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Landslide frequency in the Kivu Rift

impact of landscape evolution and deforestation

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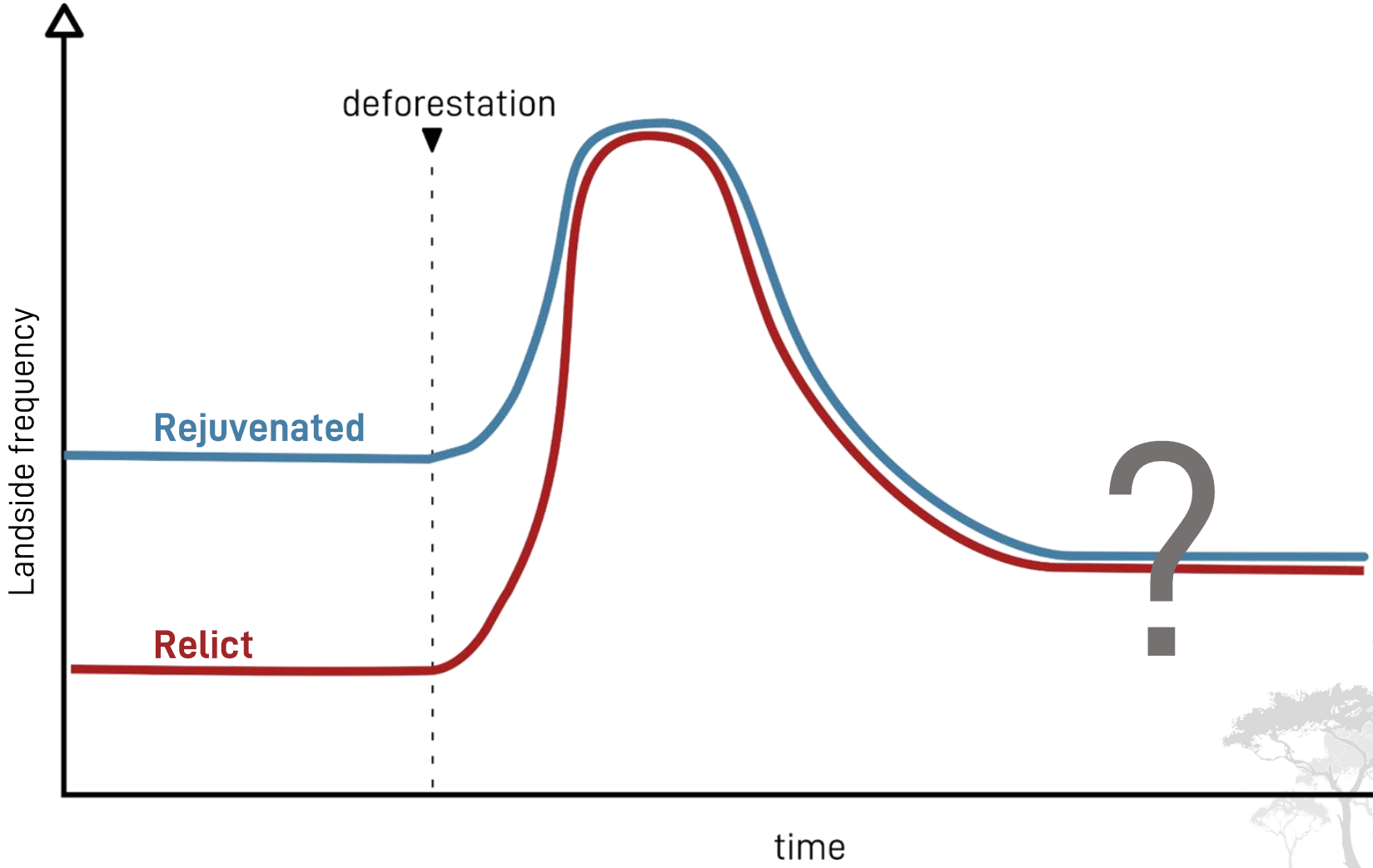
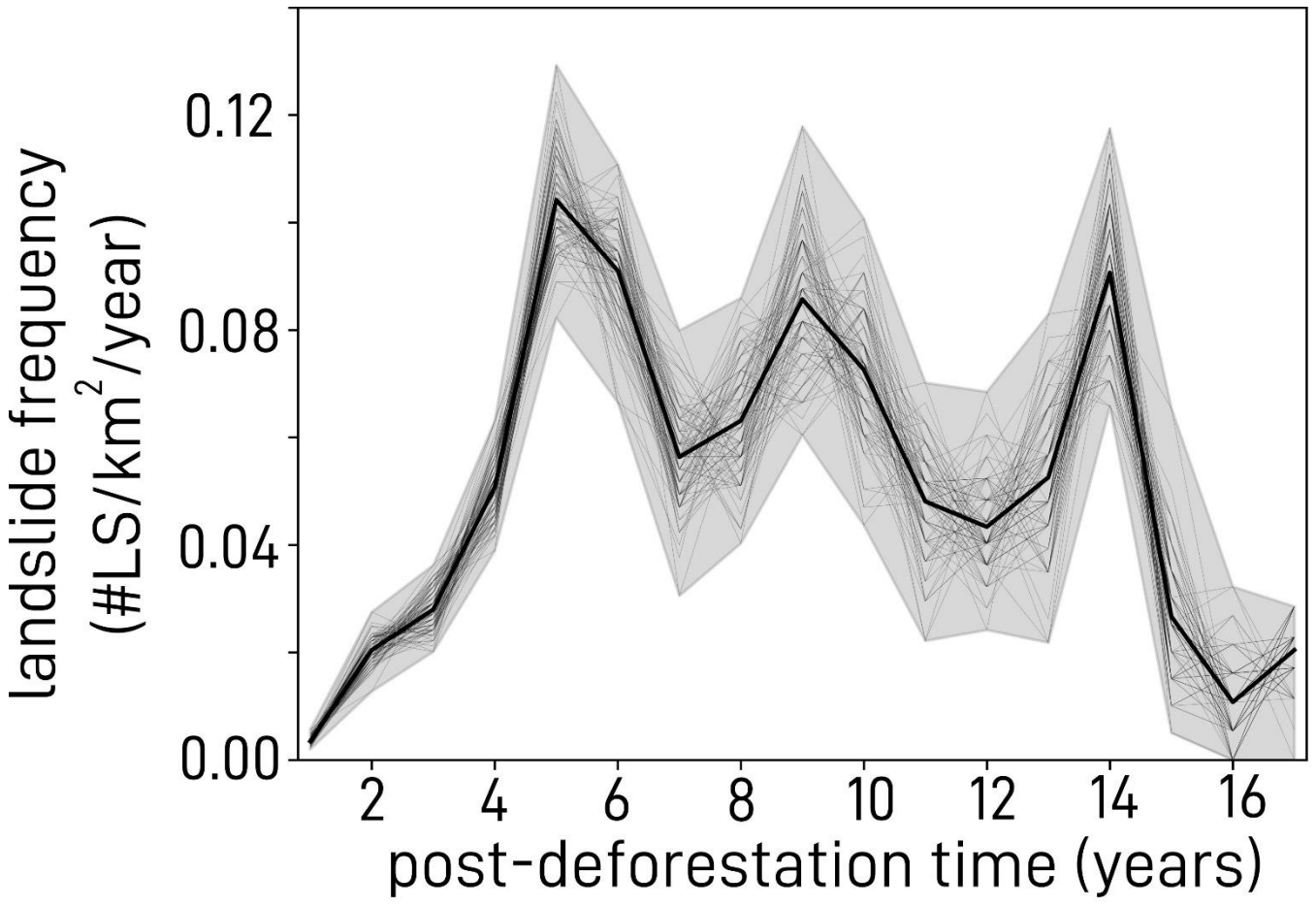
- Forest cover has a different effect in the rejuvenated and relict landscapes of the Rift



- Deforestation initiates landslide peak

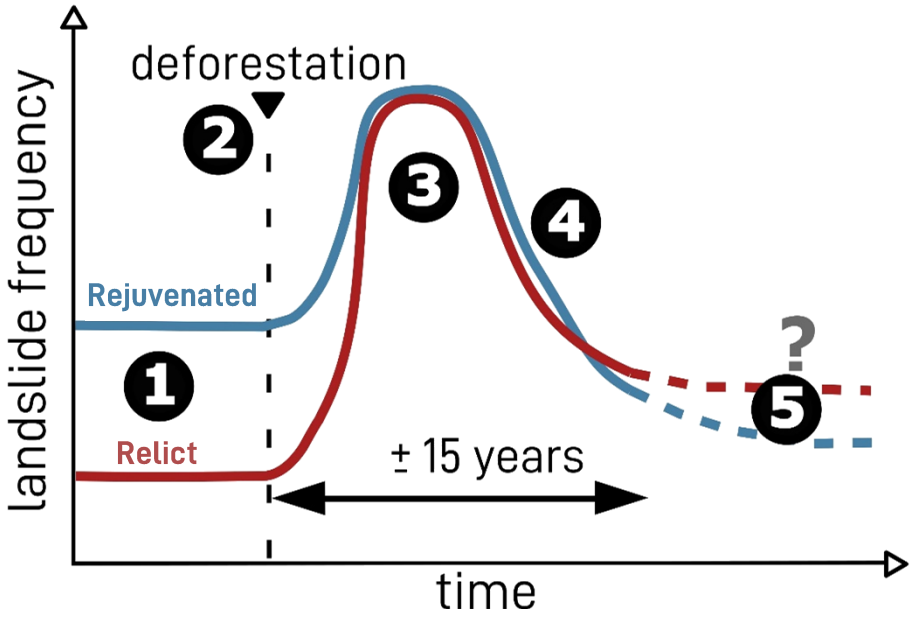


Overview

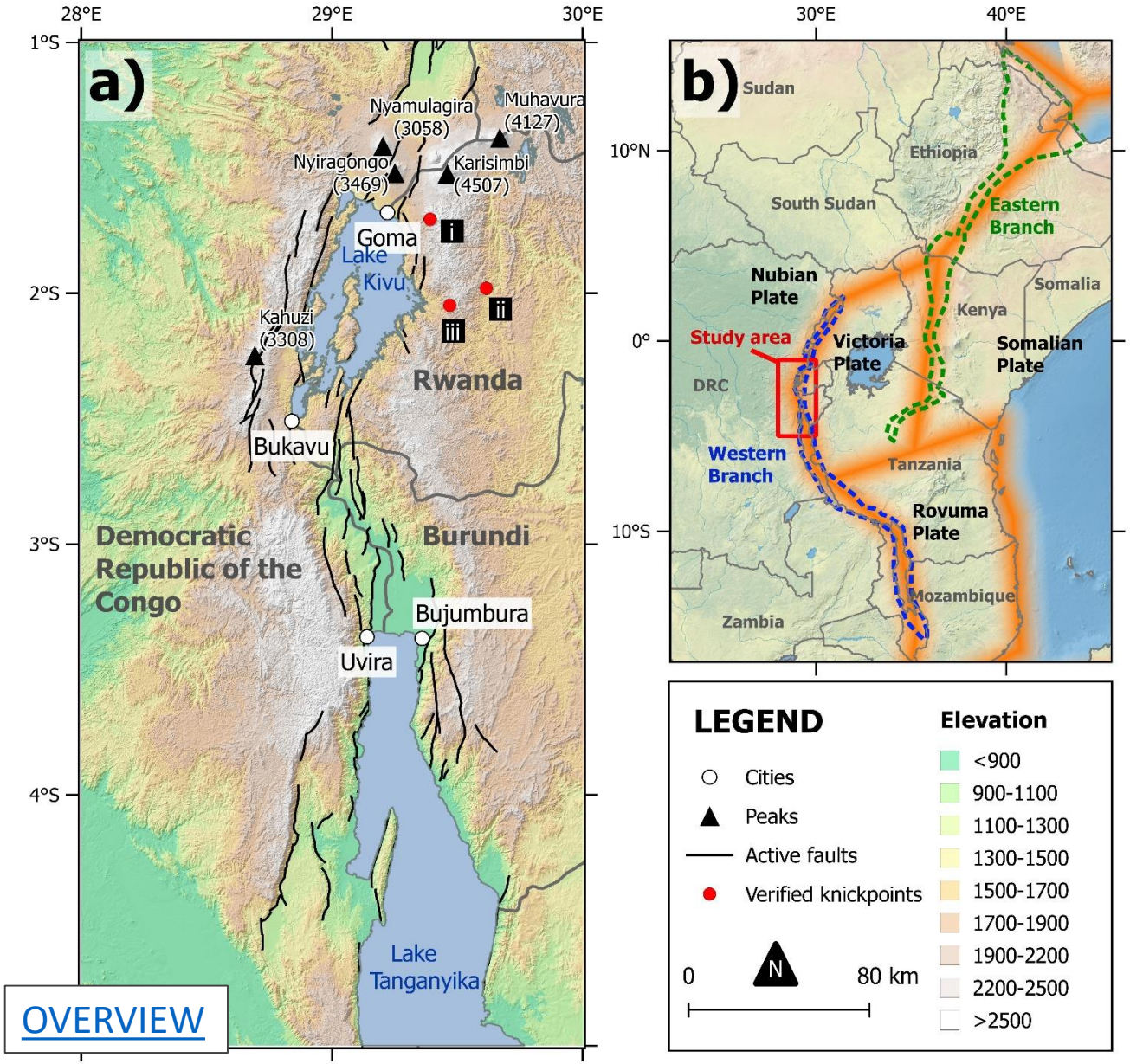
- Introducing: The Kivu Rift

1. More landslides in the rejuvenated Rift due to rifting
2. 4.3% deforestation between 2000-2017
3. Deforestation initiates landslide peak
4. Landsliding alters hillslope properties, reducing the rifting effect
5. Not clear how landslide frequency evolves in the long term

- EXTRA: relict versus rejuvenated landscape
- EXTRA: dealing with lithology



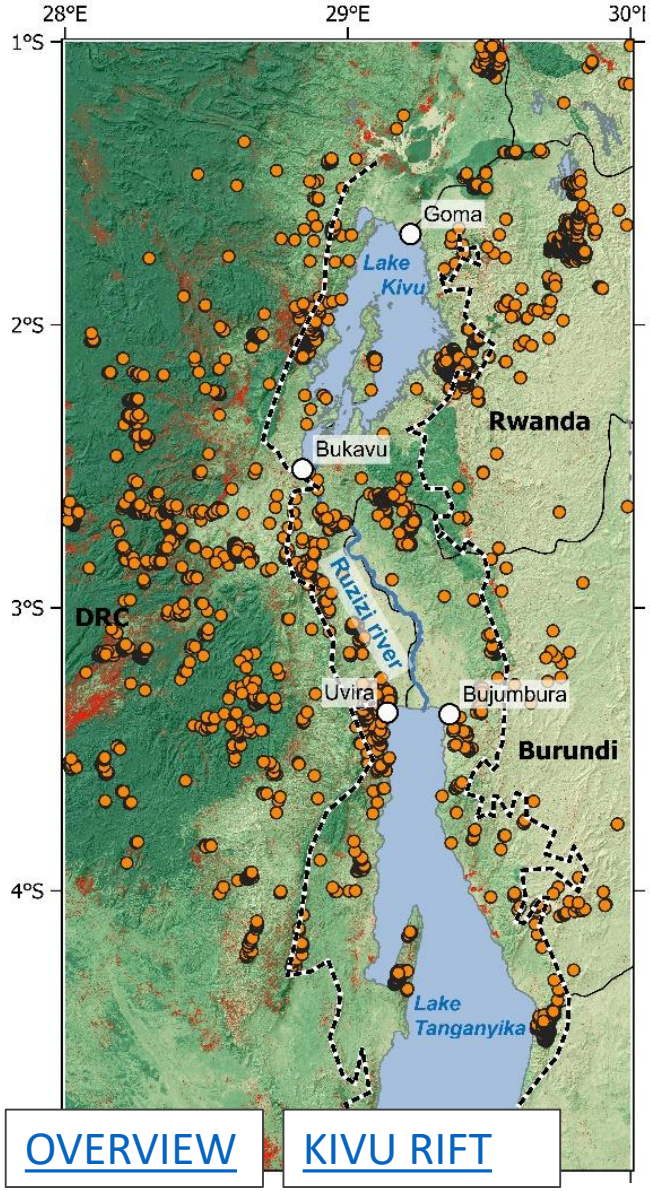
The Kivu Rift



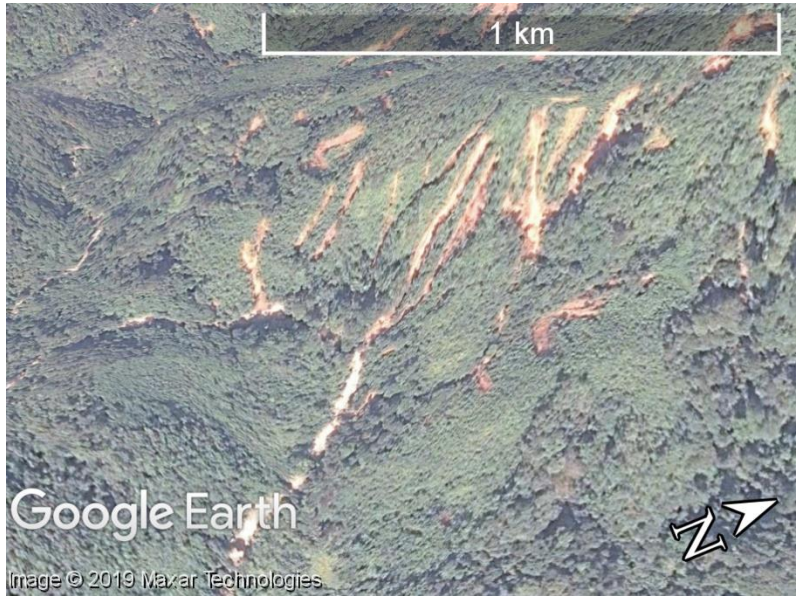
- Western Branch of the East African Rift
- Active continental rifting
- Rejuvenation through knickpoint retreat
- Diverse lithology
- Heavy deforestation
- Lots of landslides

OVERVIEW

Landslide database

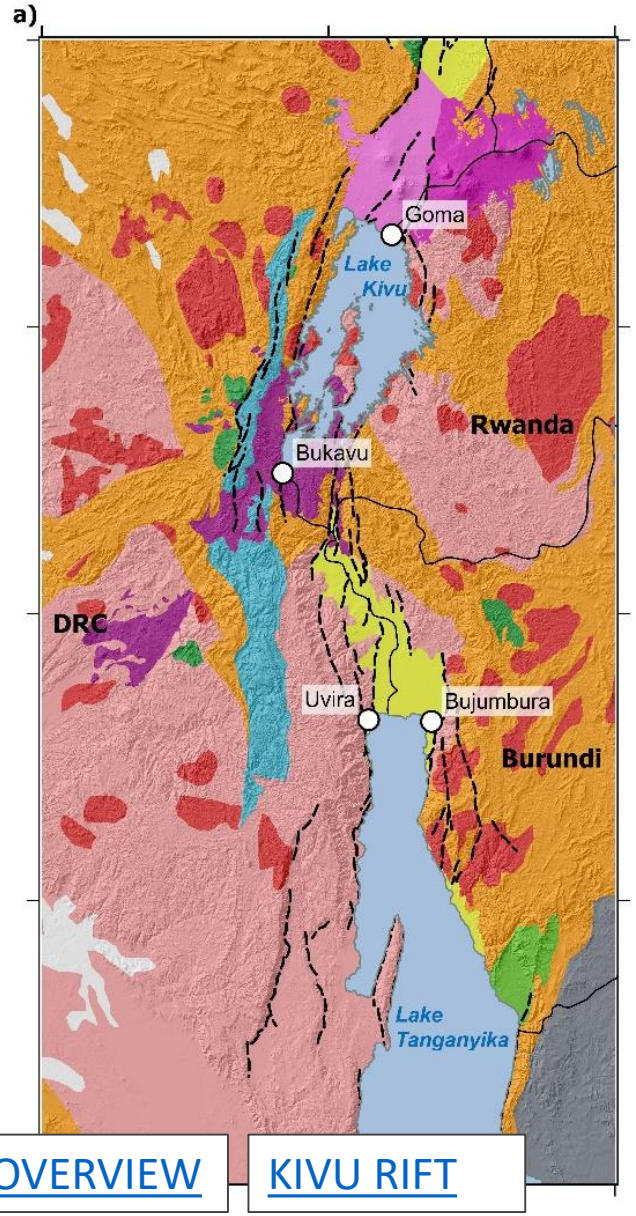


- 7900 shallow recent landslides

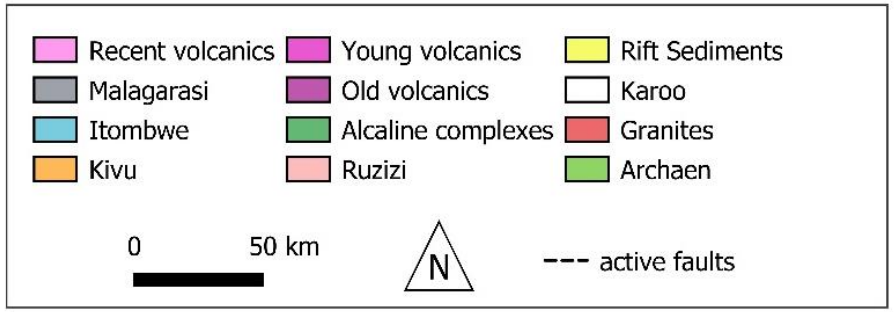


OVERVIEW | KIVU RIFT

Diverse lithology

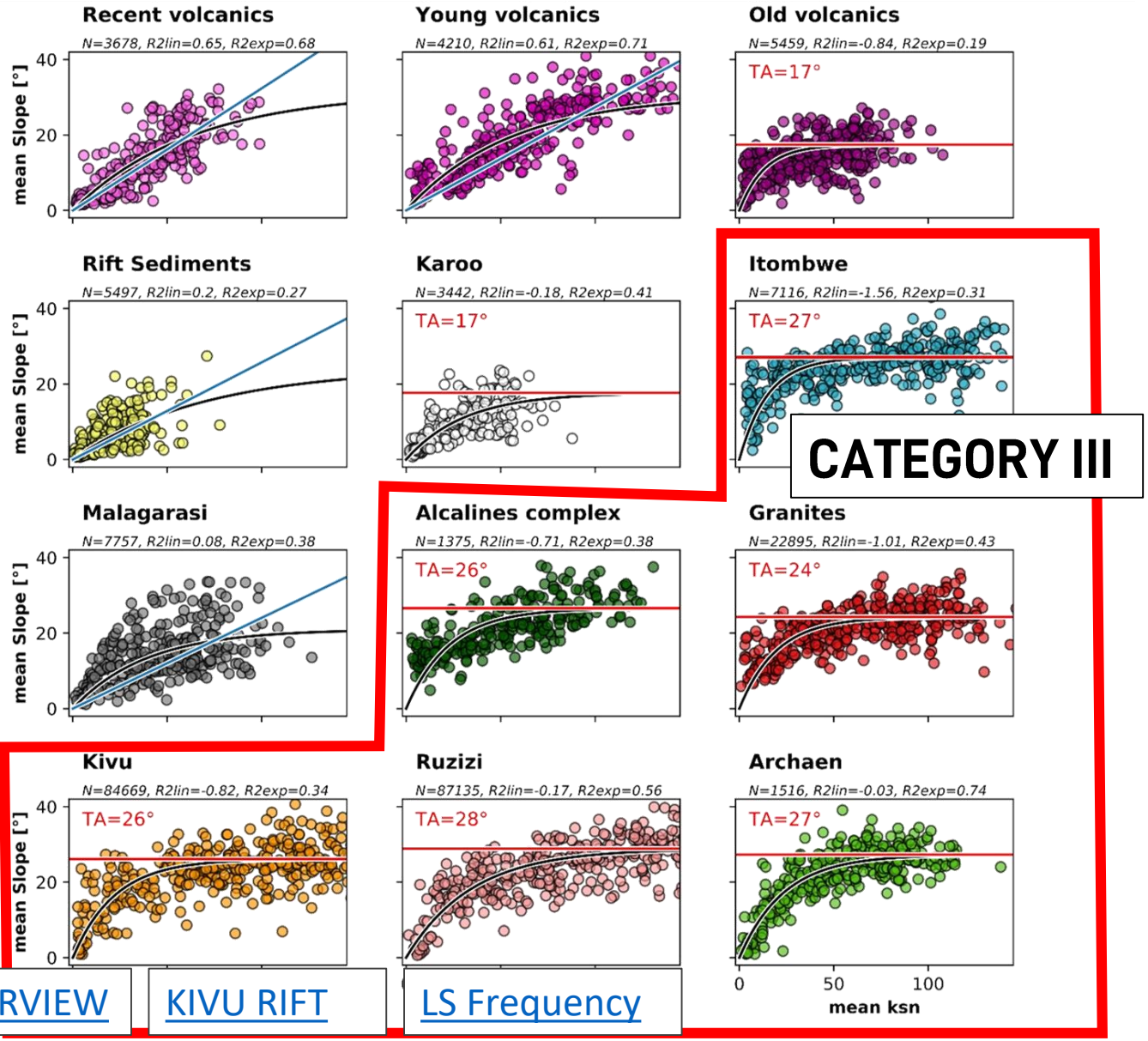


- Rock strength can influence
  - Knickpoint retreat
  - Landsliding
- Catchment slope steepness increases with incision until threshol is reached
- Incision ~ normalized steepness index $\mathbf{k_{sn}}$
- We identify 3 categories
  - **I** No threshold
  - **II** Threshold of 17°
  - **III** Threshold of 24-28°



OVERVIEW KIVU RIFT

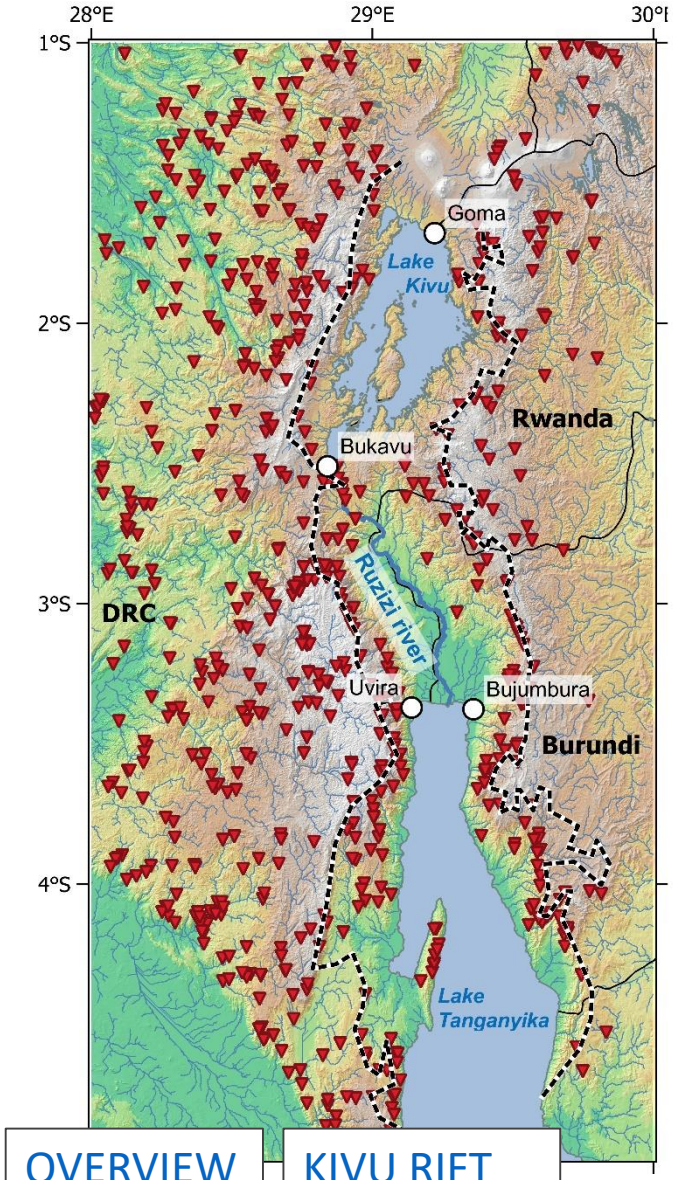
Rock strength per lithostratigraphy



- Category III contains
  - 86% of the study area
  - 95% of all landslides
- Check the frequency results here

OVERVIEW | KIVU RIFT | LS Frequency

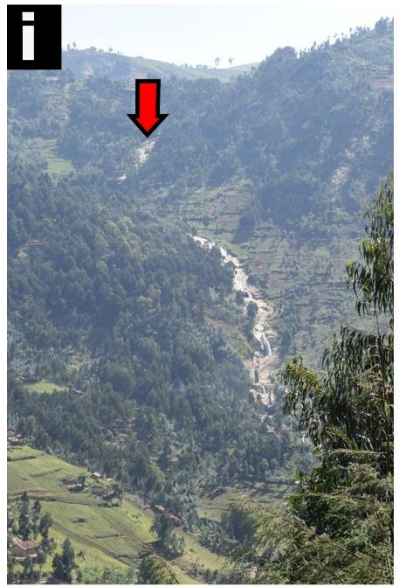
Rejuvenated versus Relict

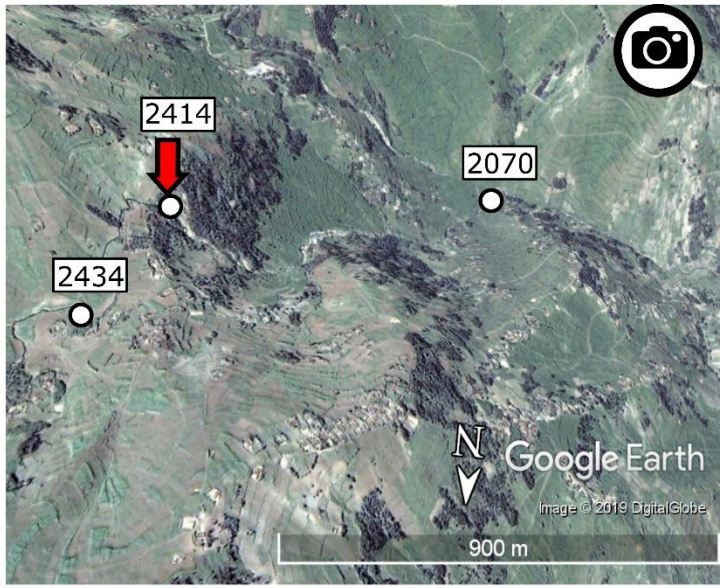


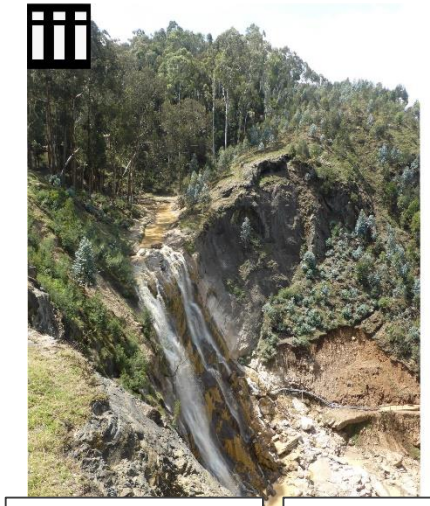
- Rift is rejuvenated through knickpoint retreat
  - Retreat is affected by rock strength!
- 673 non-stationary knickpoints identified
  - Of which some field-validated

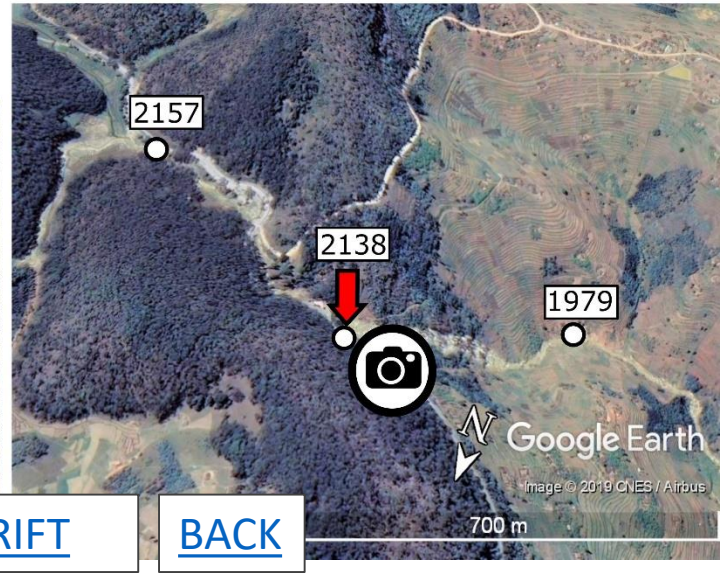
OVERVIEW | KIVU RIFT

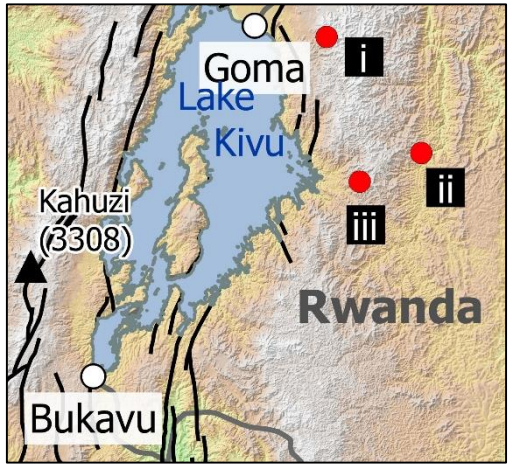
Field-validated knickpoints





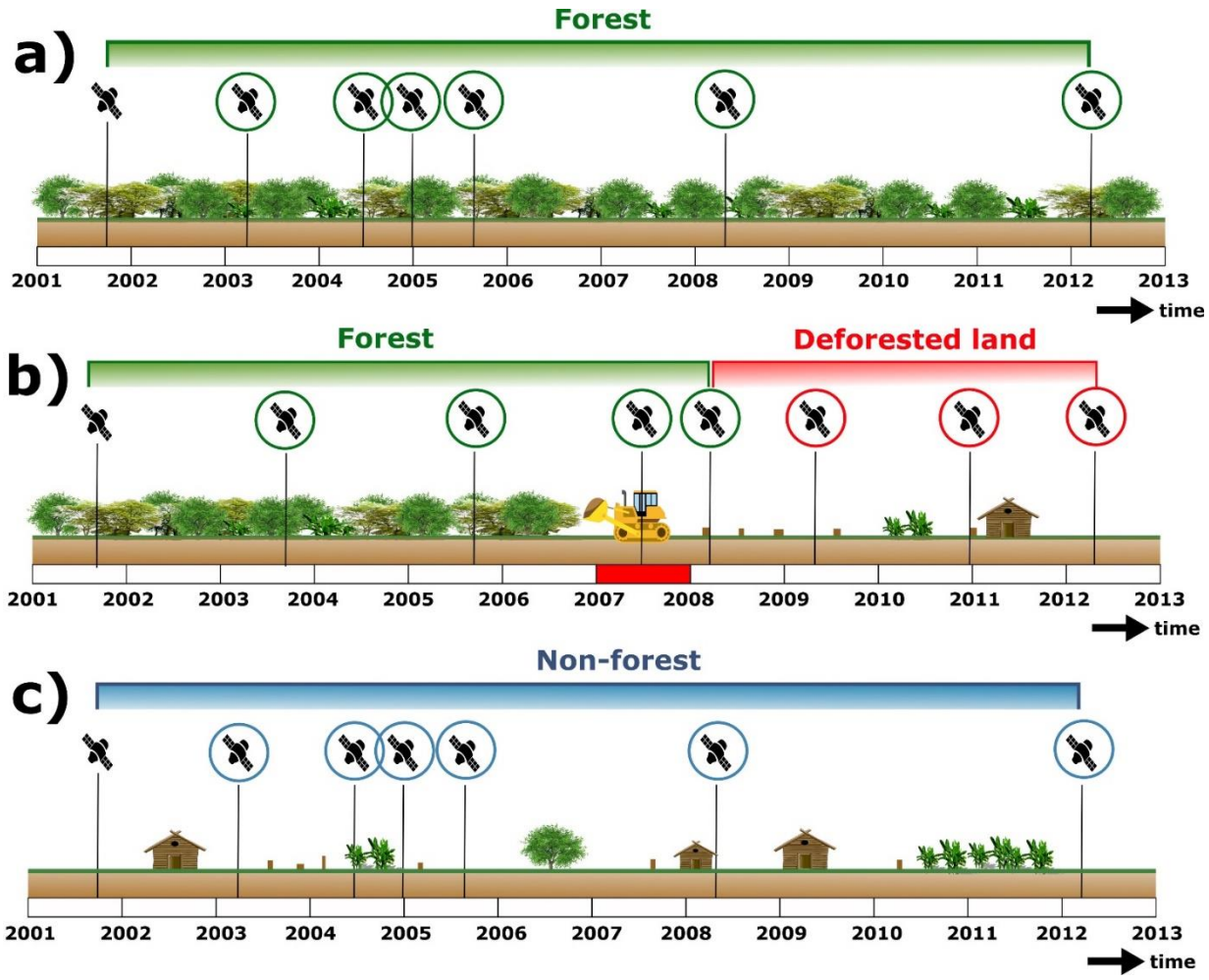






OVERVIEW | KIVU RIFT | BACK

Forests and Deforestation

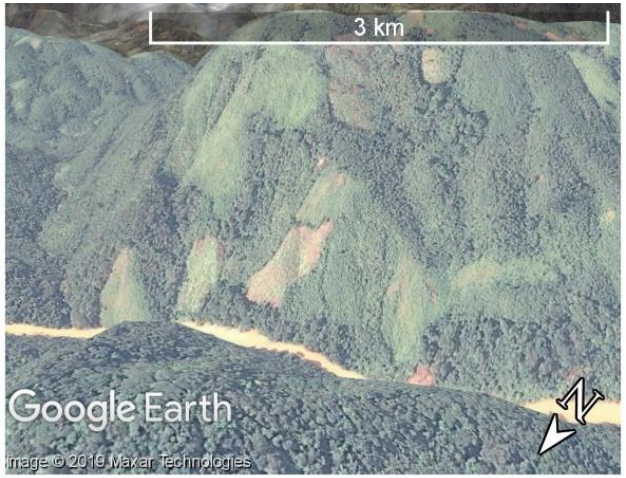


- Important to make a clear difference in between:
  - Landslides causing deforestation
  - Deforestation causing landslides
- Data: Hansen et al. (2013)
  - Forest cover 2000
  - Deforestation 2000-2017

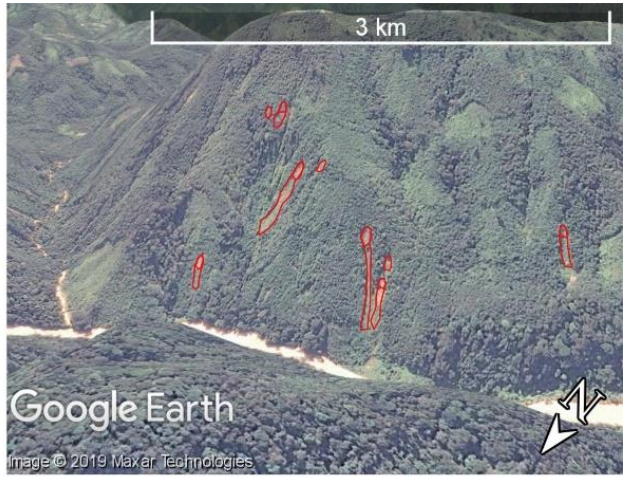
OVERVIEW | KIVU RIFT

Deforestation causing landslides

April 2, 2003

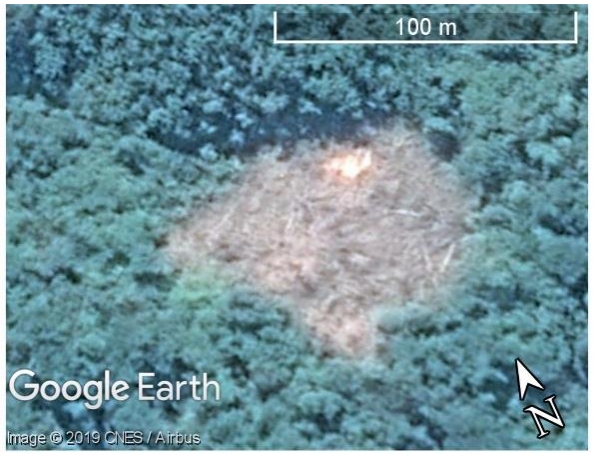


June 24, 2014

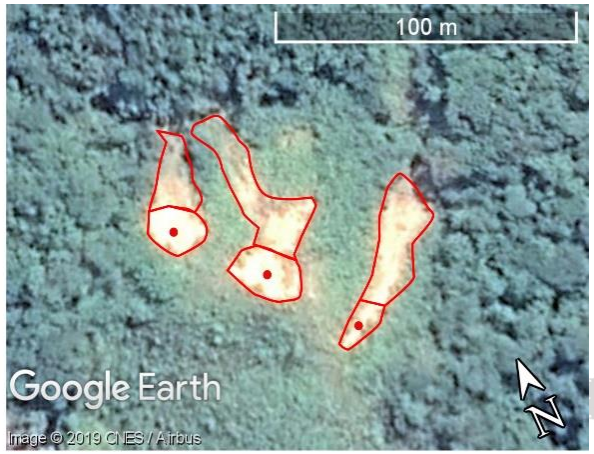


January 21, 2017

June 24, 2014



May 30, 2015



June 27, 2017

OVERVIEW | KIVU RIFT | BACK

Landslide frequency

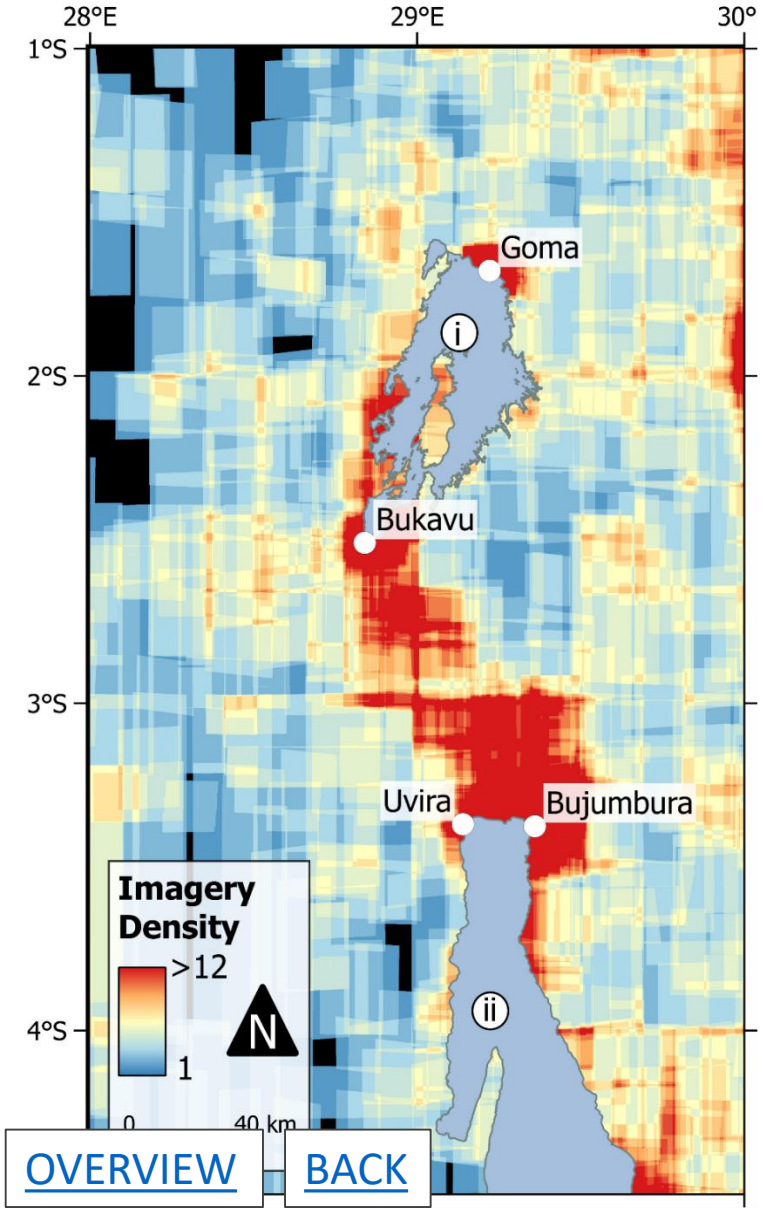
- Observed rates (#LS/km^2/year)
  - Overall: 0.015
  - Rejuvenated: 0.039
  - Relict: 0.010

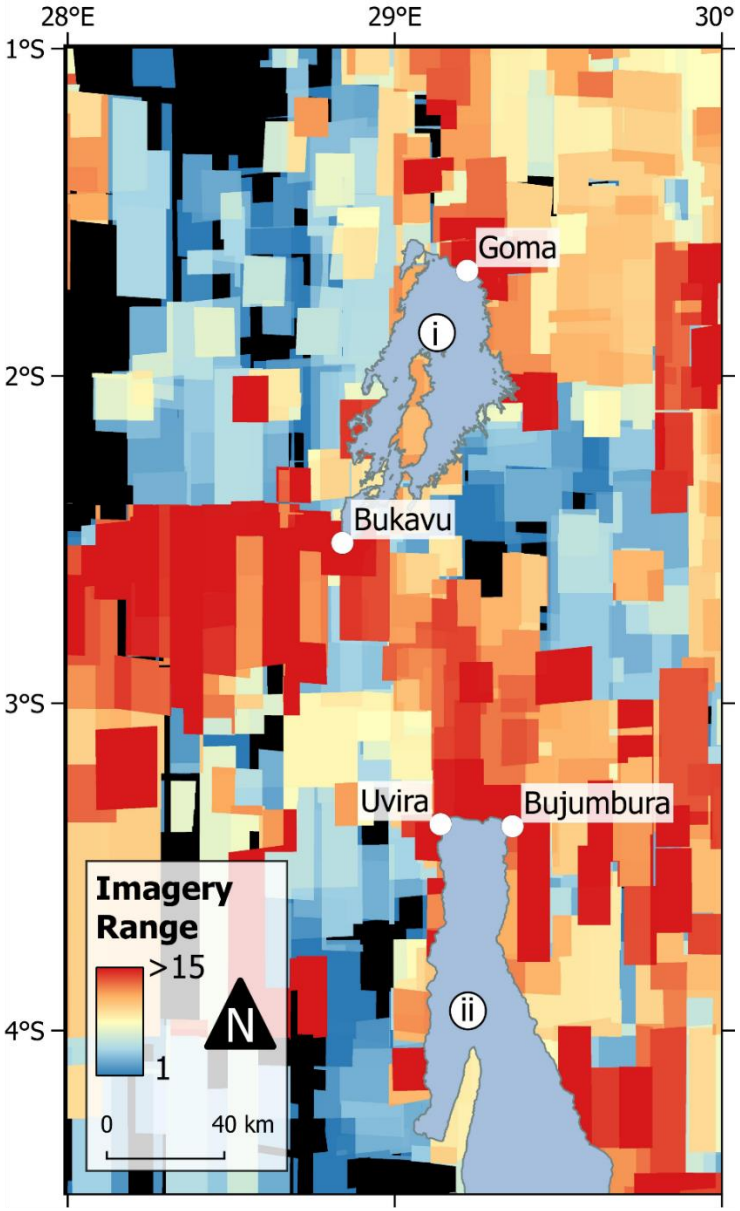
Why are there more landslides in the rejuvenated Rift??

- We only considered Category III rocks
- We mitigated the imagery bias in Google Earth
  - **Range** = time between oldest and newest available image
  - **Density** = number of available images

OVERVIEW

Google Earth Imagery Bias

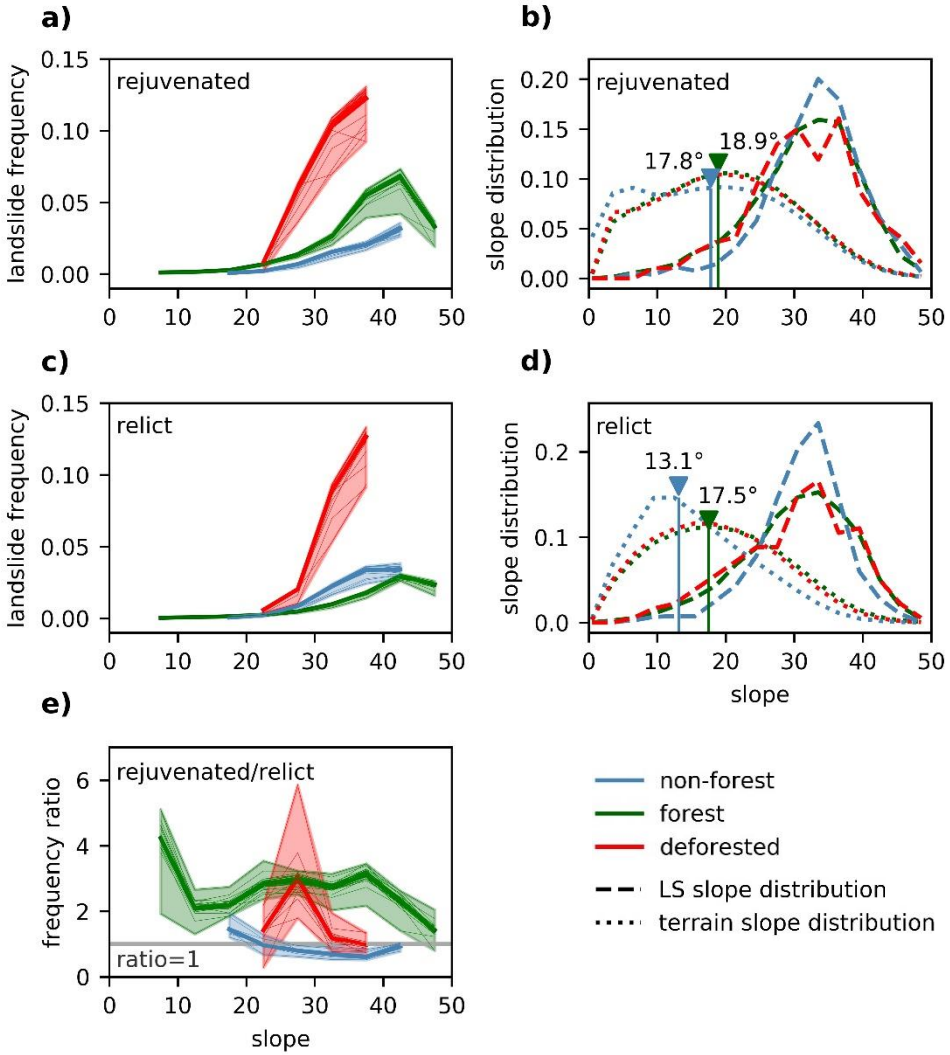




- frequency= $\frac{1}{A}\sum_i^N \frac{1}{R_i}$
  - A = total area
  - N = number of landslides i
  - R_i = **imagery range** at landslide i
- To compare different regions, correct for density:
  - frequency= $\frac{1}{A}\sum_i^N \frac{1}{D_i R_i}$
  - D_i = **imagery density** at landslide i

OVERVIEW BACK

The effect of slope and forests



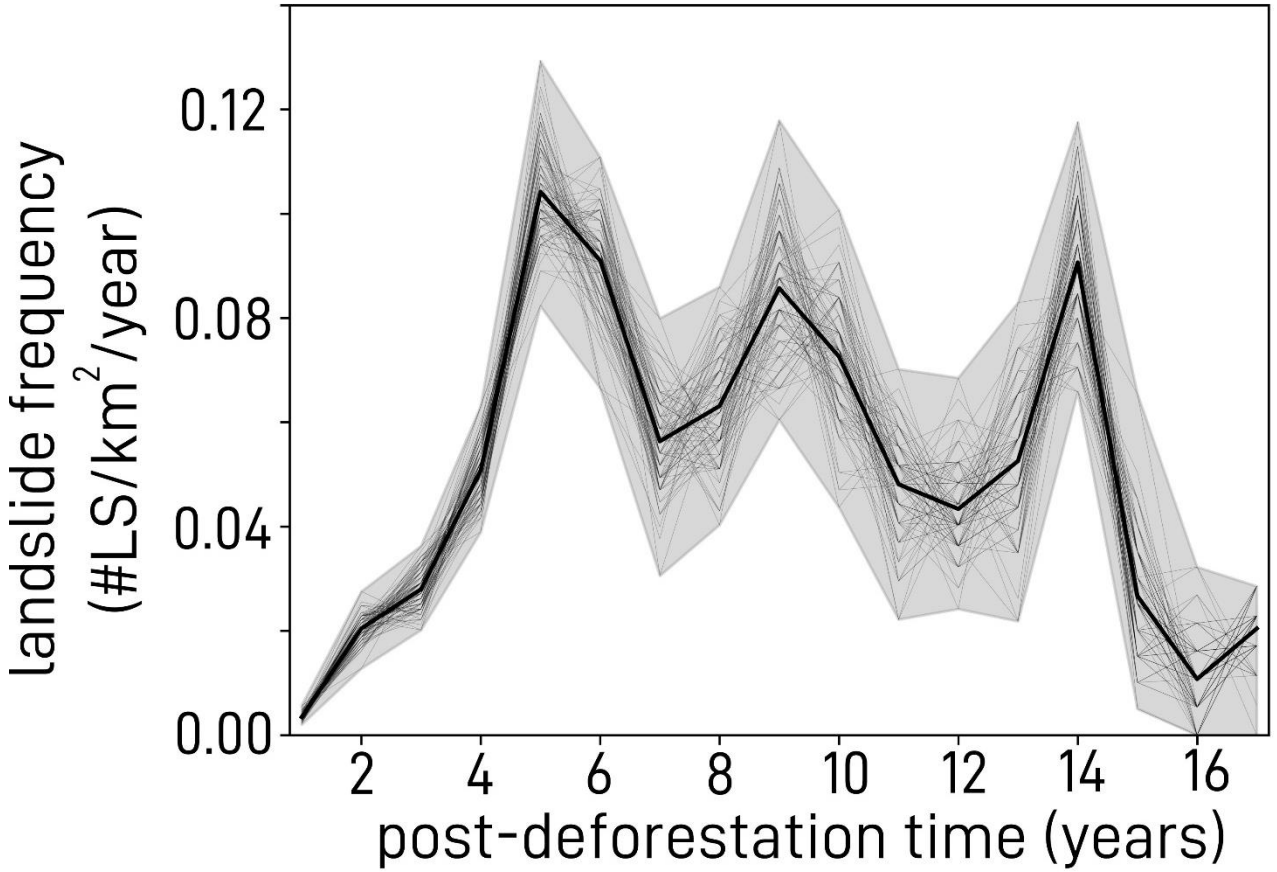
- Slopes are steeper in the rejuvenated Rift
- **In non-forests**: no clear difference between rejuvenated and relict Rift for similar slopes
- **Deforestation** gives similar landslide peak in rejuvenated/relict landscape
- **In forests**: equally steep slopes have more landslides in the rejuvenated Rift!

Slope distribution is not sufficient to explain the difference between rejuvenated and relict landscapes

- **We propose a 'RIFTING EFFECT'**

OVERVIEW | LS Frequency

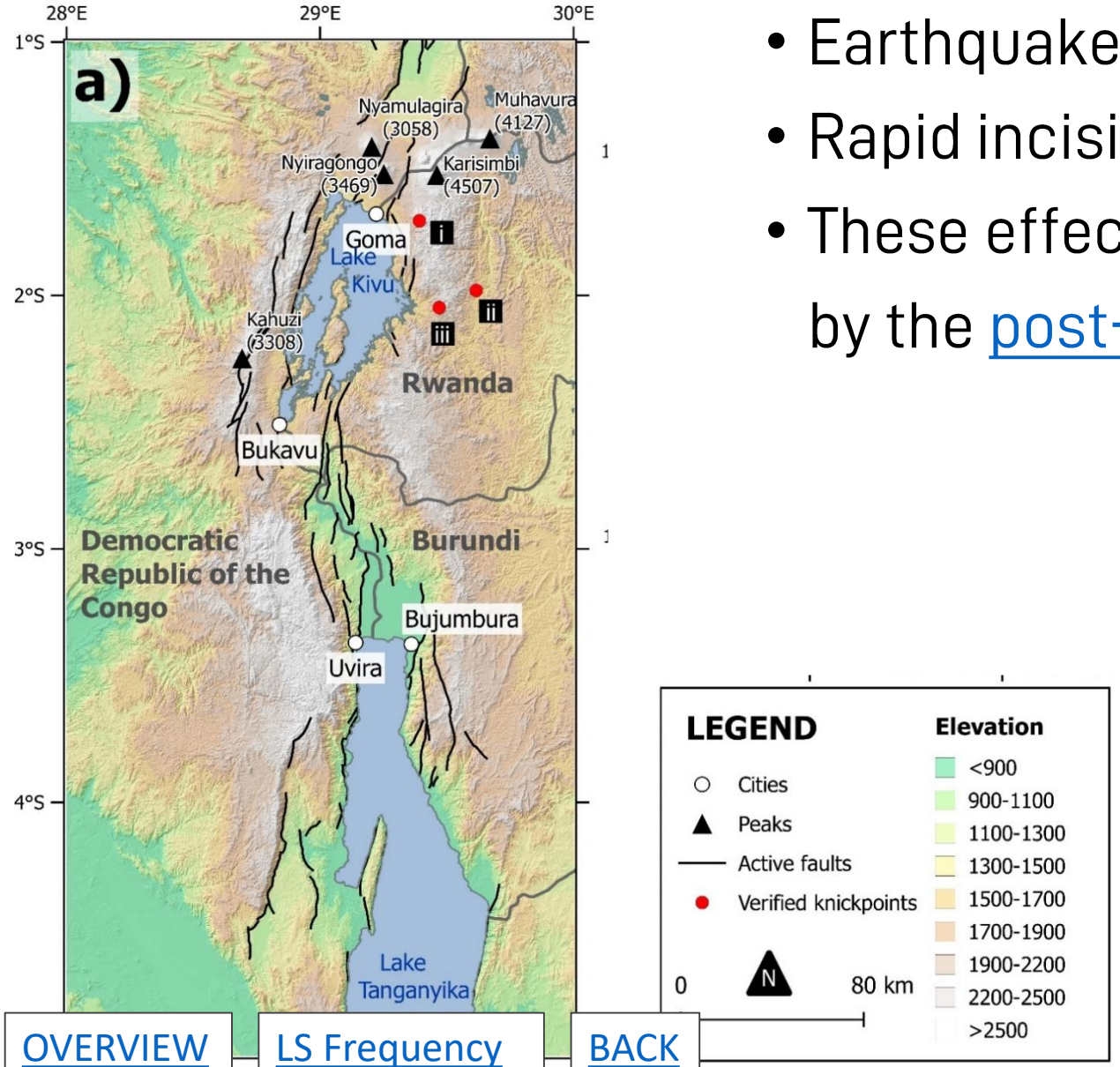
Deforestation causes landslide peak



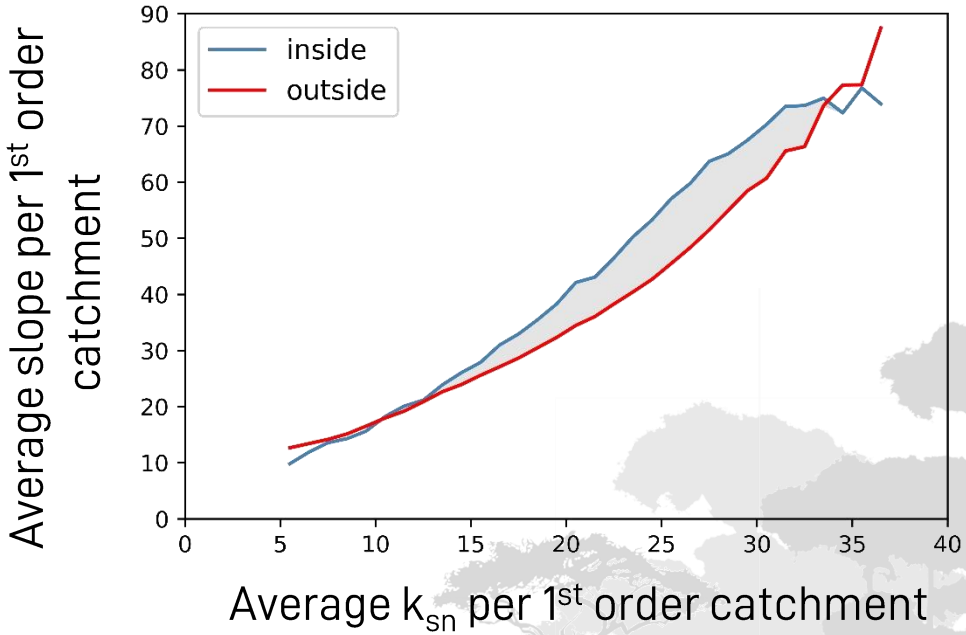
- Landslide peak lasts up to 15 years
- Landslides alter hillslope properties

OVERVIEW | LS Frequency | BACK

Rifting effect



- Earthquakes weakening hillslopes
- Rapid incision undercutting river banks
- These effects are mitigated by the post-deforestation landslide peak



OVERVIEW | LS Frequency | BACK

Landslide peak alters hillslope properties

- Most sensitive soil is removed
- Landslide sediments armour
  - the slope, and
  - river beds, inhibiting incision
- More run-off in non-forest. In the rejuvenated Rift where conditions are drier due to less rainfall, the lowering of pore-water pressure has reached a turning point
- In the short term: rifting effect in non-forest land is mitigated
- On the long term?

Rainfall in the Rift

- We compare rainfall threshold exceedence for different rainfall models
  - 2 days 15 mm exceedance
  - Mann-Whitney *U* test applied for rainfall averaged over 5th order catchments
- Conclusion: the rejuvenated Rift is significantly drier than the surrounding relict landscape.
  - This might explain why an increase in run-off might have a different effect in the rejuvenated and relict landscapes
  - Rainfall does not explain why we have more landslides in the rejuvenated Rift

		p-value	
Model	**Resolution**	**H1: in < out**	**H1: in > out**
TAMSAT	5×5 km	0.000	1.000
IMERG	11×11 km	0.000	1.000
COSMO-CLM	2.8×2.8 km	0.000	1.000

OVERVIEW BACK

Long term effects of deforestation

- Local increase of landsliding is expected in highly weathered regions due to terracing
- In general, agricultural practices increase landsliding
- Erosion rate exceeds soil formation
- So on long-term, LS frequency in non-forest land might decrease

OVERVIEW BACK