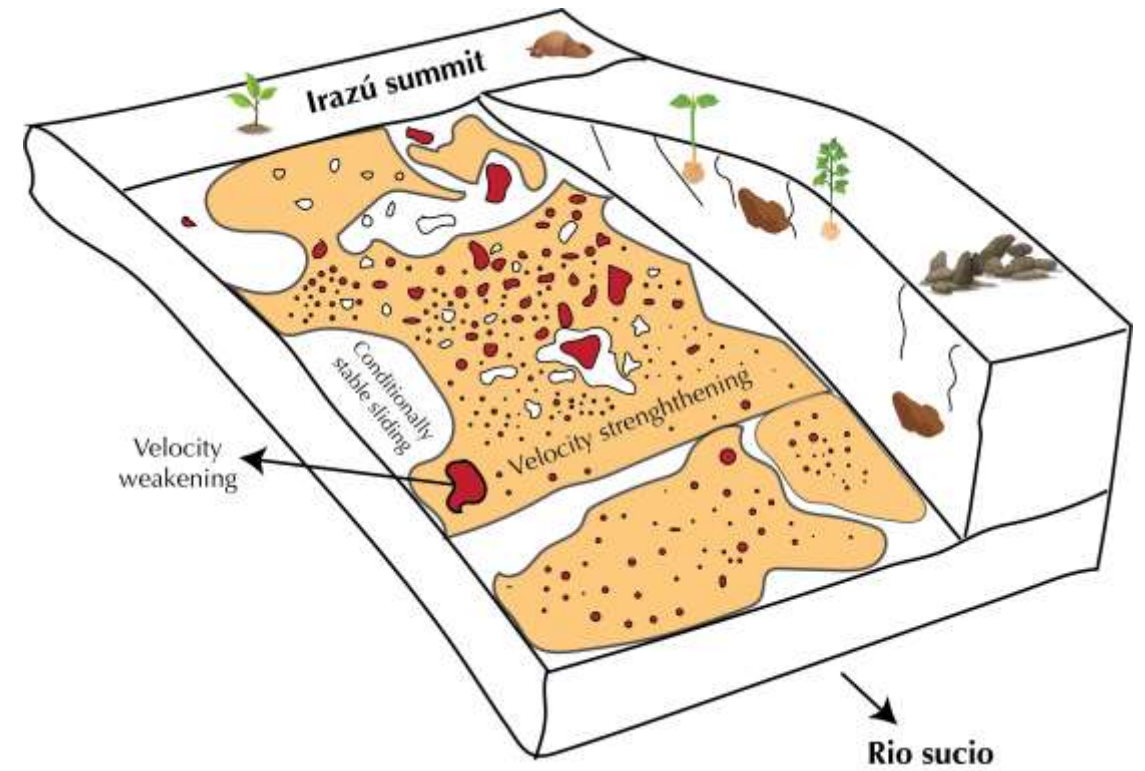
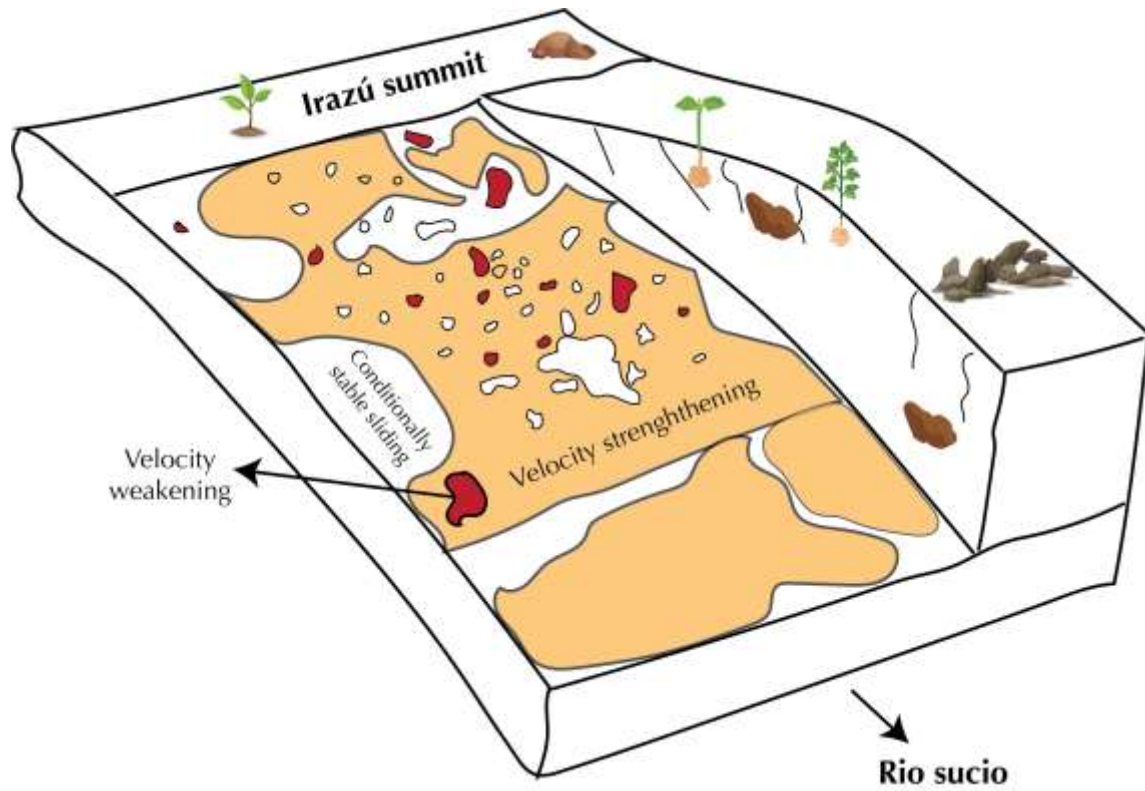
$\mu$  = Shear modulus

A = Rupture Area

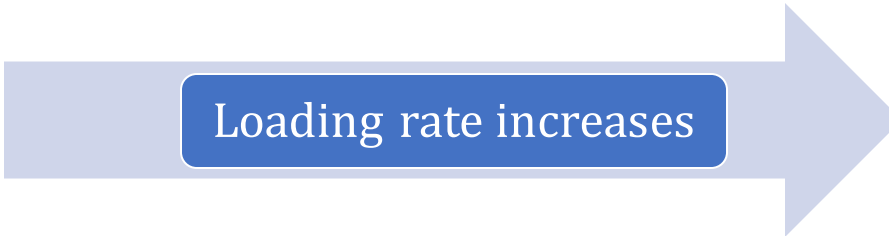
$\bar{D}$  = Average rupture displacement

An increase in amplitude is directly related to an increase in seismic moment...





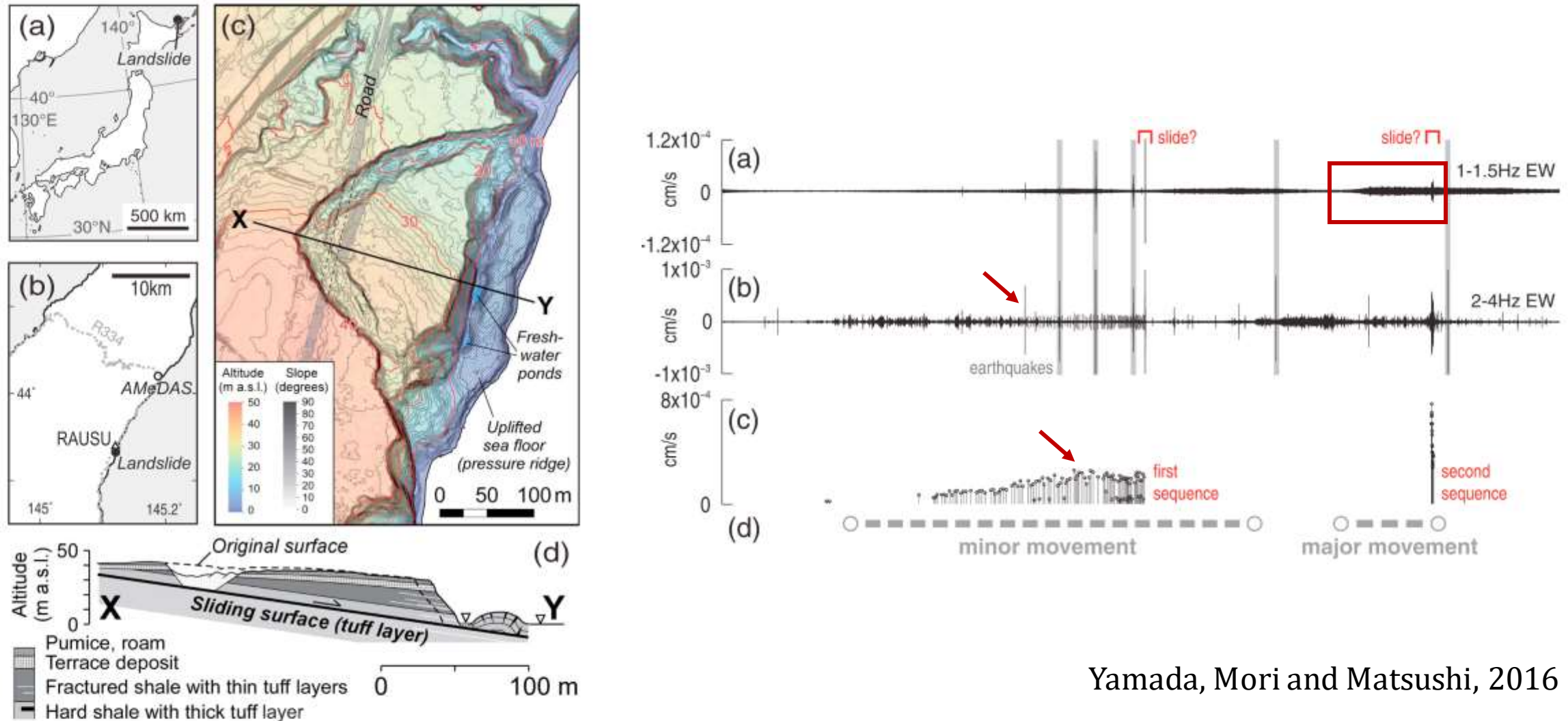
$$M_o = \mu \cdot A \cdot \bar{D}$$



Chaves et al., 2022 (in progress)



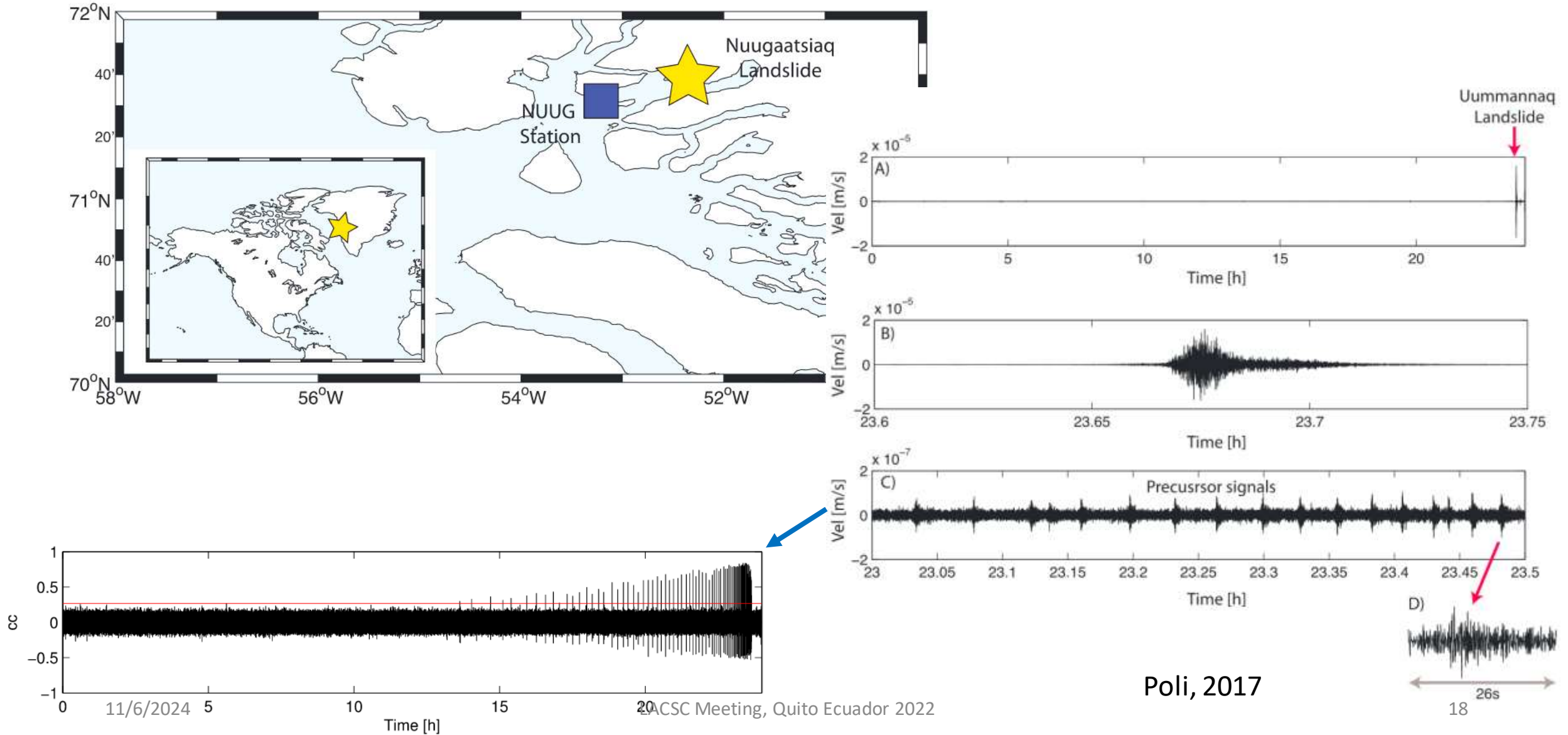
# Previous observations of rock landslides



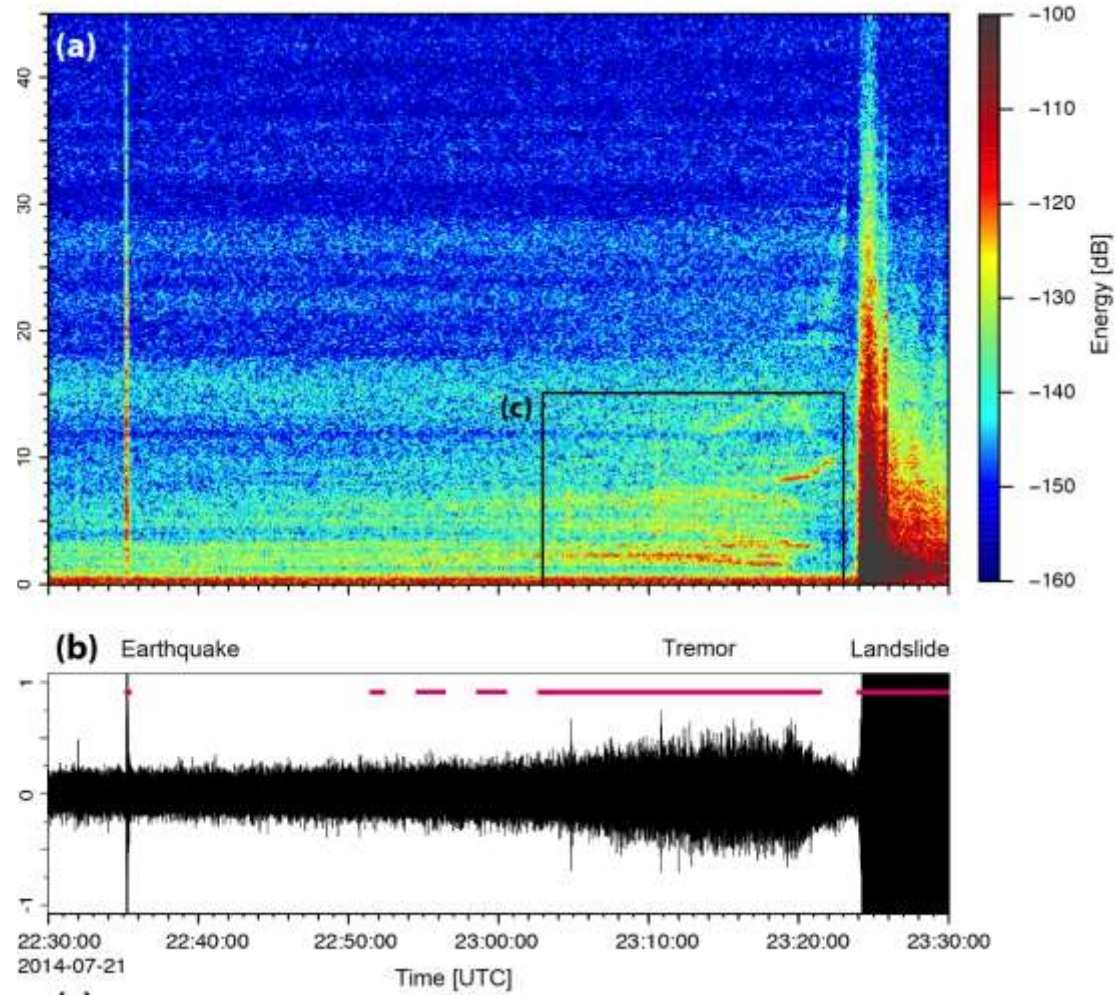
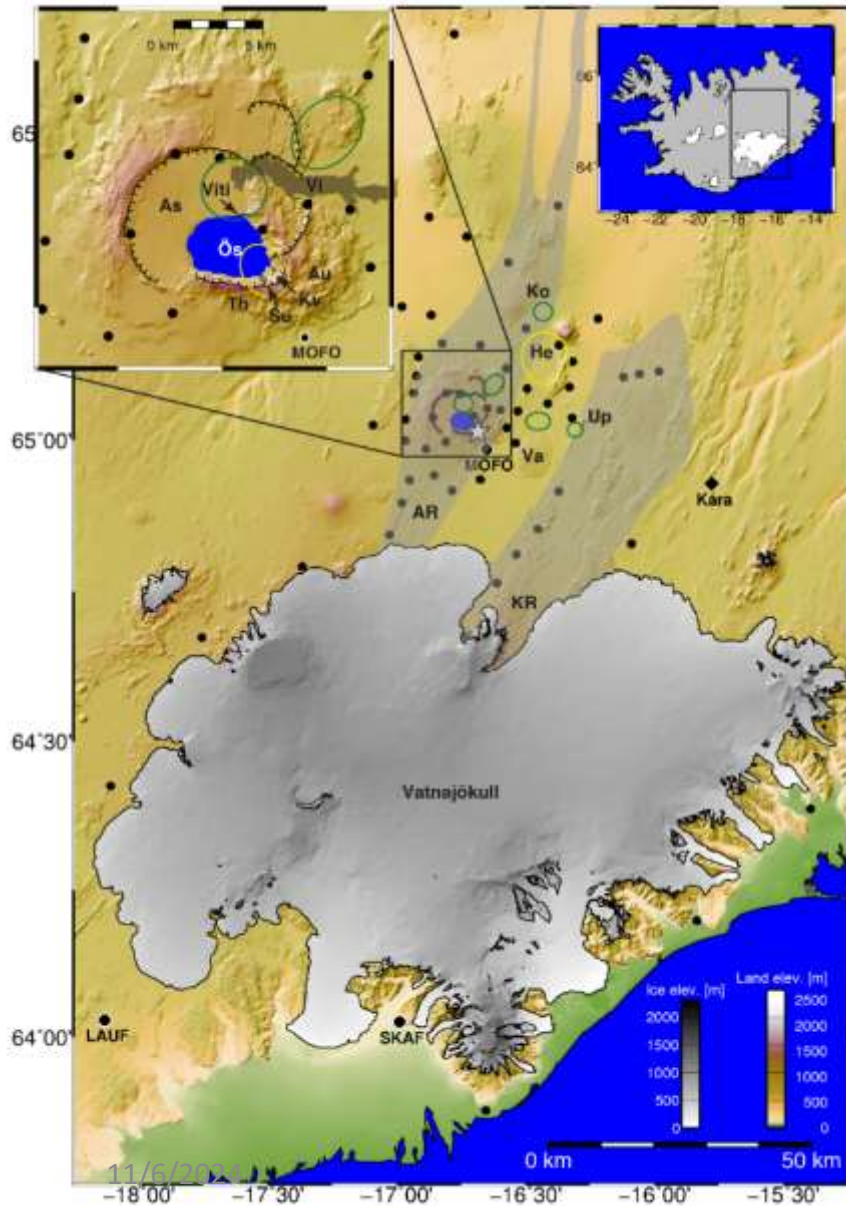
Yamada, Mori and Matsushi, 2016

**Figure 1.** Map and digital elevation model. (a) Map of Japan showing the location of landslide. (b) Map of Shiretoko peninsula with location of the landslide. Seismic stations are shown with triangles, and a meteorological station (Automated Meteorological Data Acquisition System (AMeDAS)) is shown with an open circle. (c) Digital elevation model of the landslide constructed from airborne lidar topographic surveys. (d) Geological section of the landslide along X-Y in Figure 1c.

# Previous observations of rock landslides

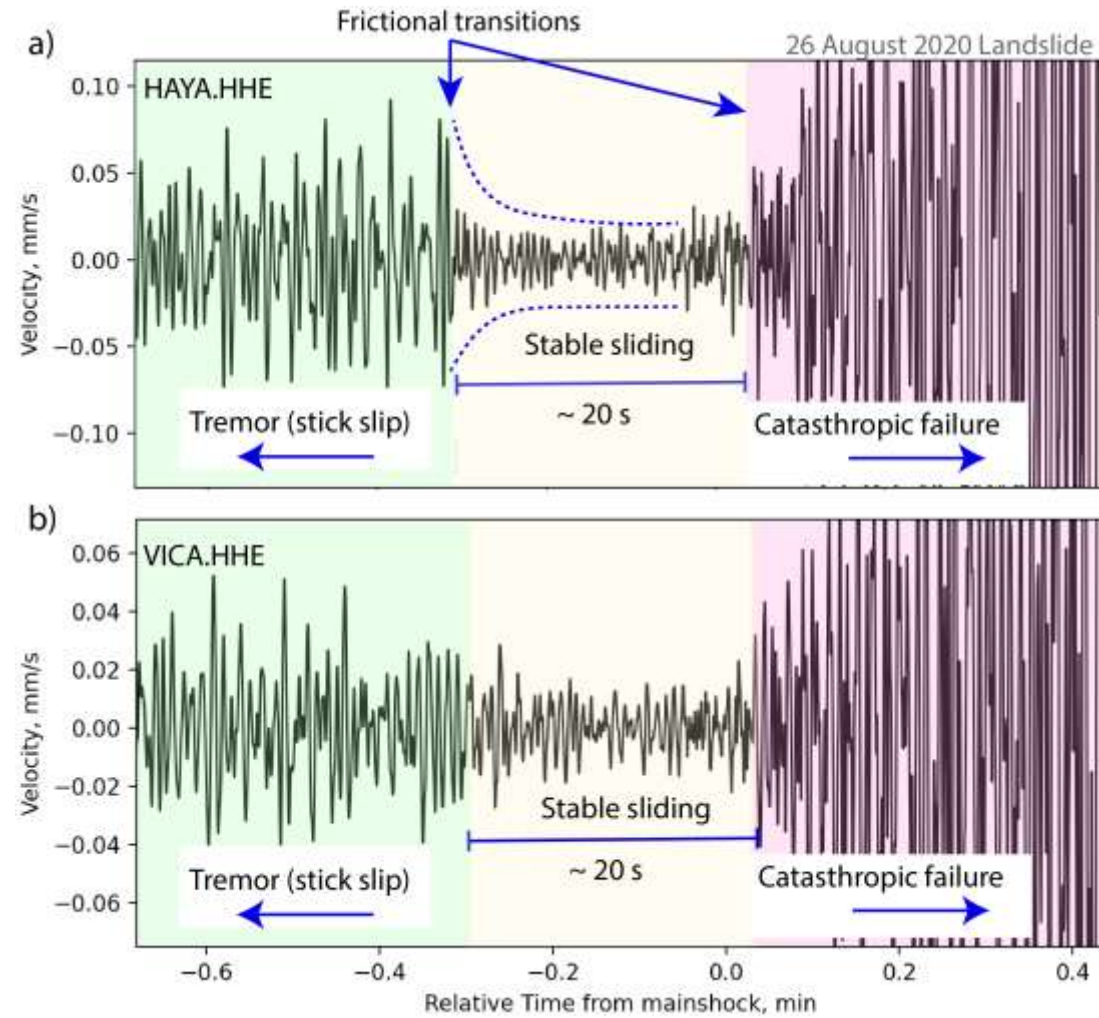


# Previous observations of rock landslides

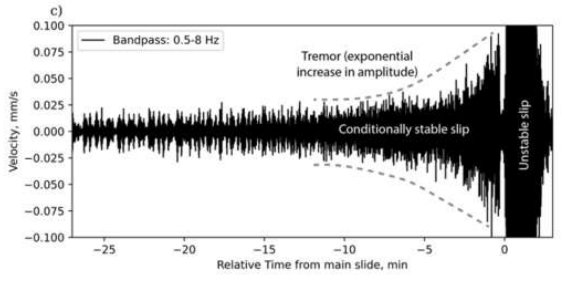


Schöpa et al., 2018

# Tremor stops 20 s before catastrophic collapse



Chaves et al., 2022 (in progress)



Appearance of discrete LFEs triggered by slow slip

Increase in strain rates

Patches switch slip behavior from velocity strengthening to velocity weakening

High strain rates

The recurrence interval of REs reduces

Tremor stops 20 s before catastrophic collapse

