Investigation of postglacial faults in Finland - An update

Timo Ruskeeniemi, Ismo Aaltonen, Antero Lindberg,
Jussi Mattila, Nicklas Nordbäck, Antti E.K. Ojala,
Jukka-Pekka Palmu and Raimo Sutinen

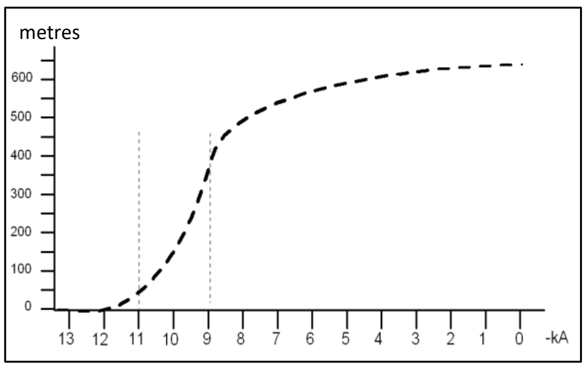
GTK
gtk.fi

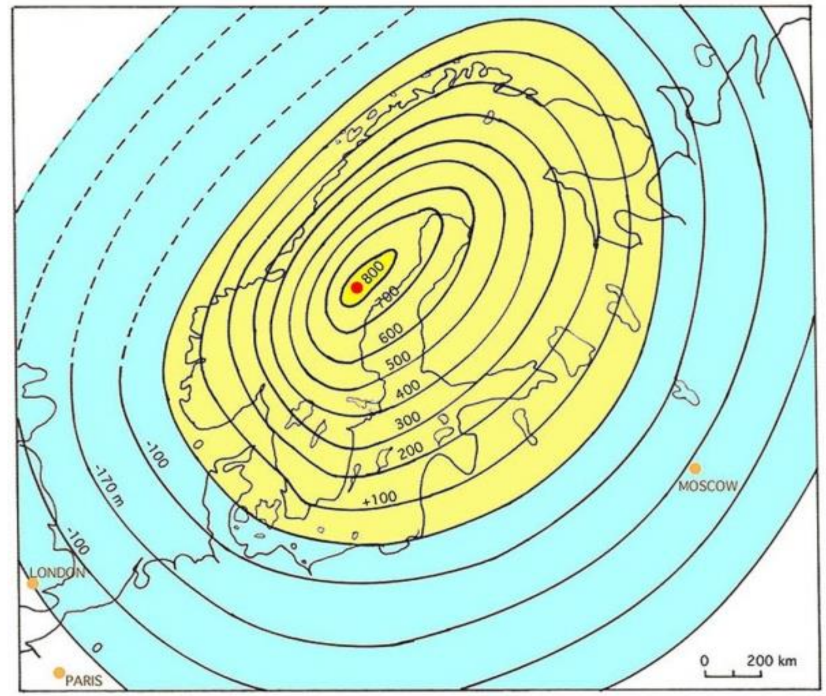
Quaternary glaciations and neotectonics

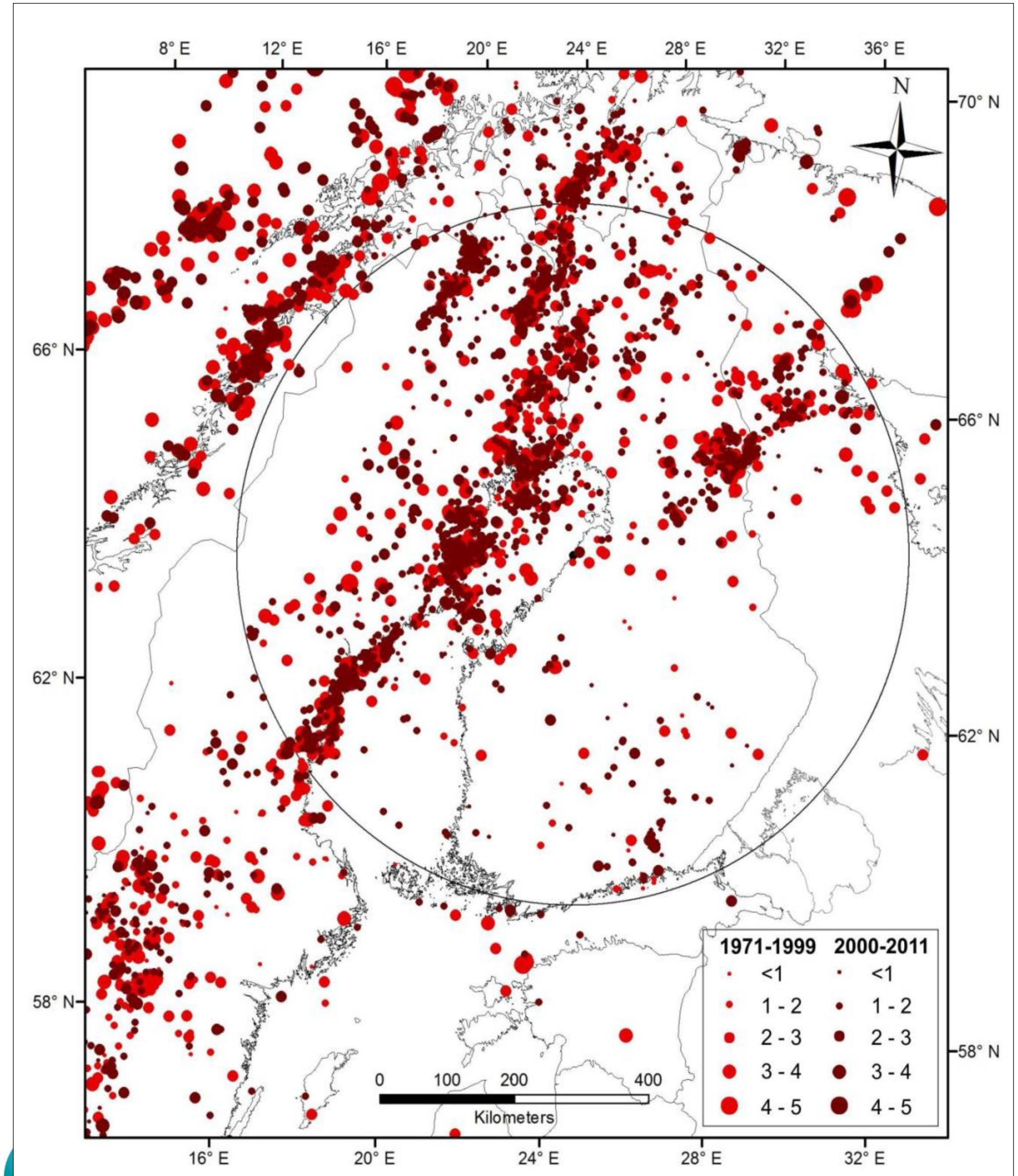
- During the Quaternary (2.6 Ma- present) at least 20 stages with substancial ice sheets
- Postglacial seismic activity (neotoctonics) occurs when the excess horizontal lithospheric Stresses accumulated in Earth's crust during glacial periods are released during deglaciation and postglacial times

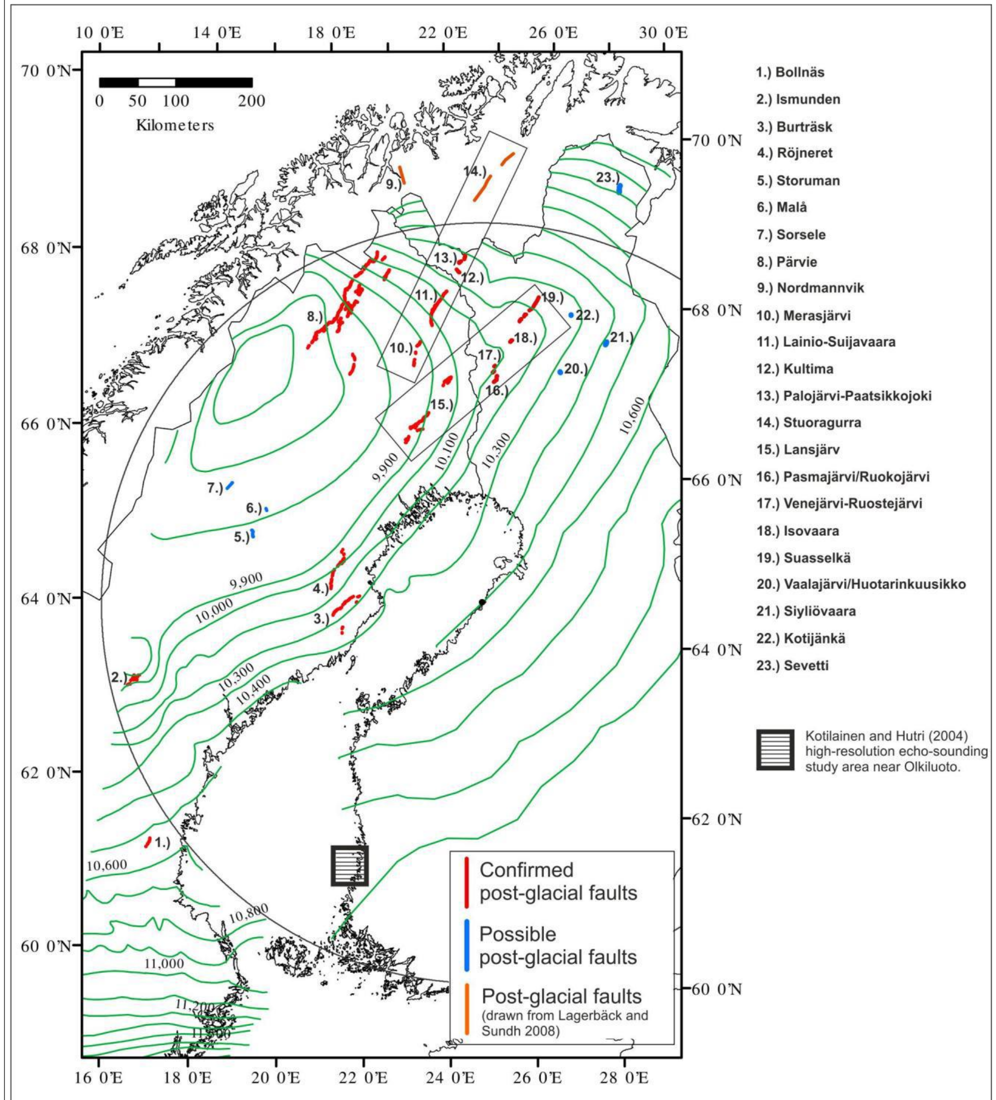
LGM, Late Weichselian

- Max. bedrock depression 800-900 m
- Current uplift rate 3-9 mm/a
- Remaining uplift 100-150 m









Sutinen et al. 2014c

Lund et al. 2014

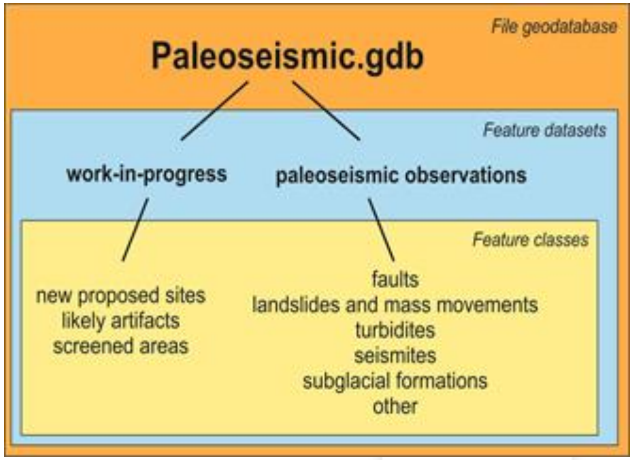
Postglacial faults and their dynamics (PGSDYN)

- GTK & Posiva, 2014 – 2017
  - Screening of the whole country using LiDAR based elevation model
    - Fault scarps, morphological features in Quaternary deposits related to seismic activity
    - Location and characteristics (orientation, dimensions, geometry, date etc.)
  - Field investigations (geophysics, trenching, drilling….)
  - Systematic storage of data in Paleoseismic.gdb database

→ increased understanding of the reactivation mechanisms, internal geometry and properties of the faults

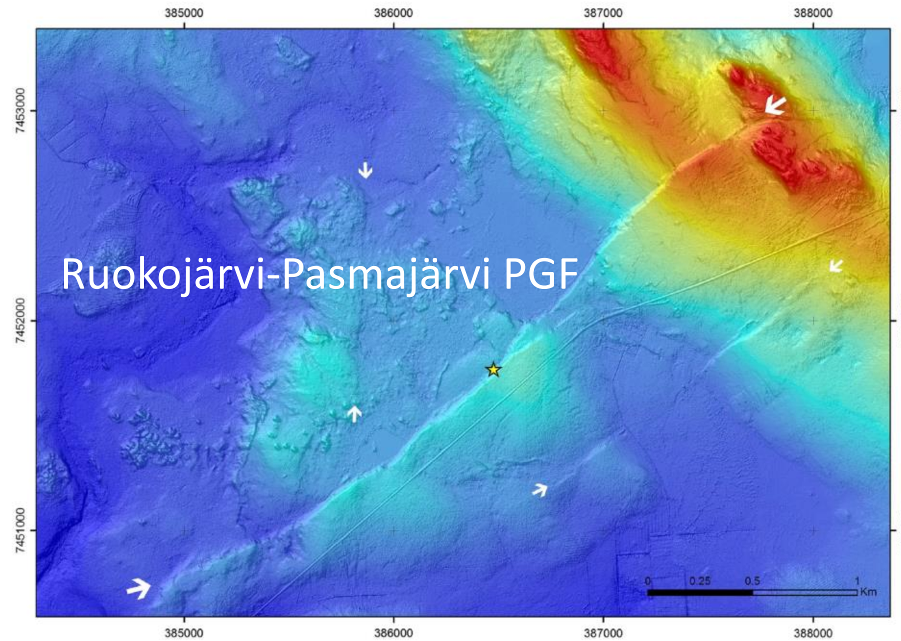
→ 'neotectonic' map of Finland

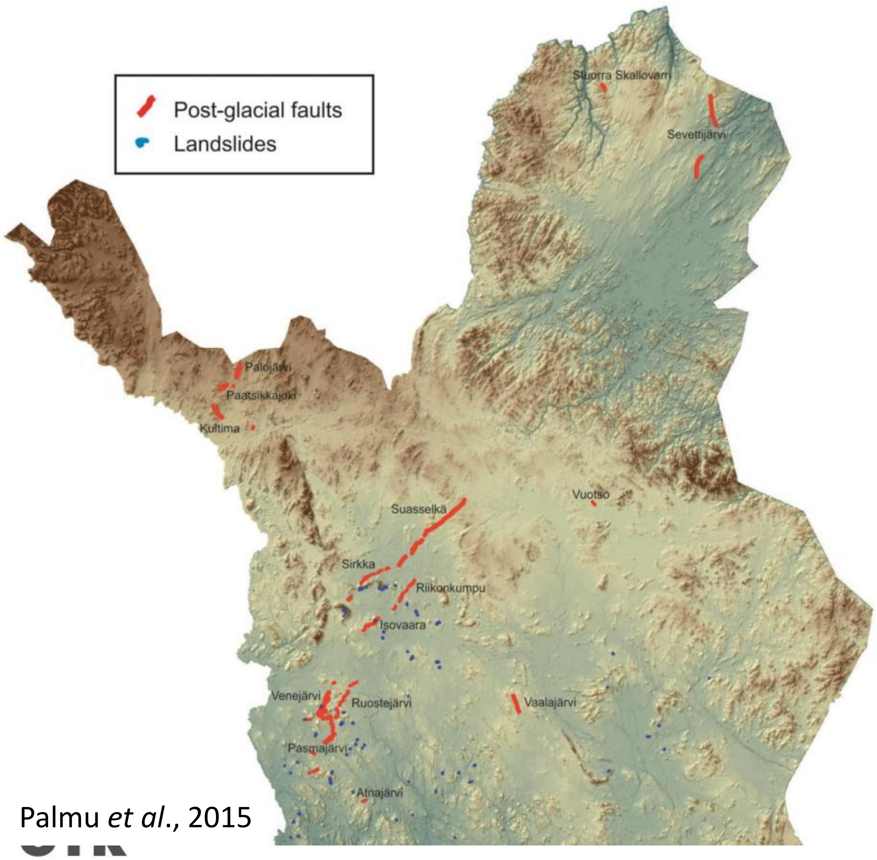
→ stability of structures in Olkiluoto (NA aspect)



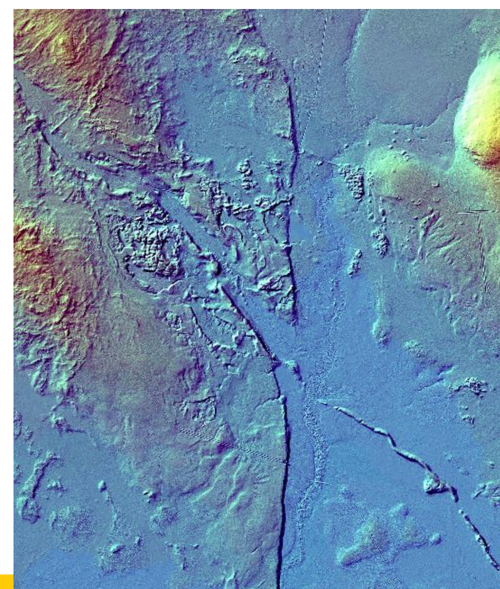
Multiple line of evidence for seismic activity

- **Postglacial faults** (**PGF**) that crosscut glacial sediments
- **Turbidites** and fluid-escape features (aquatic env.)
- **Seismites** liquefied and deformed sediments
- **Subglacial deformations** ('spreads')
- **Landslides**



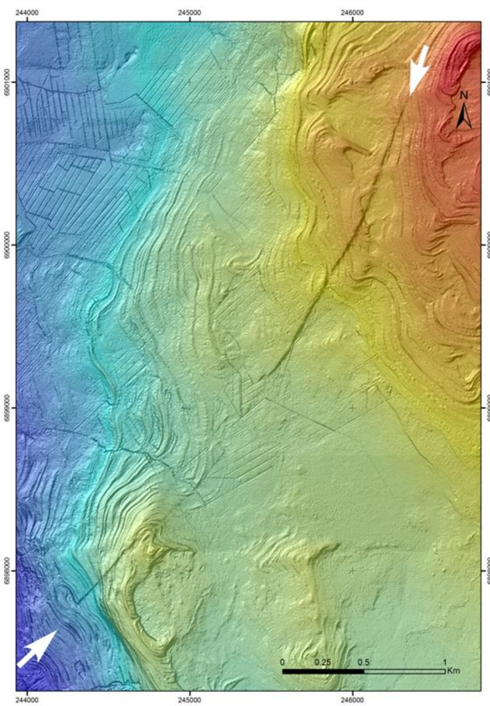


Palmu *et al.*, 2015

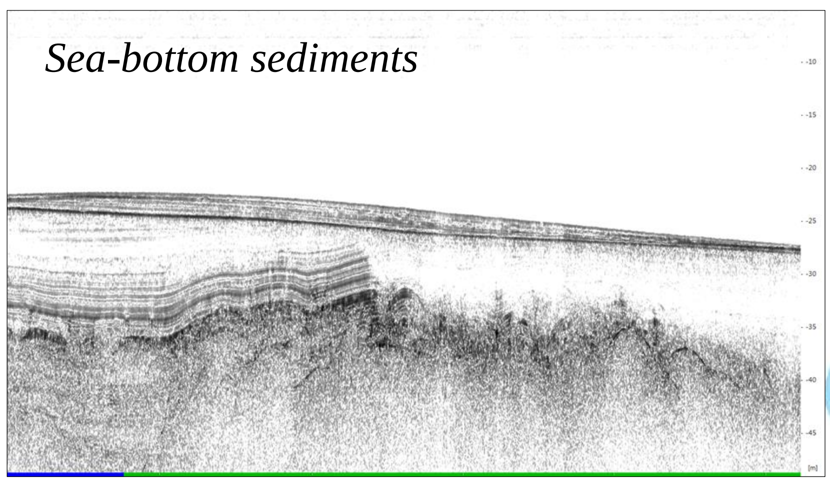


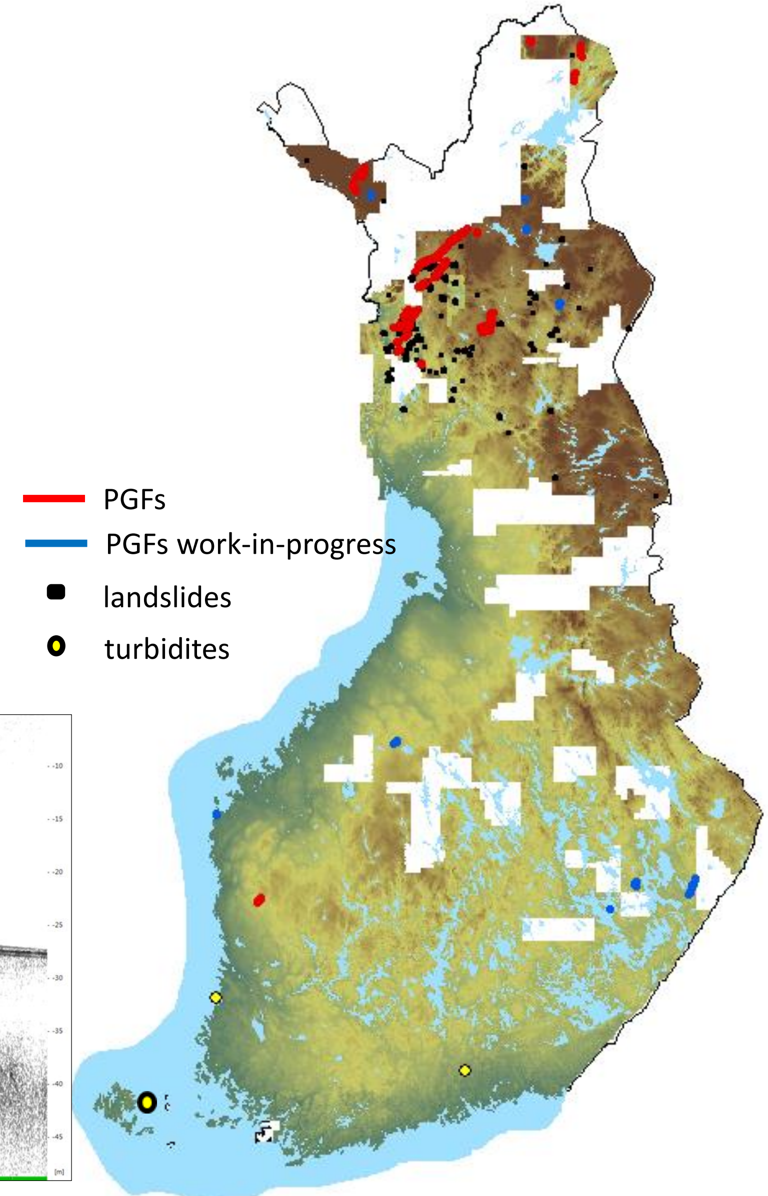
Work in progress and content of the paleoseismic database

- LiDAR DEM -screened area **297 605 km²** (338 424 km²)
- Verified and/or almost certain PGFs: **119 lines, 206.4 km**
- PGFs work-in-progress: ca. 10 sites to be checked
- Likely artefacts (mostly field controlled): **214 features**
- Landslides in PGFs vicinity: **121**
- Turbidites (lacustrine, marine): **2-3**

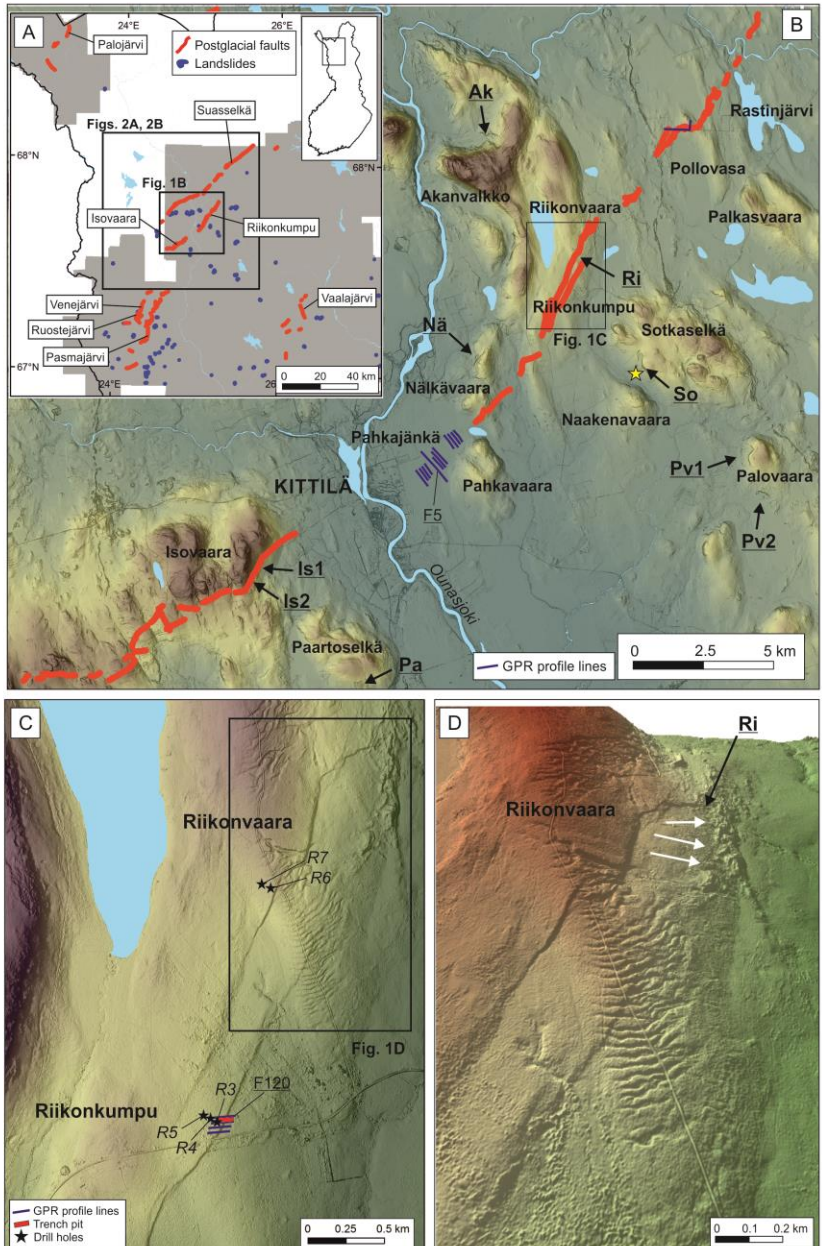


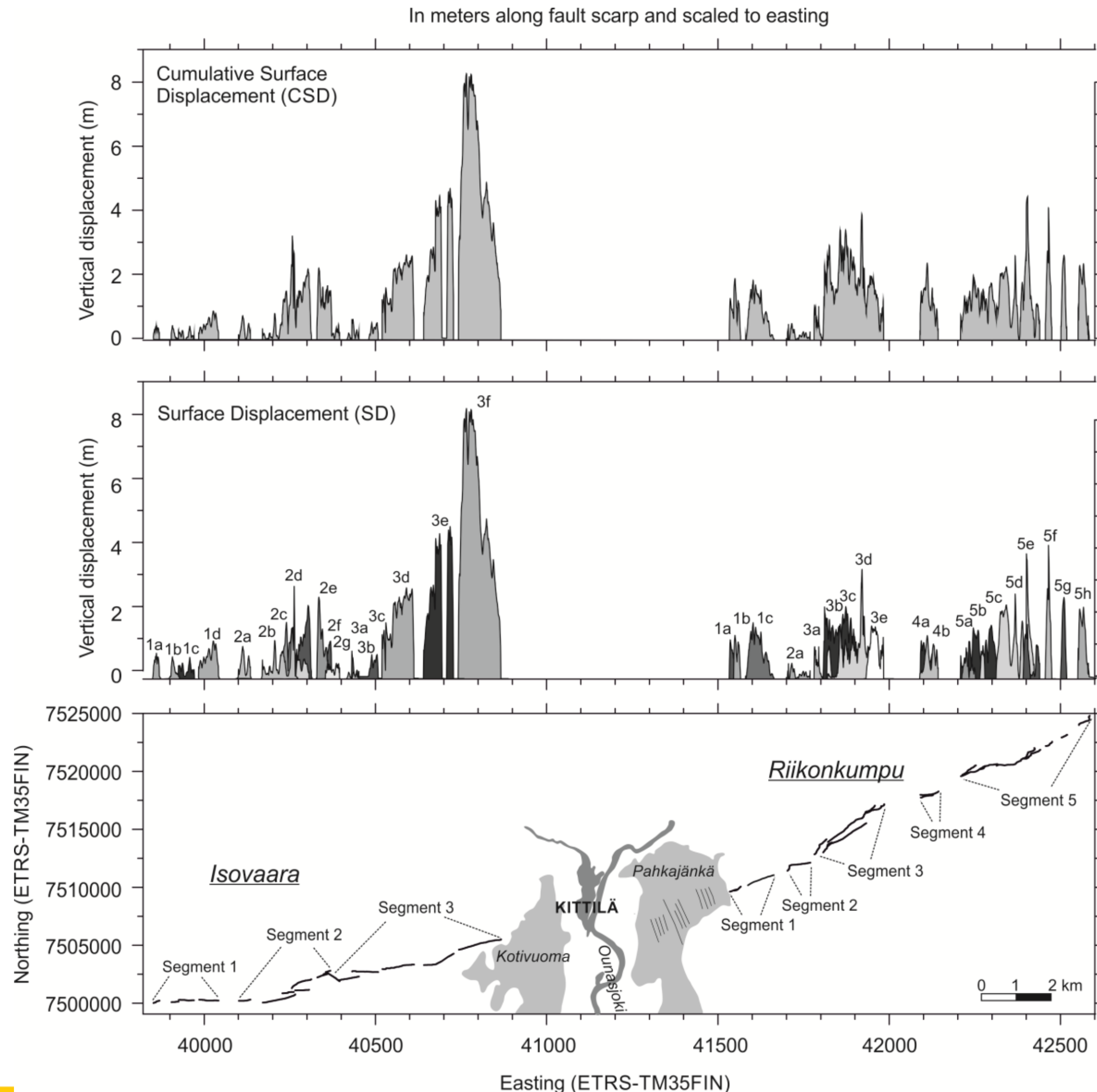
Lauhavuori, 100 km
NNE from Olkiluoto





Riikonkumpu-Isovaara PGF, Kittilä



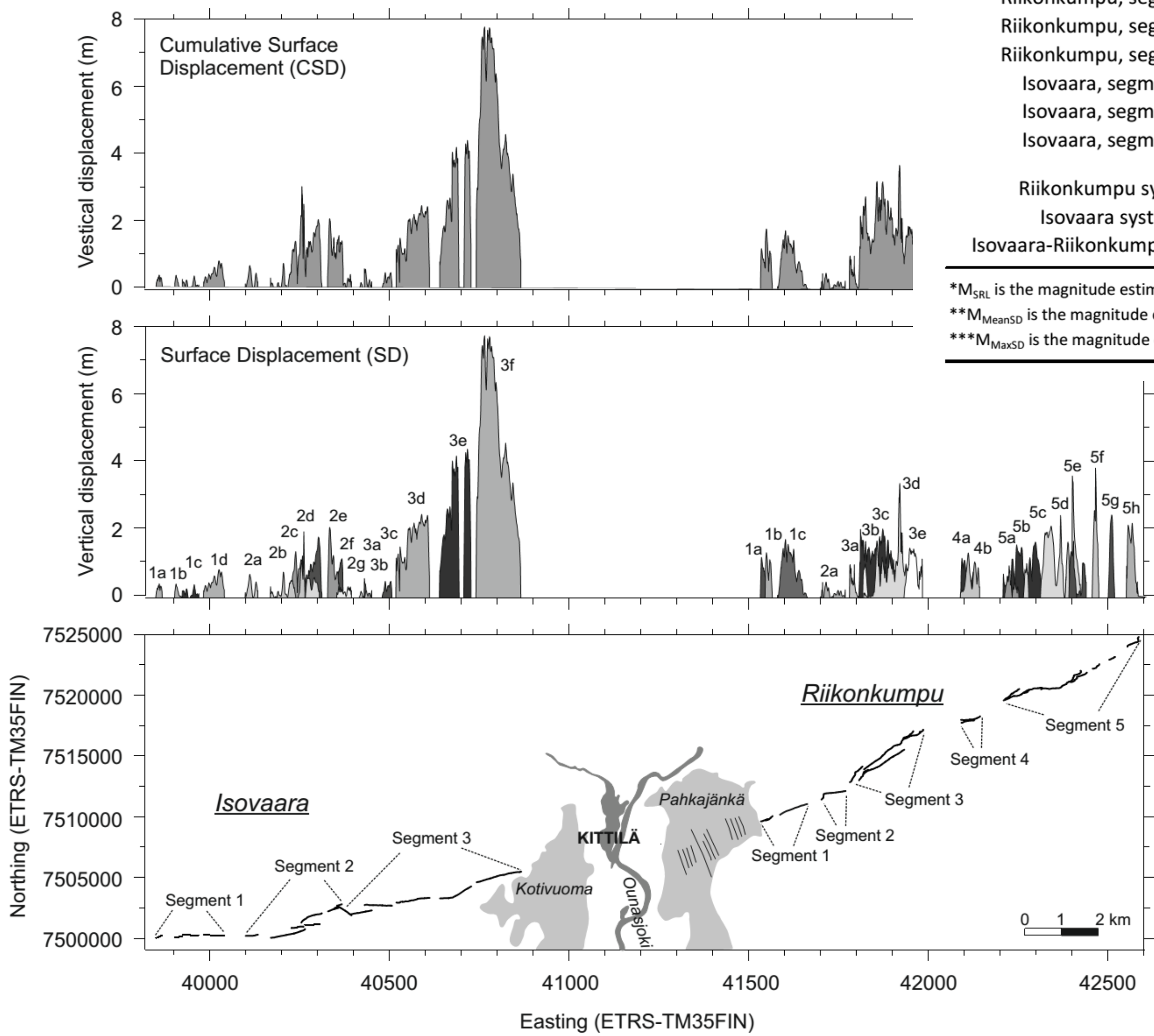


PGF's and paleoseismicity

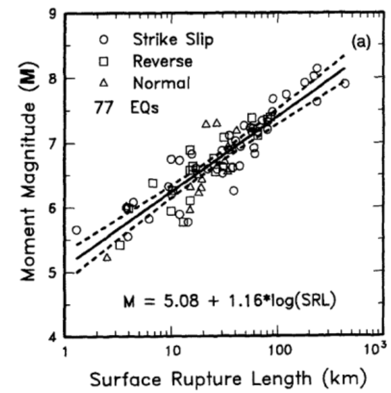
Riikonkumpu-Isovaara PGF, Kittilä

Surface rupture	SRL (km)	MeanSD (m)	MaxSD (m)	M_{SRL}*	M_{MeanSD}**	M_{MaxSD}***
Riikonkumpu, segment 1	1.8	0.8	1.4	5.3	6.9	6.8
Riikonkumpu, segment 2	1.1	0.2	0.5	5.1	6.4	6.5
Riikonkumpu, segment 3	4.9	0.9	3.4	5.9	6.9	7.1
Riikonkumpu, segment 4	0.8	0.7	1.3	5.0	6.8	6.8
Riikonkumpu, segment 5	6.6	1.0	3.9	6.0	6.9	7.1
Isovaara, segment 1	3.7	0.3	0.9	5.7	6.5	6.7
Isovaara, segment 2	3.3	0.5	2.1	5.7	6.7	6.9
Isovaara, segment 3	6.3	2.5	7.8	6.0	7.3	7.4
Riikonkumpu system	19	0.9	3.6	6.6	6.9	7.1
Isovaara system	12	1.3	7.8	6.3	7.0	7.4
Isovaara-Riikonkumpu complex	38	1.1	7.8	6.9	7.0	7.4

*M_{SRL} is the magnitude estimated based on surface rupture length (SRL)
**M_{MeanSD} is the magnitude estimated based on mean surface displacement (MeanSD)
***M_{MaxSD} is the magnitude estimated based on maximum surface displacement (MaxSD)



Wells and Coppersmith (1994)



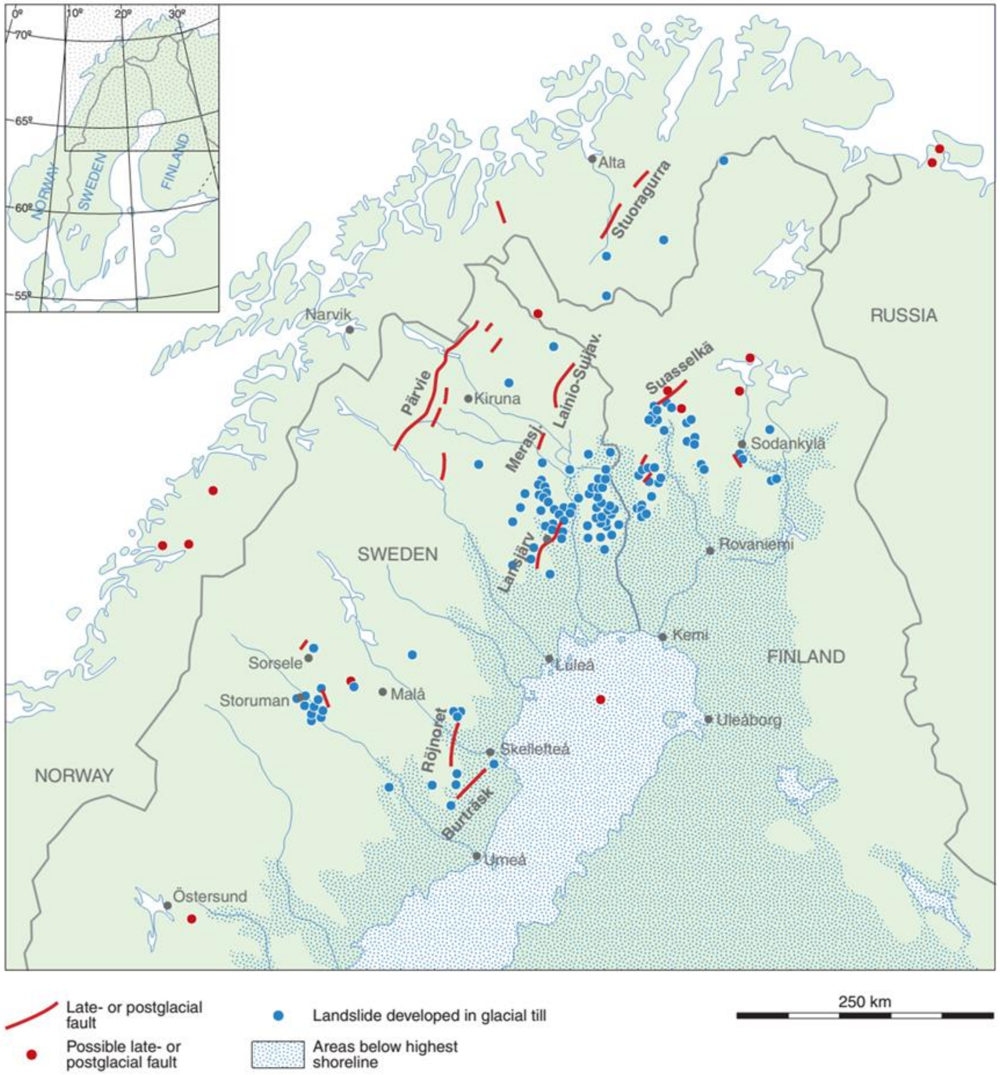
$M_W = 5.08 + 1.16 \times \log(SRL)$

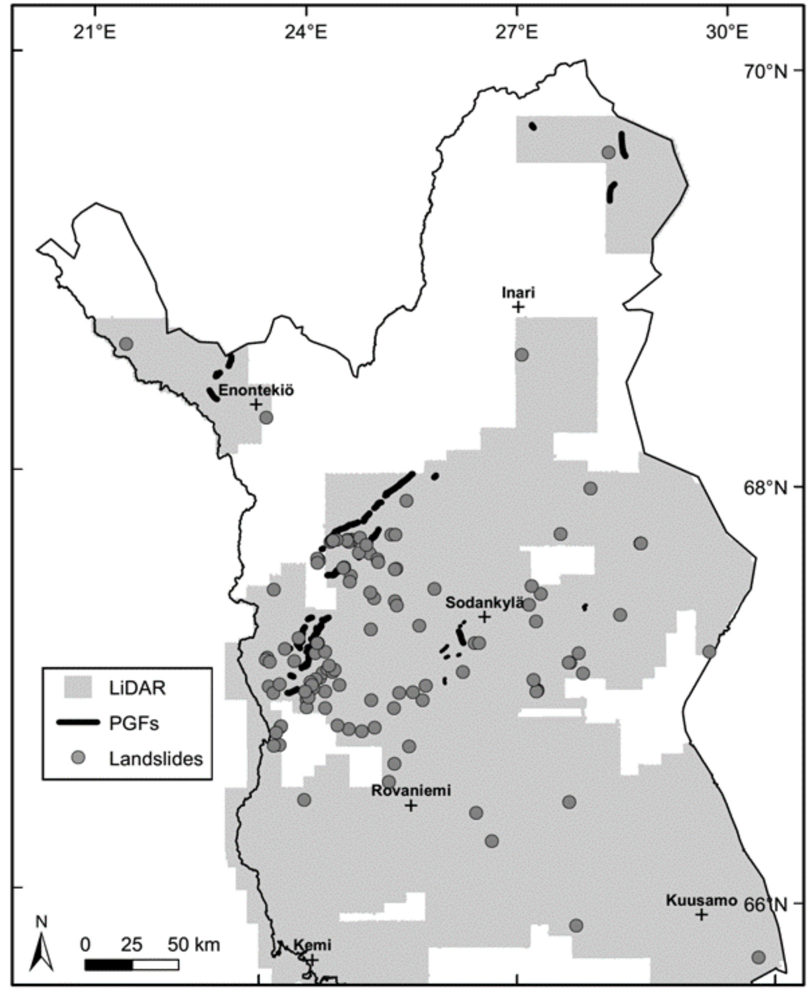
$M_W = 6.69 + 0.74 \times \log(MaxSD)$

$M_W = 6.93 + 0.82 \times \log(MeanSD)$

Mattila *et al.*, 2016
Ojala *et al.*, submitted

Landslides in Finland and Sweden

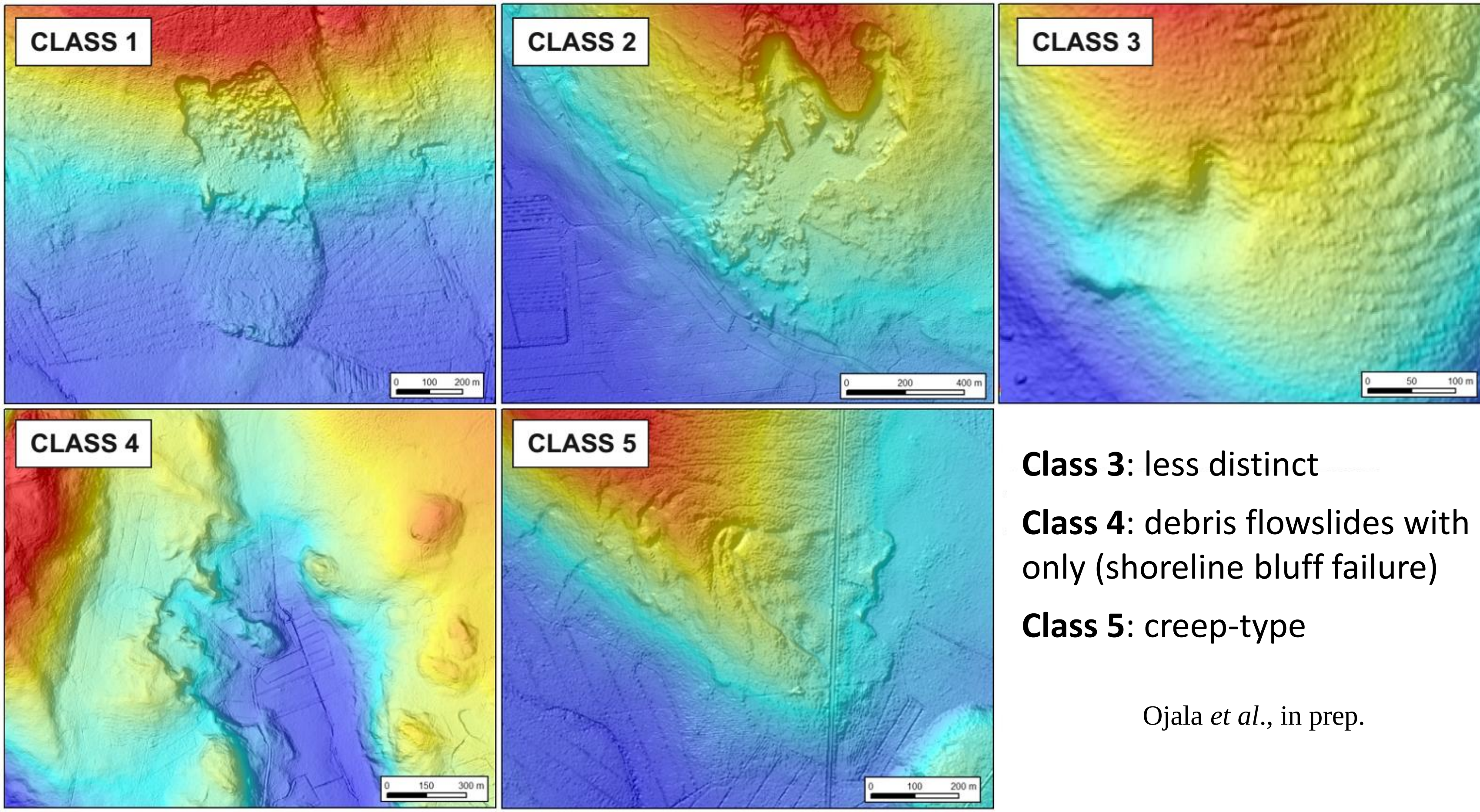




Ojala *et al.*, in prep.

GTK
gtk.fi

Landslides: types and characteristics in northern Finland



Class 3: less distinct

Class 4: debris flowslides with distinct scarp only (shoreline bluff failure)

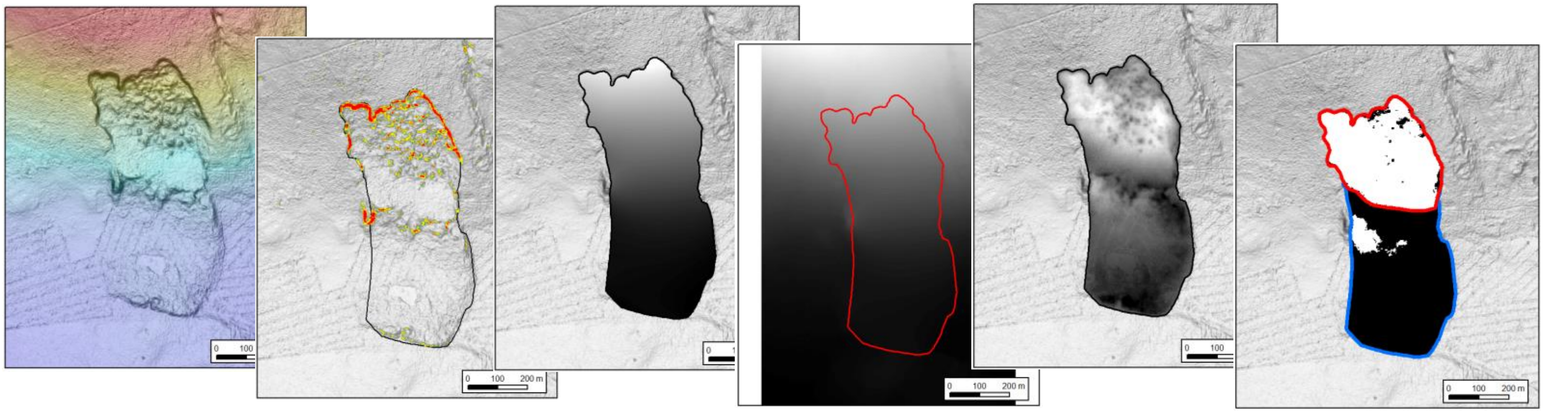
Class 5: creep-type

Ojala *et al.*, in prep.

Class 1: debris slides with distinct scarp and colluvial toe + flow-like component

Class 2: debris slides with distinct scarp and more randomly spread masses

Analyzing 3D characteristics from LiDAR DEMs

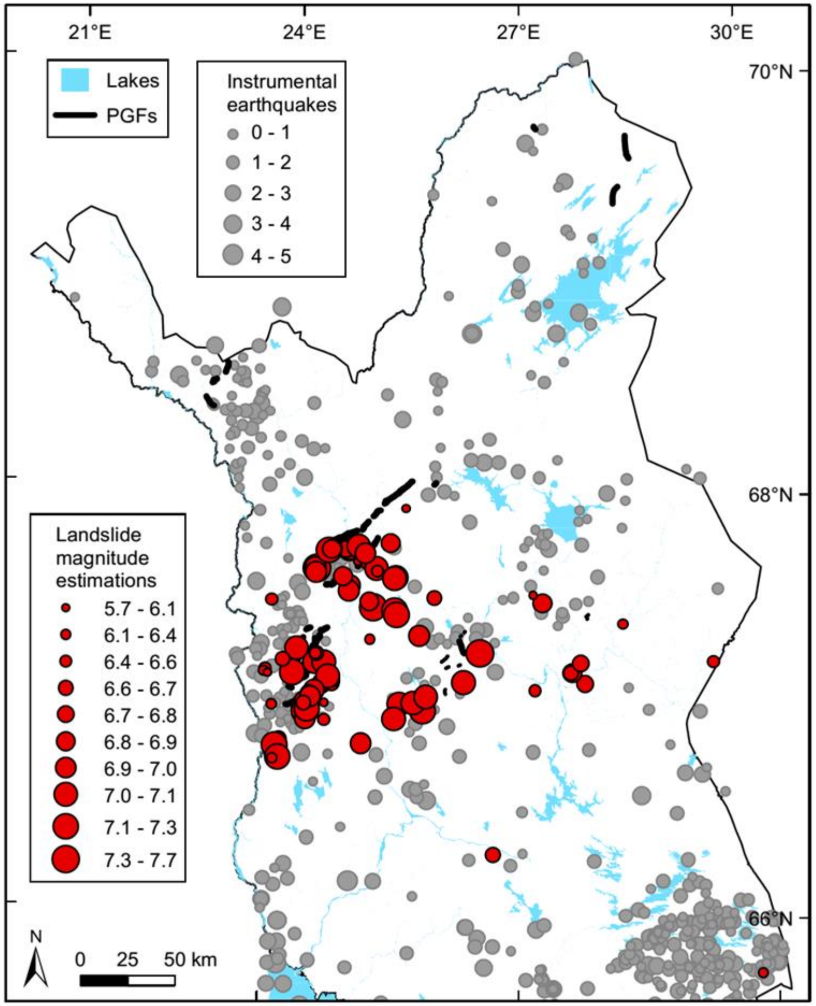


- ***Total area*** of the landslide and ***areas of the scarp and slid masses*** using the refined polygons
- ***Volume of the scarp***, based on the total landslide area and scarp area only
- Scarp **depth variability;** maximum, mean, variance and 75-percentile
- ***Volume of slid masses***
- ***Original slope*** of the terrain where the landslide occurred, determined as the average slope of the interpolated "base terrain"
- ***Slope of the scarp's backwall*** close to crown of the main scarp. This was defined as an average of the 20-30 steepest points below the crown using the slope and TDR derivatives
- ***Distance from the nearest PGF***
- ***Main direction*** of the landslide using a minimum bounding geometry
- **Roughness index**

Ojala *et al.*, in prep.

GTK
gtk.fi

Landslides and paleoseismicity

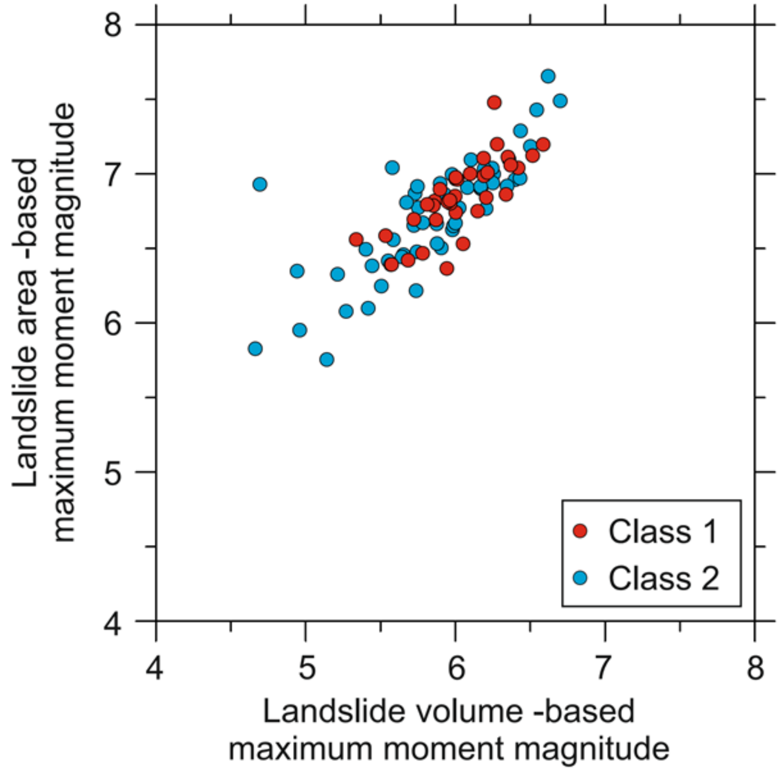


Ojala *et al.*, in prep.

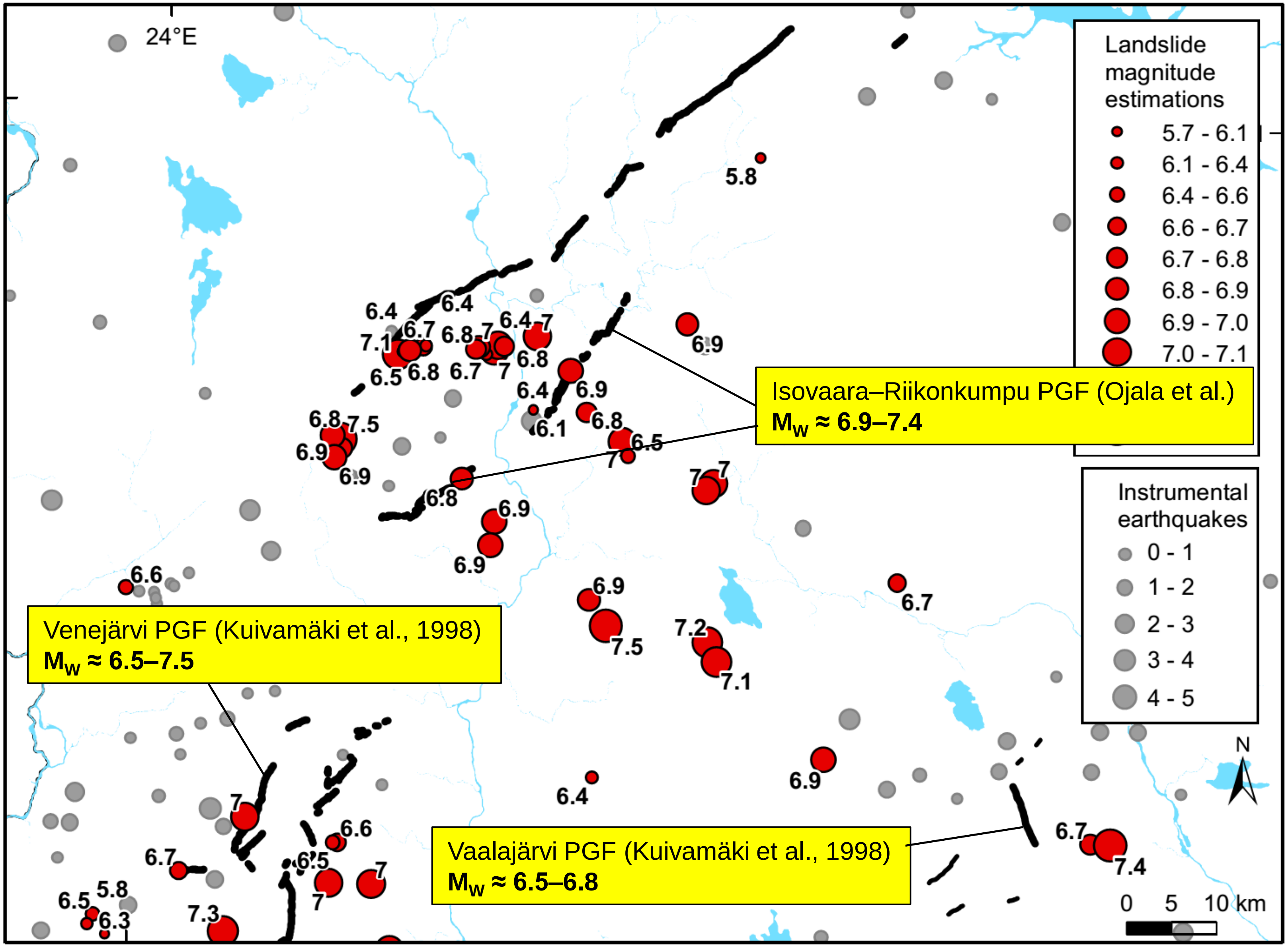
Landslide-inferred maximum moment magnitudes (Malamud et al. 2004)

$$M_{Amax} = \frac{\log(A_{max}) + (6.85 \pm 0.33)}{0.91}$$

$$M_{Vmax} = \frac{\log(V_{max}) + (11.58 \pm 0.49)}{1.36}$$

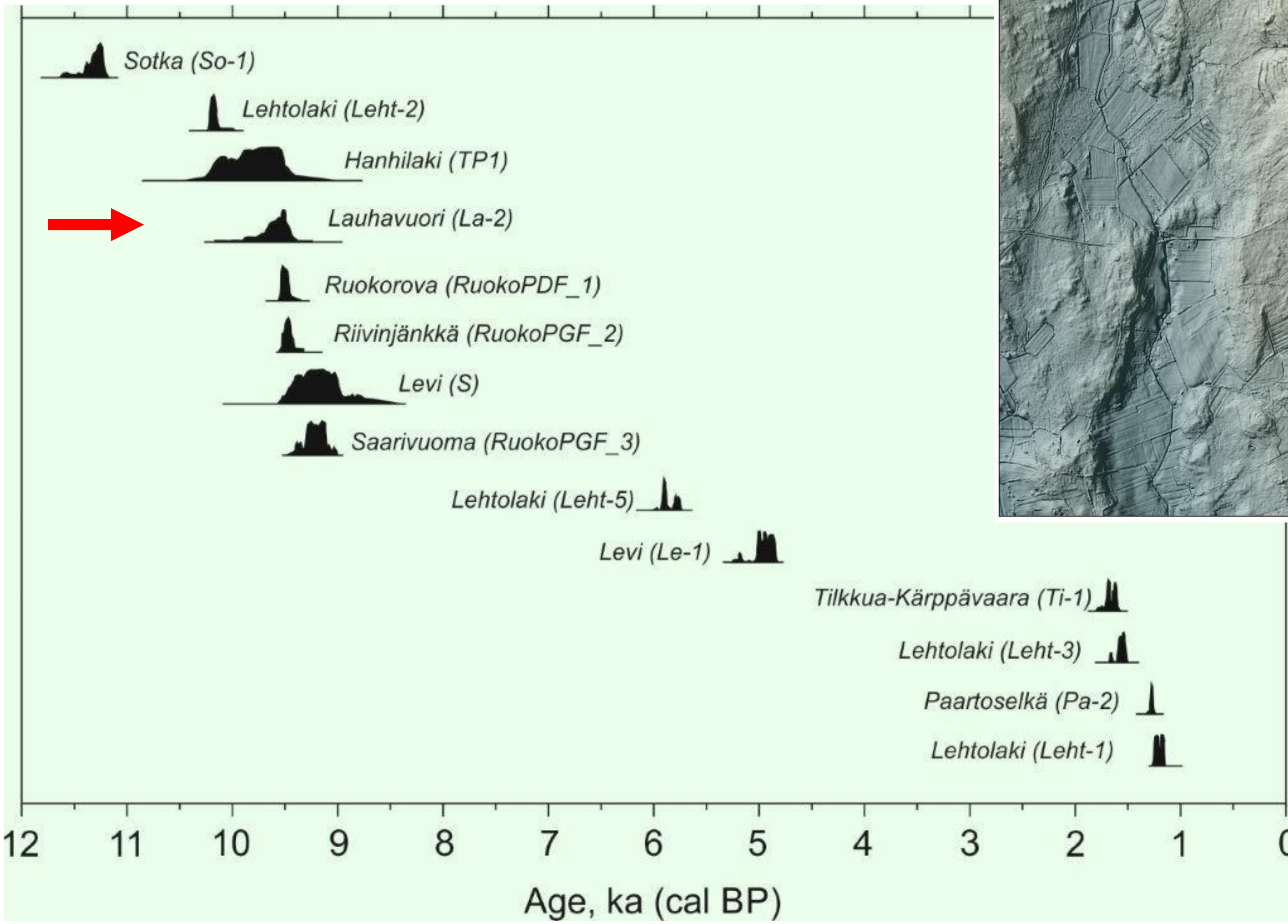


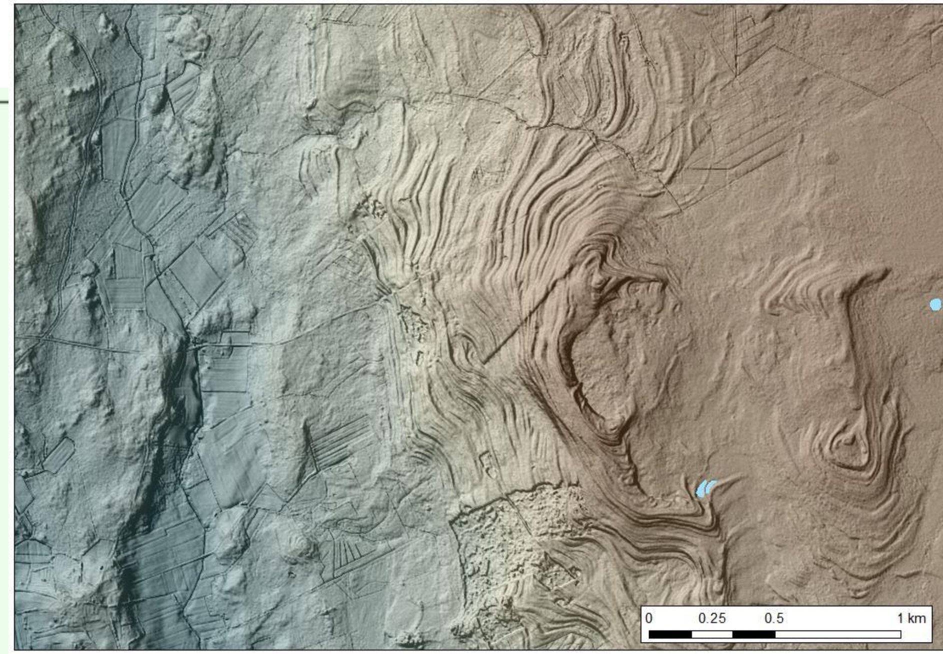
Paleoseismicity estimates: PGF's vs. landslides

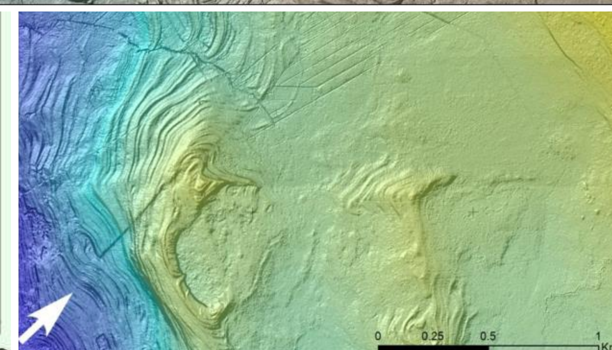


GTK
gtk.fi

Recurrence time for seismic activity







GTK
gtk.fi

Conclusions

- PGFs are focused on the northern part of the country. Only one fault, the Lauhanvuori PGF, could be confirmed from the central and southern part of the country.
- However, it is likely that more PGFs occur in South, but they can't be observed from LiDAR data
  - Suspected seismites (seismic induced deformation in soft sediments)
  - Marine geological evidence of seismically-induced sediment features
- The geometry of recognized PGFs is often complex and distinctively segmented along strike
- All PGFs studied by drilling and trenching are reactivated faults within ancient deformation zones
- Datings of landslides has provided strong indications that the recurrence cycle for seismic activity is 3000-4000 a
- Moment magnitude estimates based on fault lengths, vertical displacements and area-volume data of landslides all suggest consistently MW ≈ 6.7–7.7 for northern Finland

- Final Report 2018


VOLVO
Thank you!