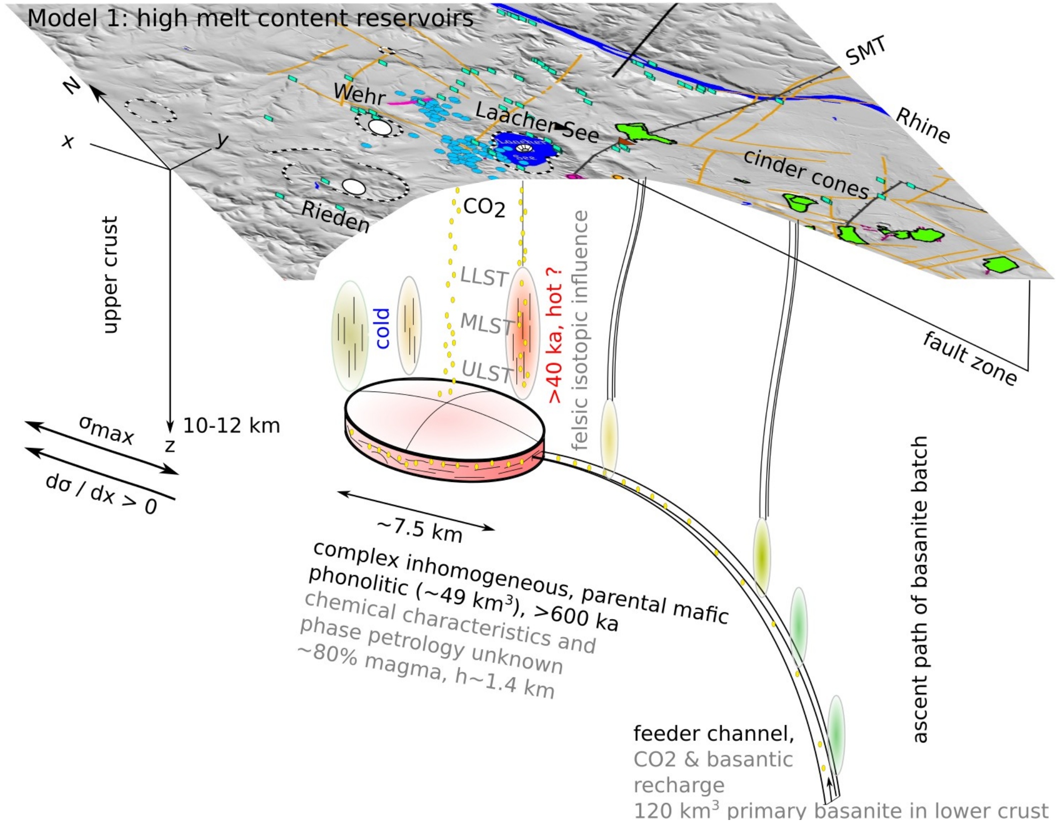
Quaternary volcanic fields in Central Europe
– activities and latent hazards –



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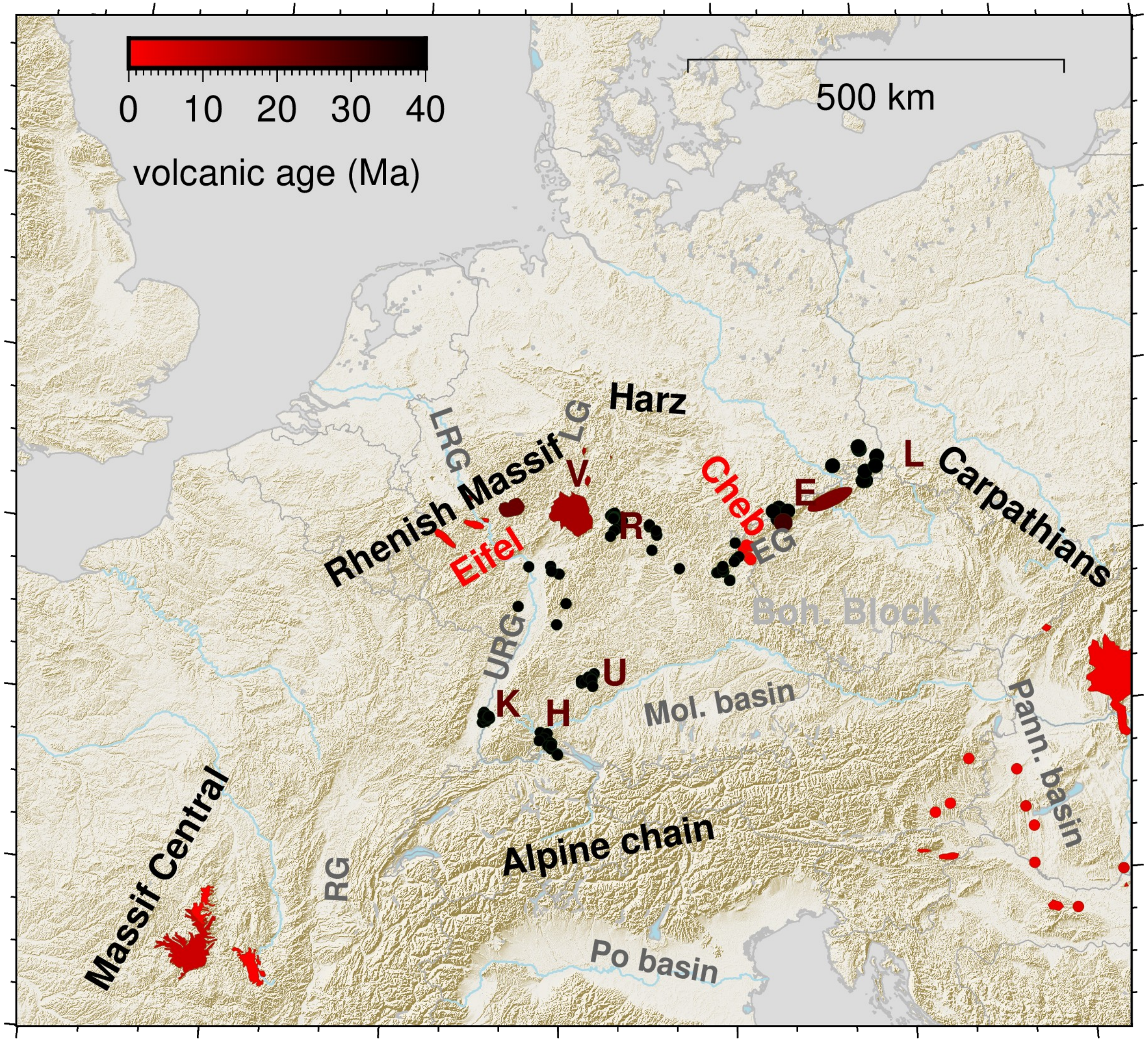
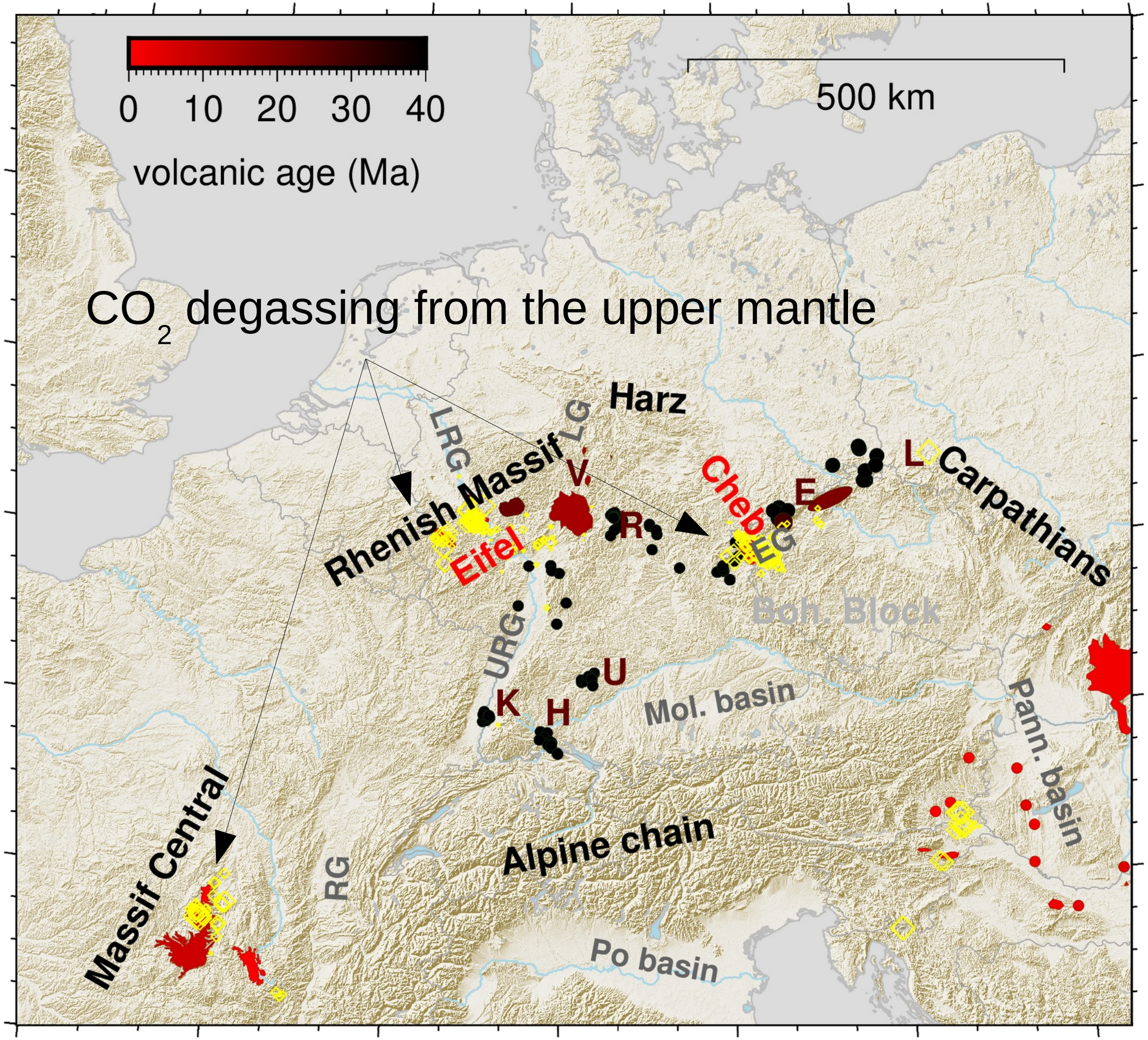
IUGG 2023, IASPEI Opening Ceremony, Fri, 14 July 2023, 9:30-10:00, Hall A

Cenozoic distributed volcanic fields in Central Europe



- Most common form of intra-continental volcanism away from plate boundaries
- Magma dynamics and hazard largely undeterminate
- Magma systems are distributed over large depths
- The Eifel is a type locality with a large number of eruptions and wide range of eruption types *(other: Massif Central, Eger, Pannonean basin)*

Cenozoic distributed volcanic fields in Central Europe

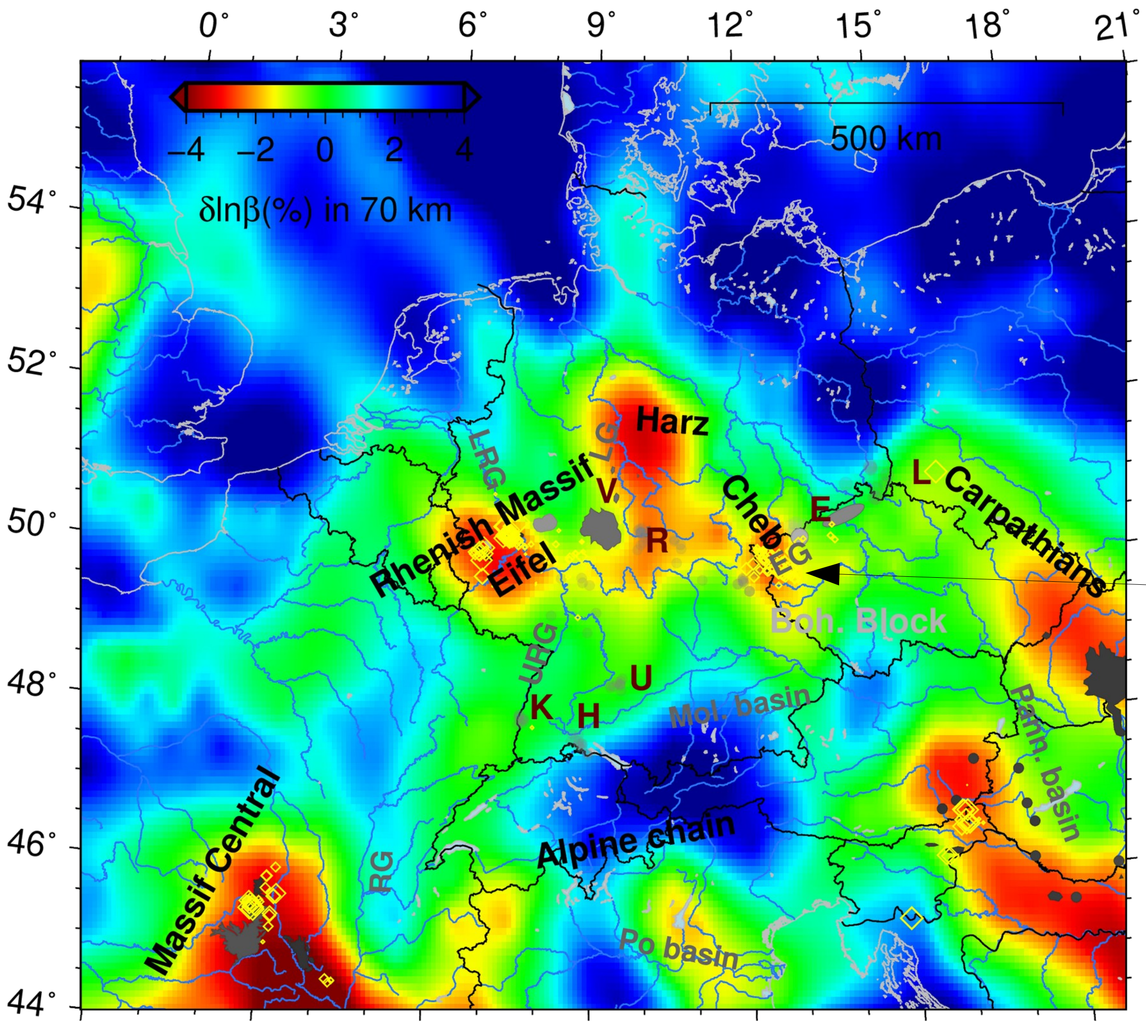


- CO_2 degassing from upper mantle in Quaternary volcanic fields

- East-, West- & High-Eifel fields comprise:

  - >800 volcanoes over 3.200 km² since 45 Mio yrs
  - >800 km³ from Quaternary eruptions
  - 11 ka youngest maar: Ulmen (West Eifel)
  - 13 ka, VEI=6 youngest Plinian eruption at Laacher See (East Eifel)

S-wave anomalies in the upper mantle



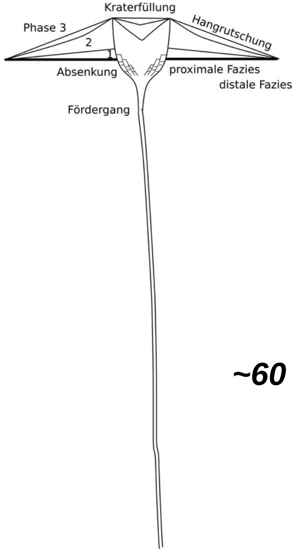
- Mantle upwelling is indicated by S-wave anomalies
- Correlates with Cenozoic volcanoes
- Mantle-derived CO_2 correlates with Quaternary volcanism

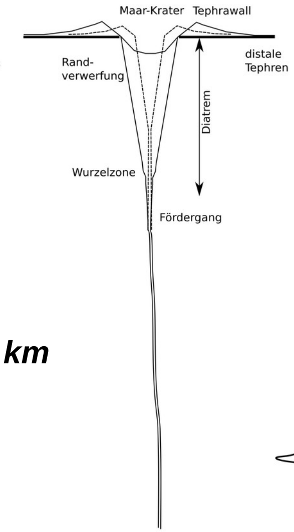
□ CO_2 mofettes and springs

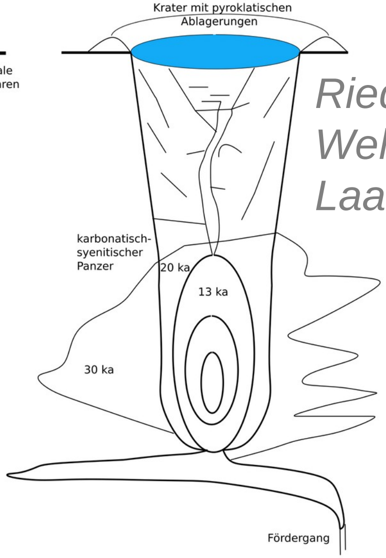
Tomography results from Zhu et al. (2015) GJI

How do magmatic system look from crust to mantle ?

Cinder cones | Maar | Explosive (phonolitic) centre





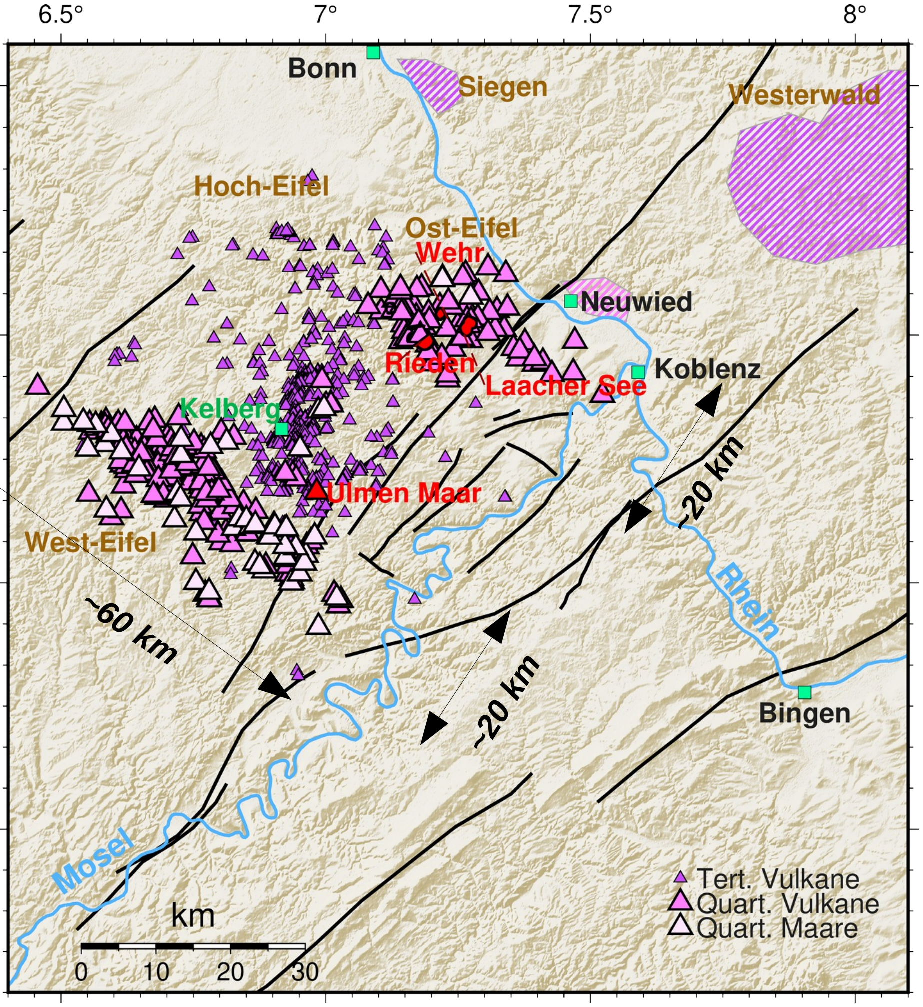


Rieden
Wehr
Laacher See

~60 km

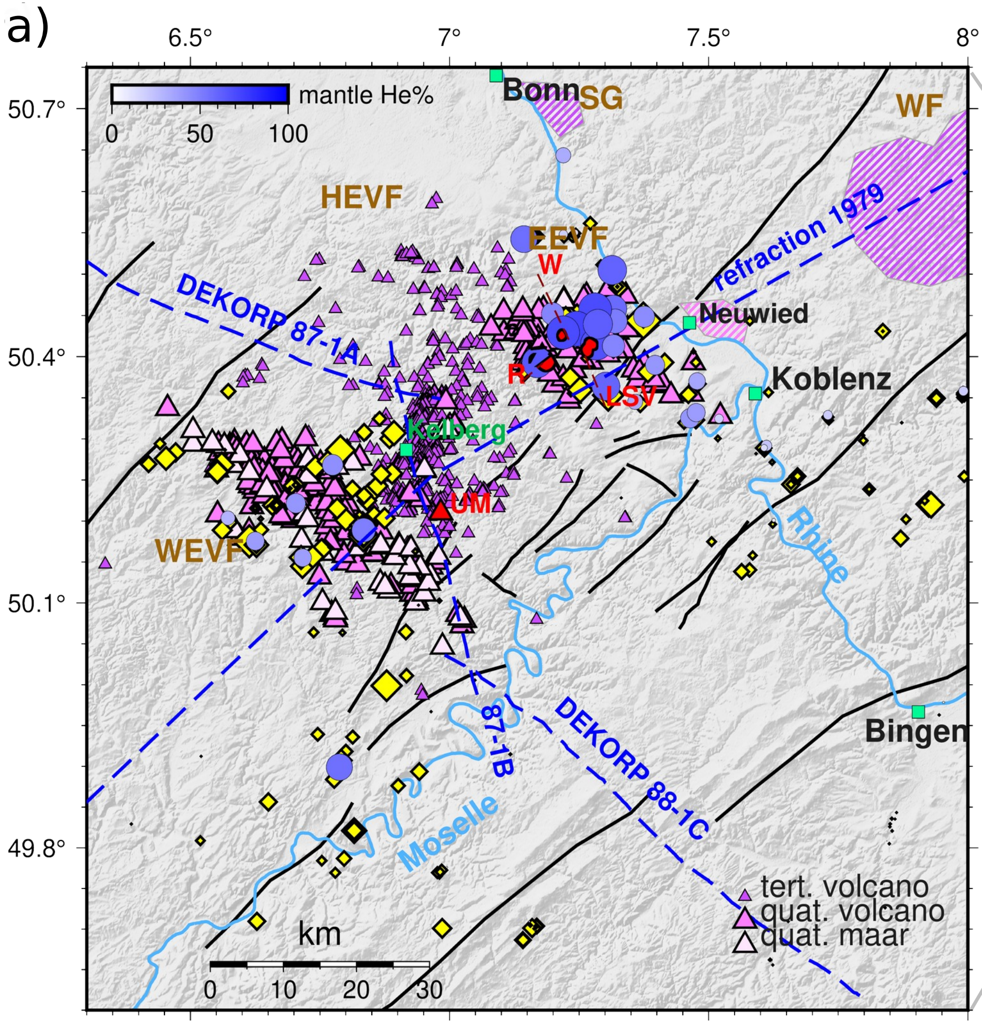
20-70 km

4-8 km

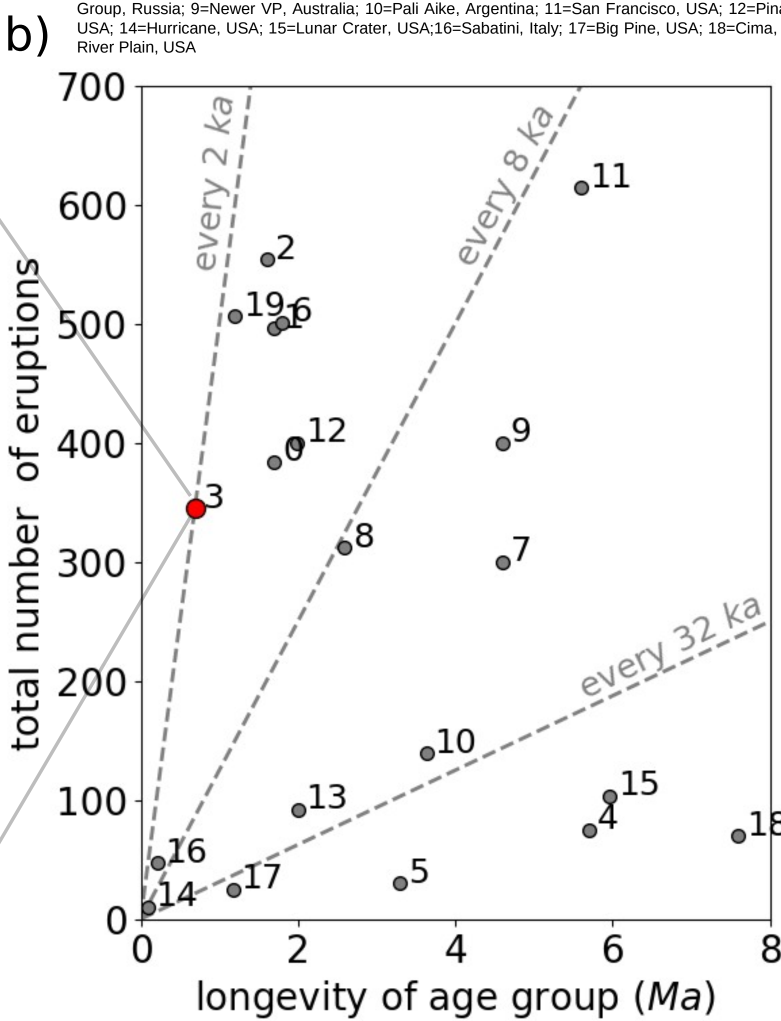


Were fed from broad range of magmatic sources between 70 to 4 km depth

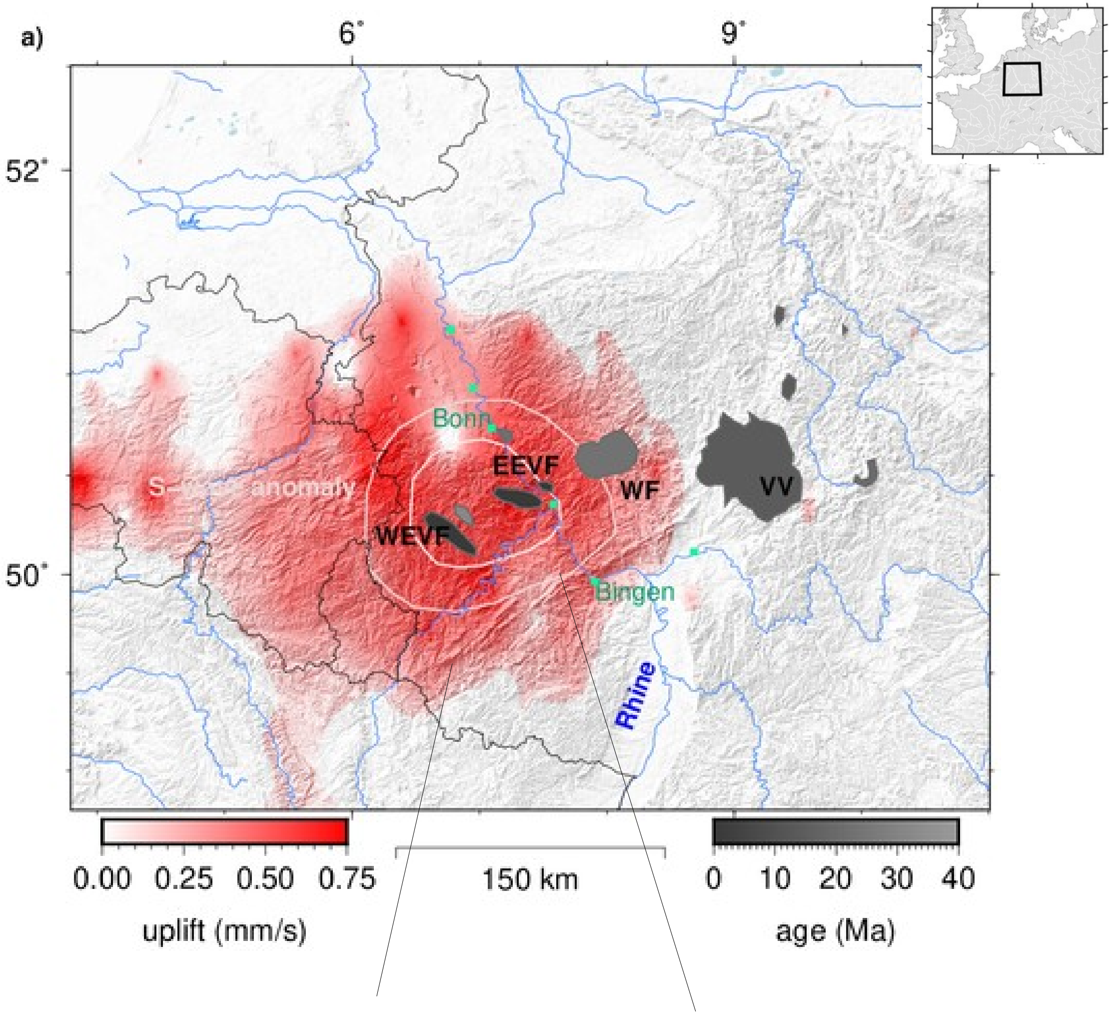
Mantle CO_2 indicates active magma degassing at depth



Compilation from Alohali et al., 2022: 0=Harrat Khaybar; 1=Northern Harrat Rahat; 2=Armenia; 3=Eifel Quaternary Volcanic Fields, Germany; 4=Pancake, USA; 5=Yucca Mountain, USA; 6=Springerville, USA; 7=Camargo, Mexico; 8=Klyuchevskoy Group, Russia; 9=Newer VP, Australia; 10=Pali Aike, Argentina; 11=San Francisco, USA; 12=Pinacate, Mexico; 13=Coso, USA; 14=Hurricane, USA; 15=Lunar Crater, USA;16=Sabatini, Italy; 17=Big Pine, USA; 18=Cima, USA; 19=Eastern Snake River Plain, USA



The Eifel experiences ongoing uplift at rates comparable to the Alps

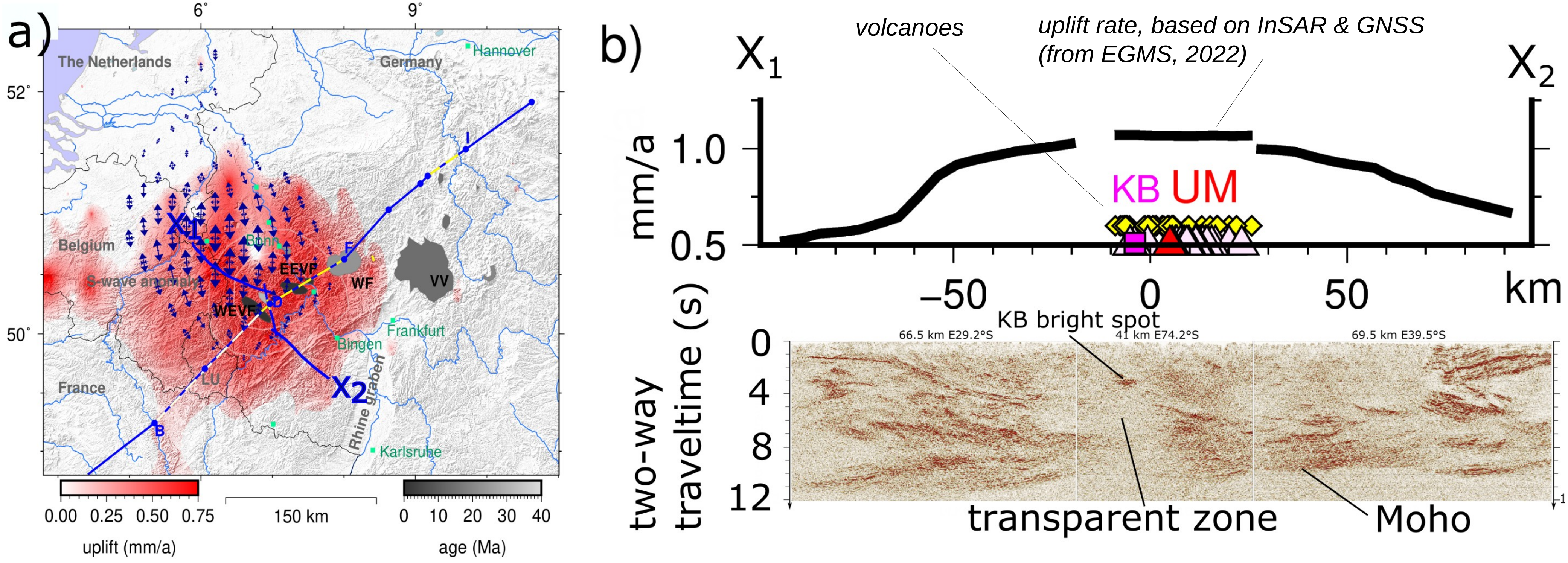


- Uplift rate to 1 mm/yr from GNSS data
- Correlates with “radial divergence”
- Uplift rate is largest where where S-anomaly in upper mantle (50-100 km) present
- Region of largest uplift rate correlates with young active volcanism (EEVF, WEVF)

Uplift & strain data from Kreemer et al. (2020) *S-anomaly 50-100 km depth, 1.4%, 2.8%, from Keyser et al. (2002)*

Regional-scale uplift and extension - correlates with transparent lower crust

GNSS results from Kreemer et al., 2019

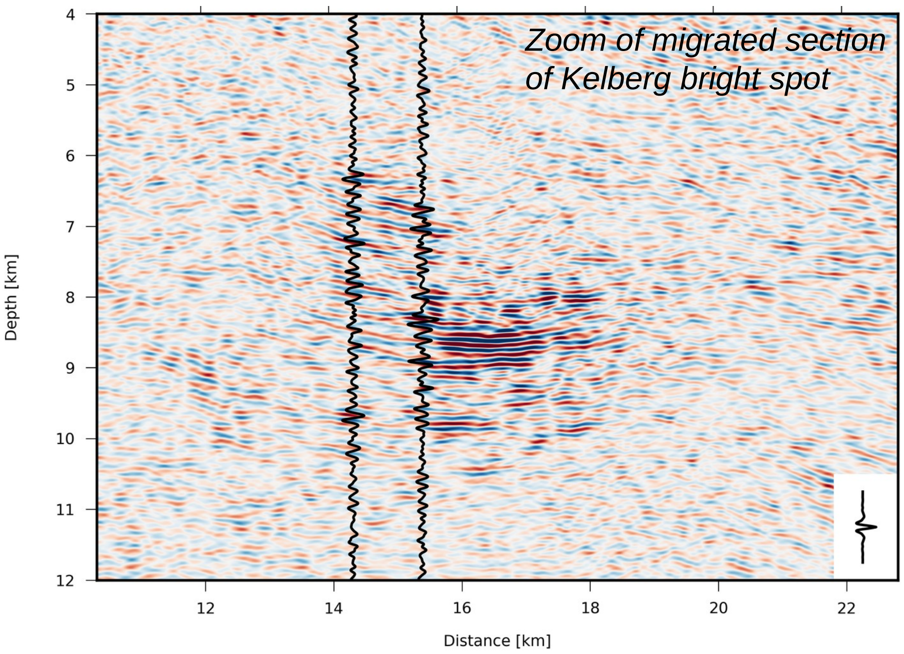


Dahm et al., 2020, G3

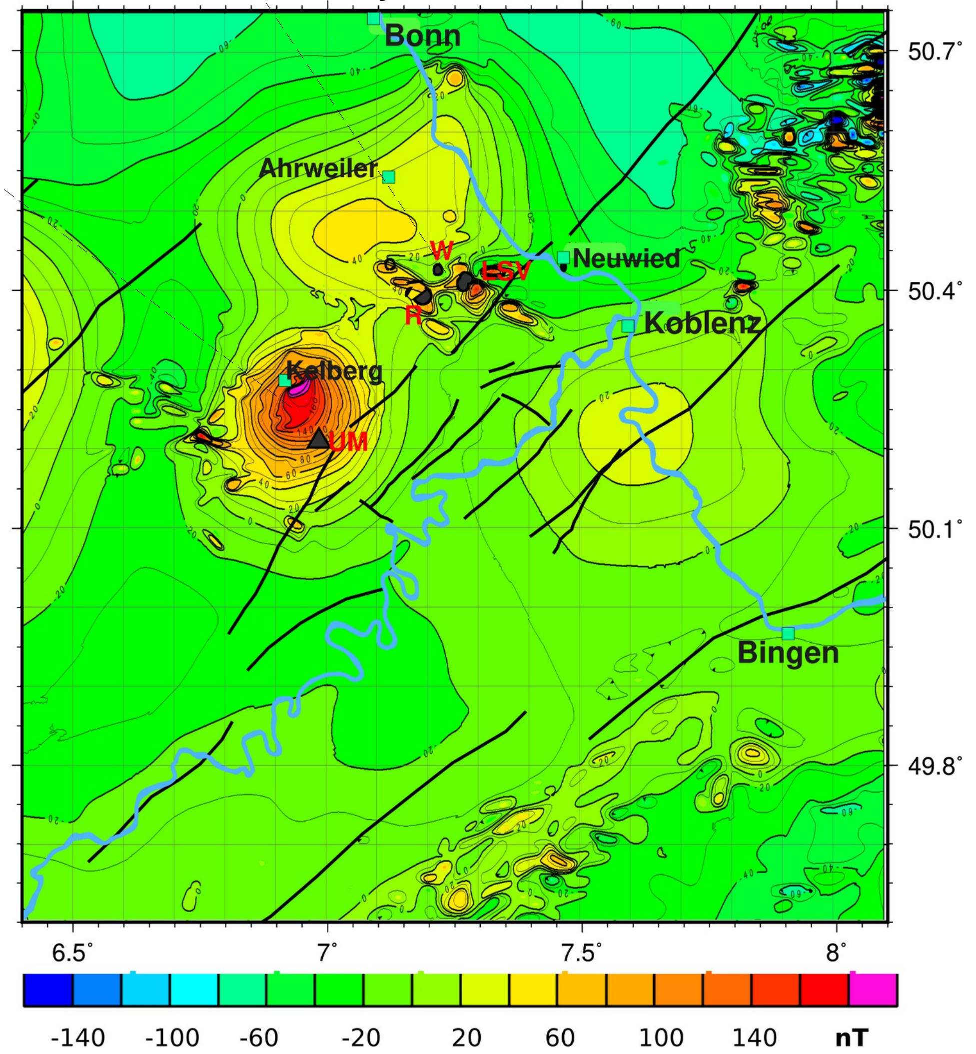
Kelberg bright spot beneath magnetic anomaly – signatures of old reservoir

Strong circular magnetic anomaly at Kelberg interpreted as magnetized body at depth

Seismic reflectors between 6-10 km depth indicate phase reversals as expected from intrusive layers



no similar anomaly beneath the LSV

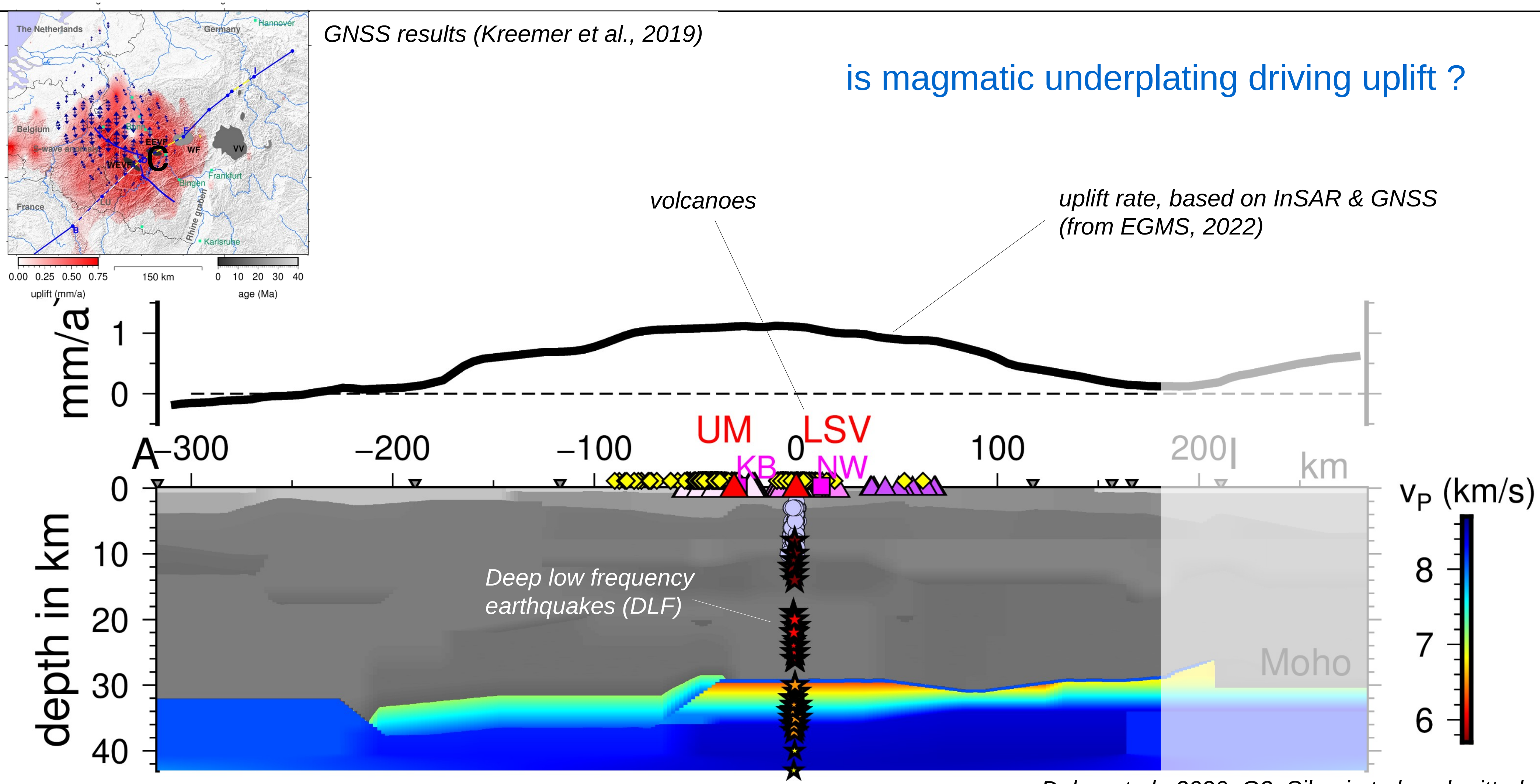


Dahm et al. (2020) G3, 10.1029/2020GC009062

Uplift largest where Moho is shallow and low P-wave gradient layer beneath

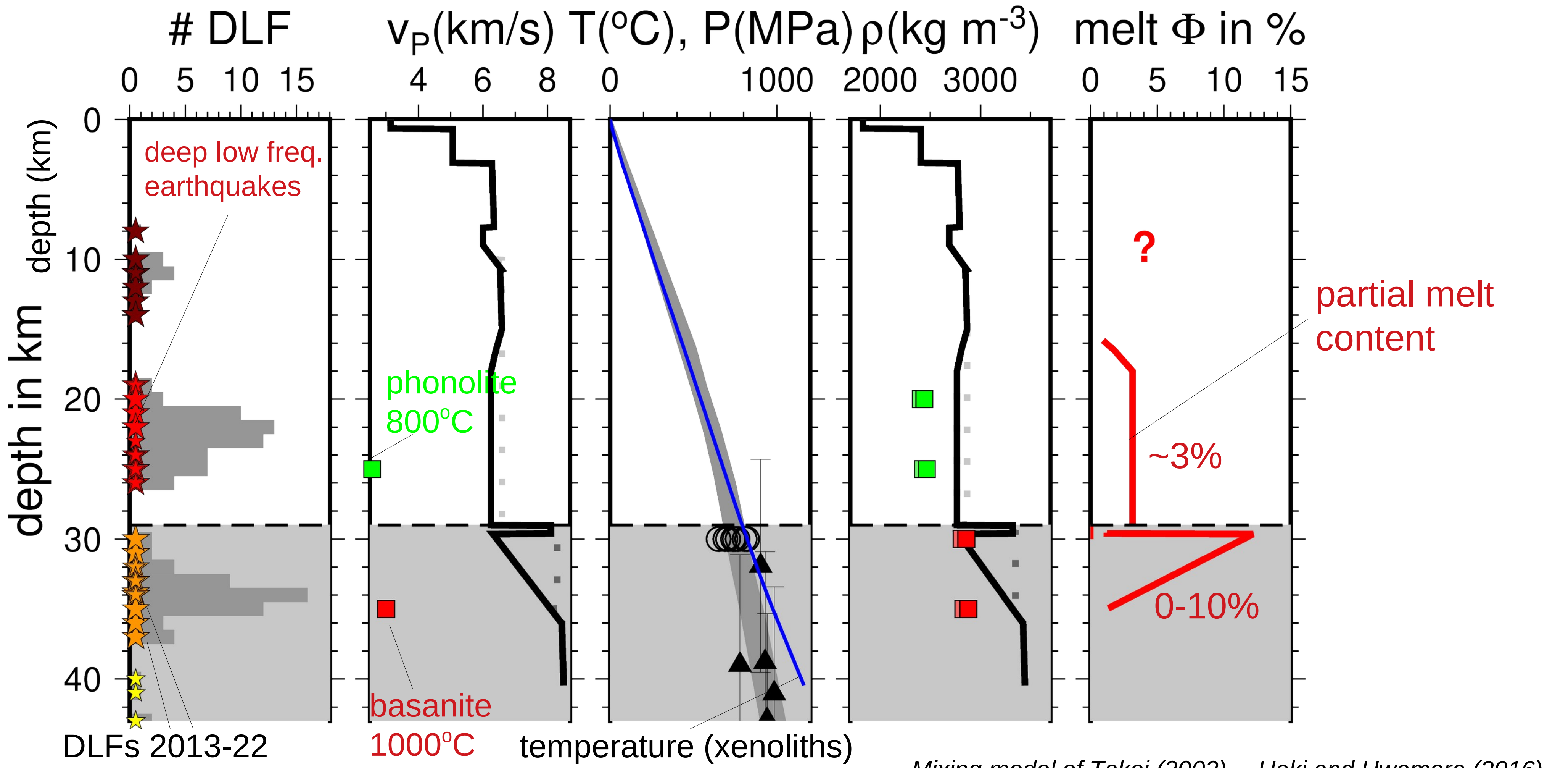
GNSS results (Kreemer et al., 2019)

is magmatic underplating driving uplift ?



Dahm et al., 2020, G3; Silveri et al., submitted

Low velocity layers used to extrapolate partial melt content



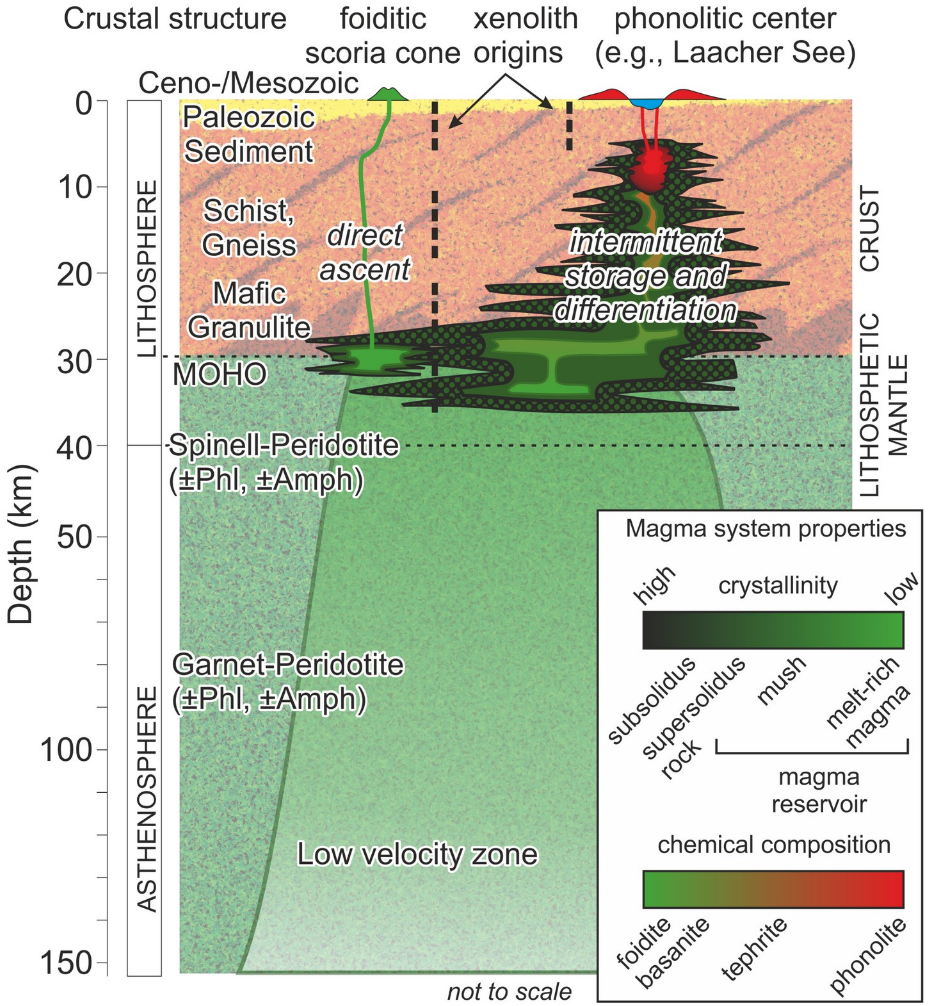
Mixing model of Takei (2002) (aspect ratio ~0.01)

Ueki and Uwamora (2016) to estimate bulk moduls

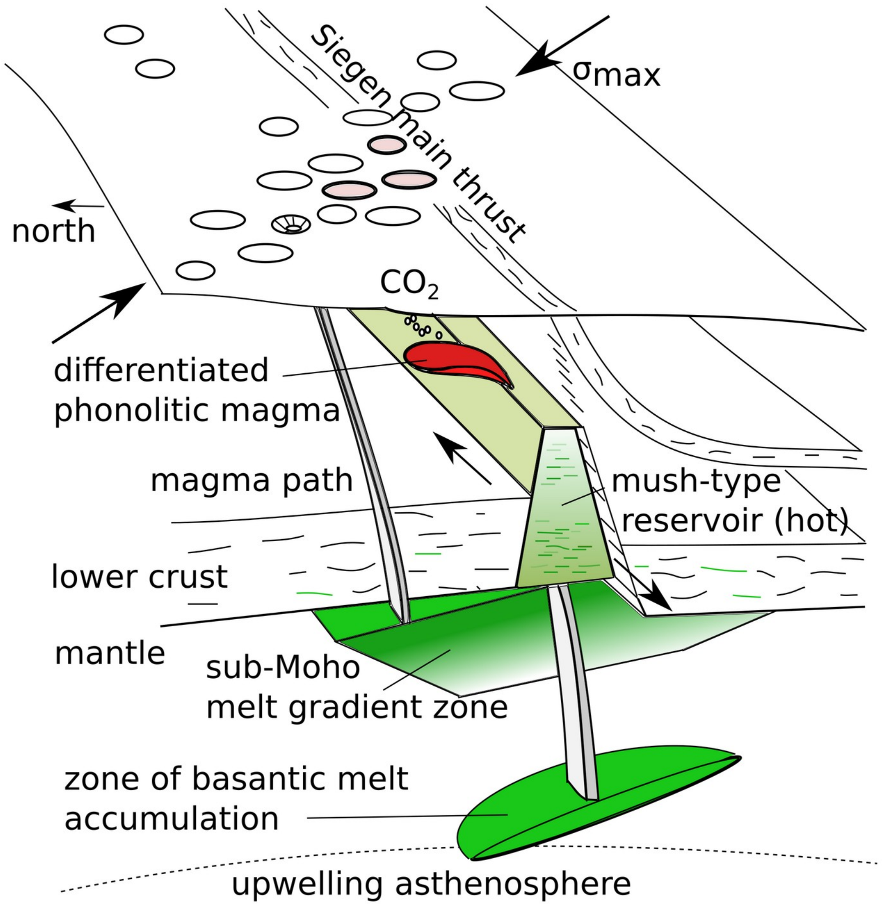
Dahm et al. (2020) G3, 10.1029/2020GC009062

How does a transcrustal magma system look ?

a) Petrological and magmatic constraints



b) tectonic and geophysical constraints



Maare proposal 2021

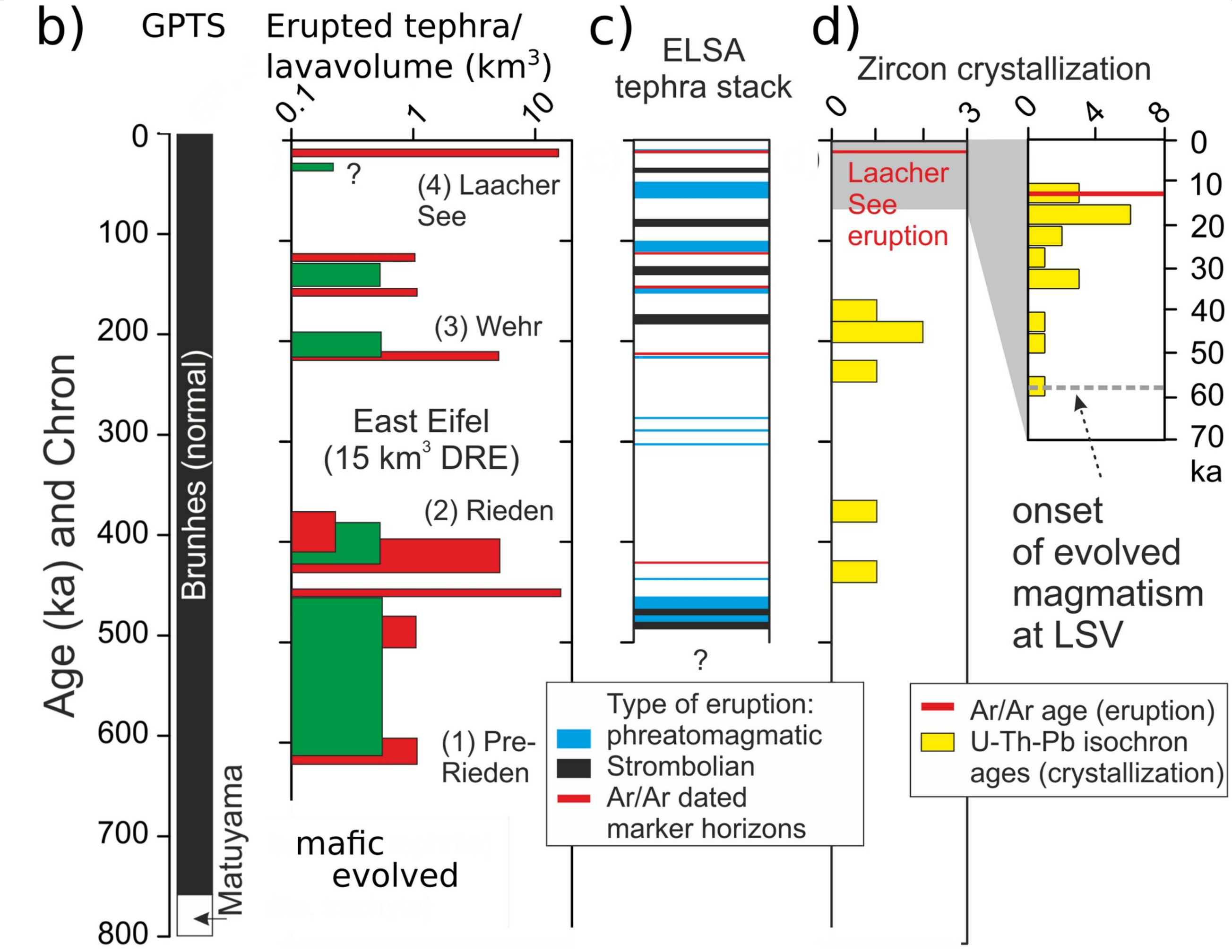
Dahm et al. (2020) G3, 10.1029/2020GC009062

What make Laacher See special ?

… the VEI=6 Plinian eruption 13 ka ago is the largest Quaternary eruption in Central Europe. It likely developed as fast as the Hunga Tonga eruption in 2022, and led to huge Tephra deposits and ash fall all over Europe. Secondary hazards as blocking of the Rhine and huge floods are documented.

We don’t know today where the crustal magma chamber of the Laacher See eruption is sitting and whether it is hot today

Eruption history of evolved, gas-riched magmas at Laacher See system

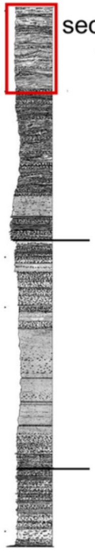


- 3 activity phases indicated in tephra & Zircon crystallization (youngest one started 13 ka bp)
- Effusive and explosive
- Onset of evolved magmatism at LSV ~60 ka bp

How did the 13 ka bp, VEI 6 LSV-eruption develop ?

Wingertsberg tephra at Mendig (Foto: Dahm)

Laacher See Tephra

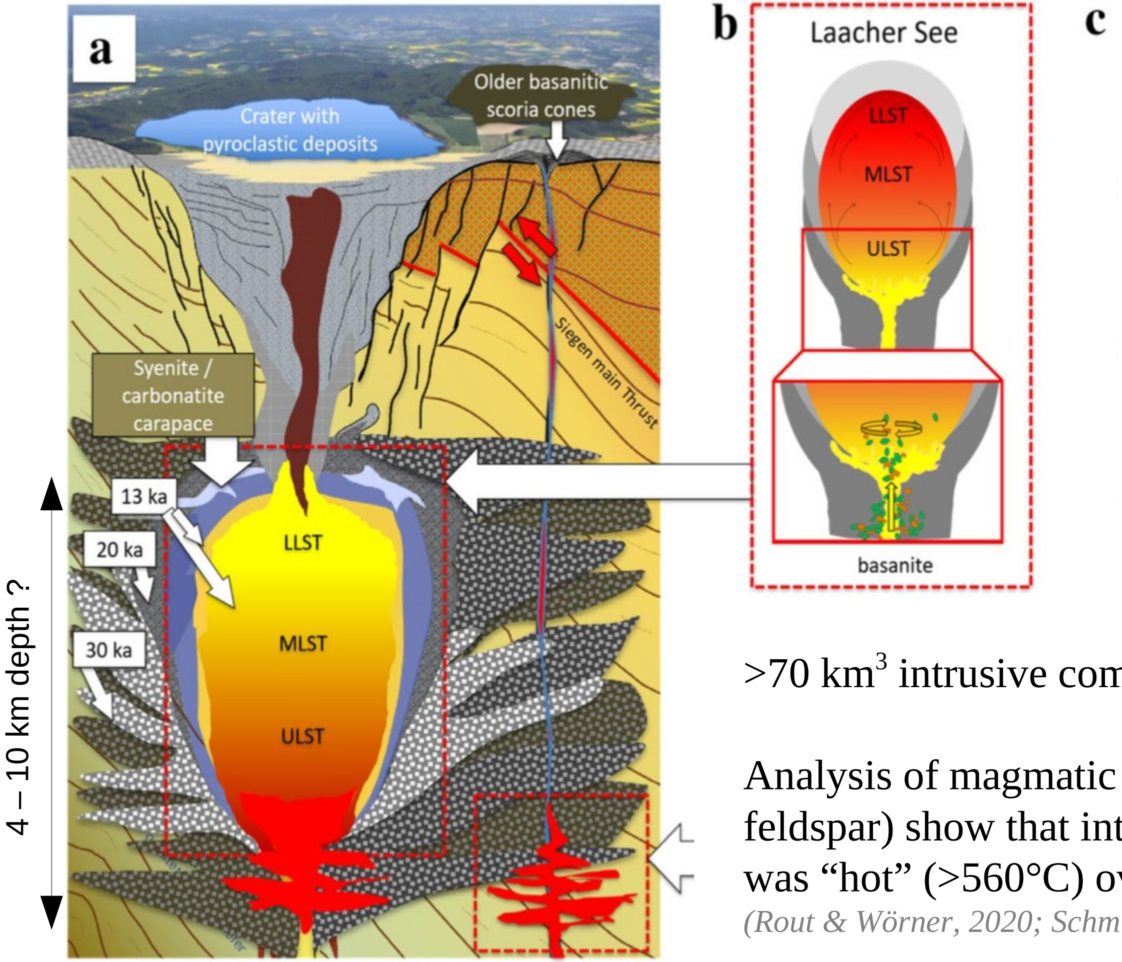


section sampled
for hybrids

upper (ULST)

middle (MLST)

lower tephra (LLST)



Sundermeyer et al. (2020)

Hours - days:
phonolite-basanite mingling & mixing

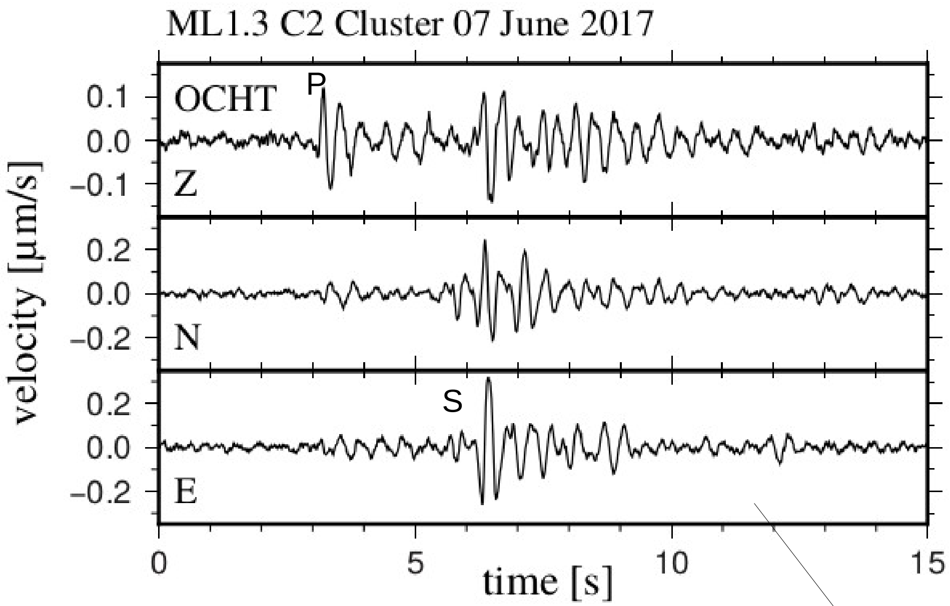
< 415 days:
basanite- basanite mixing

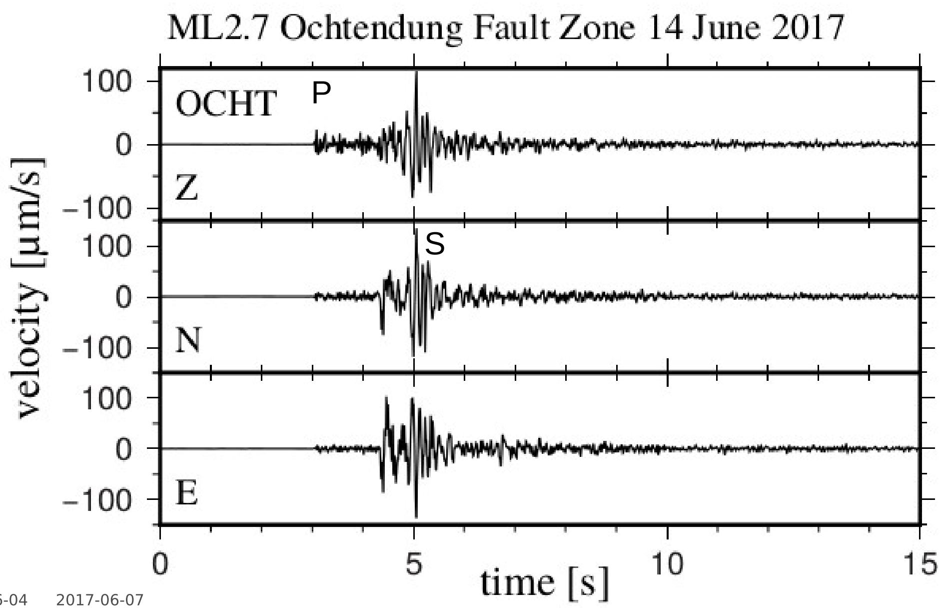
>70 km^3 intrusive complex accumulated

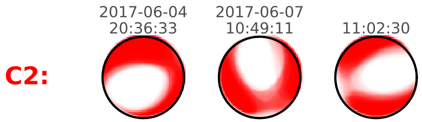
Analysis of magmatic carapace (zoned feldspar) show that intrusive complex was “hot” (>560°C) over > 63 ka

(Rout & Wörner, 2020; Schmitt et al., 2022)

Deep Low Frequency Earthquakes

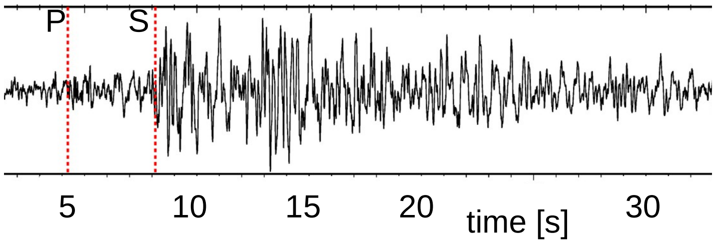






typical mechanism, 50%-80% double-couple

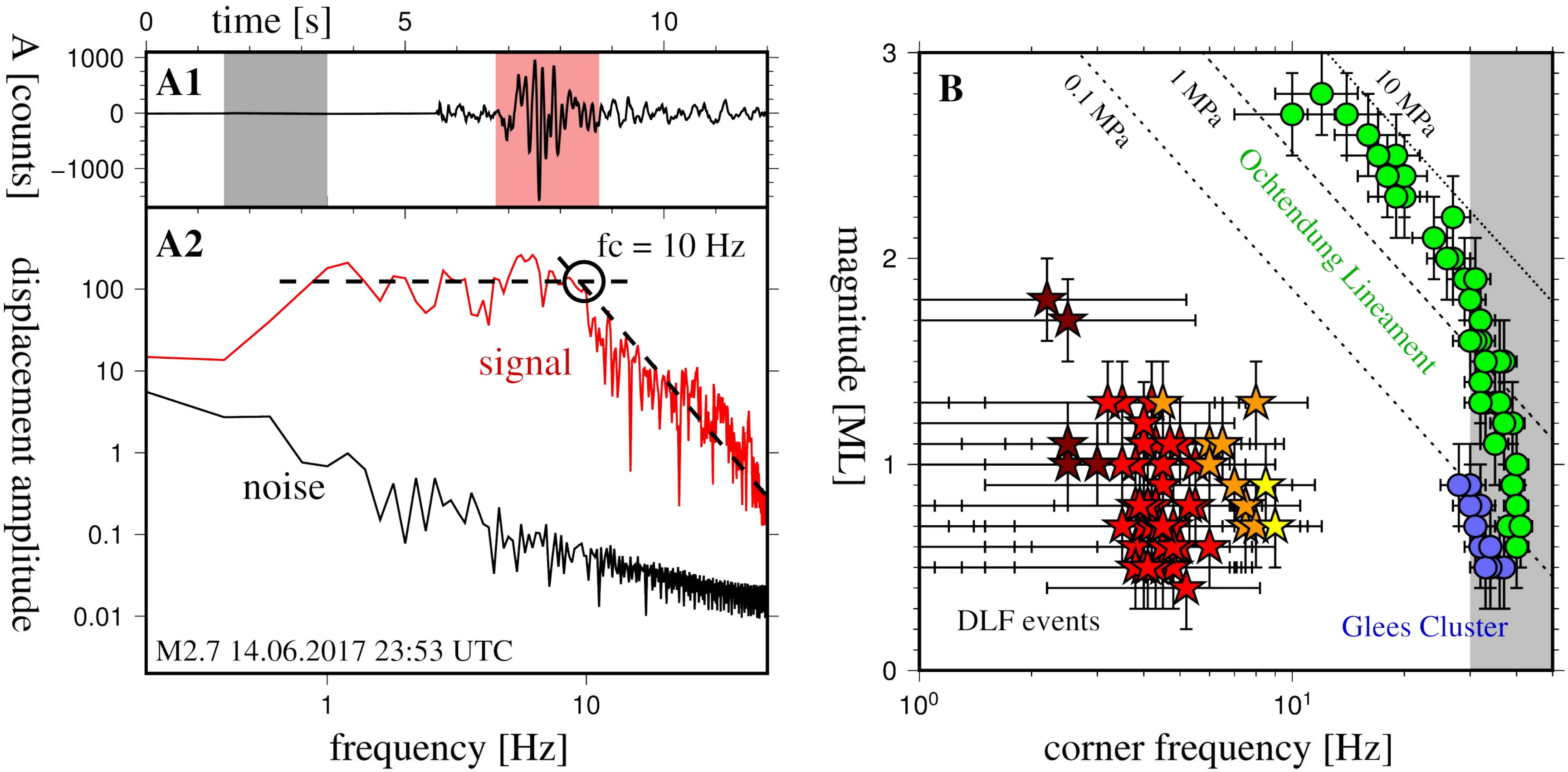
Tornillo signal, 6.5.2021, > 25 sec duration



- S-P time is 2-3.5 sec (distance to EQ is 16-30 km)
- tectonic EQ : M=2.7, radiates high frequencies
- DLF lower crust : M=1.3, low frequency
- tornillo at Moho : M=1.4, low frequency, long duration

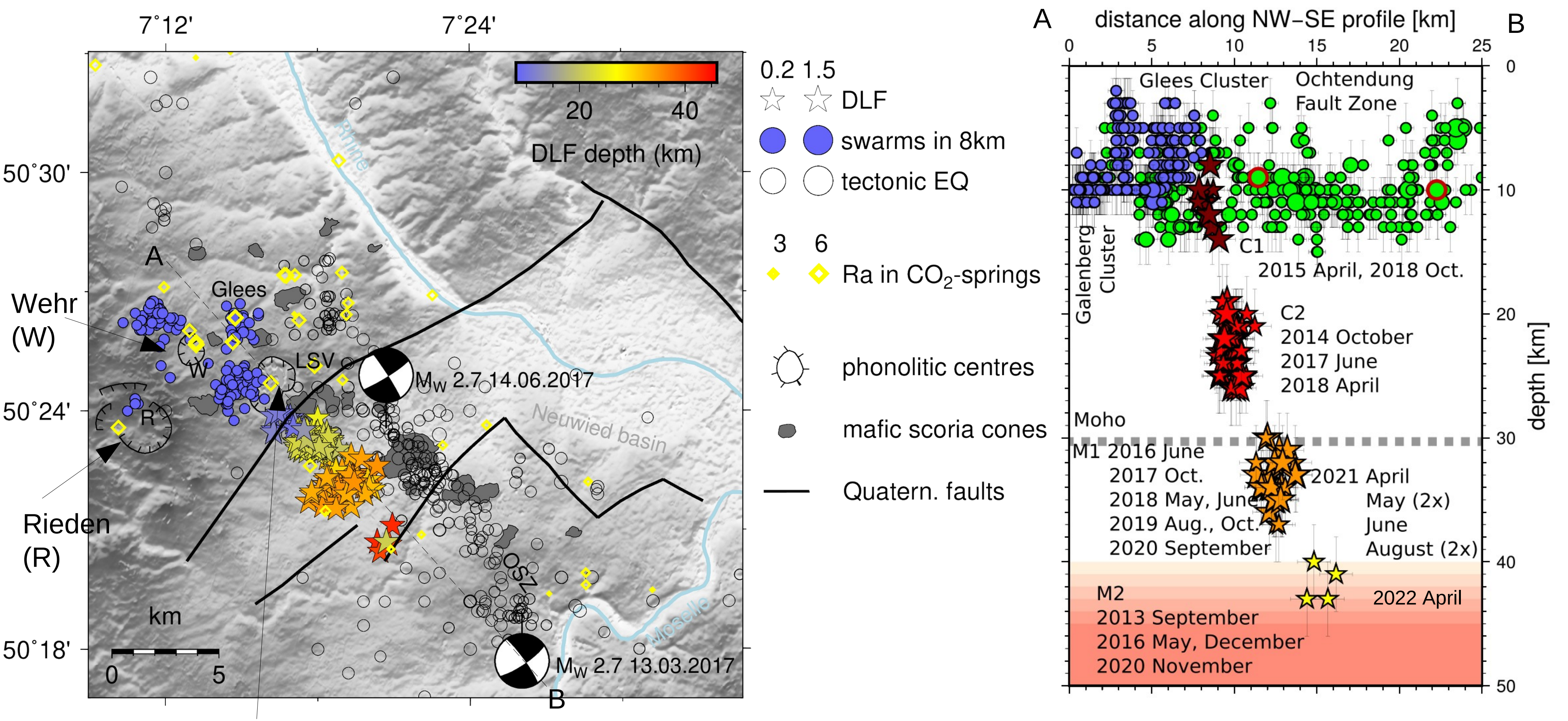
Hensch et al., 2019

Corner frequencies unusual low



Hensch et al., 2019

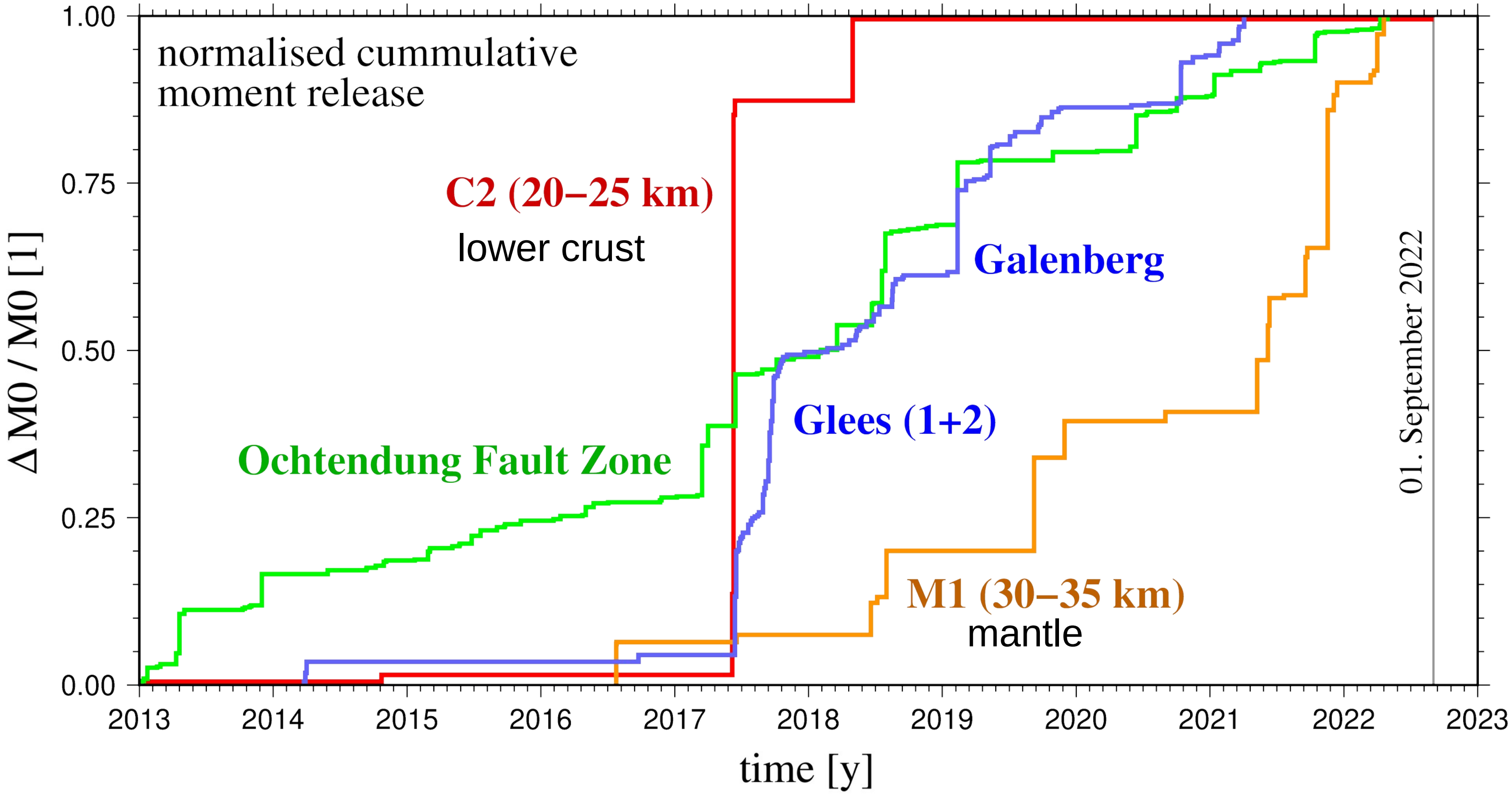
The distribution of DLF earthquakes beneath the Laacher See



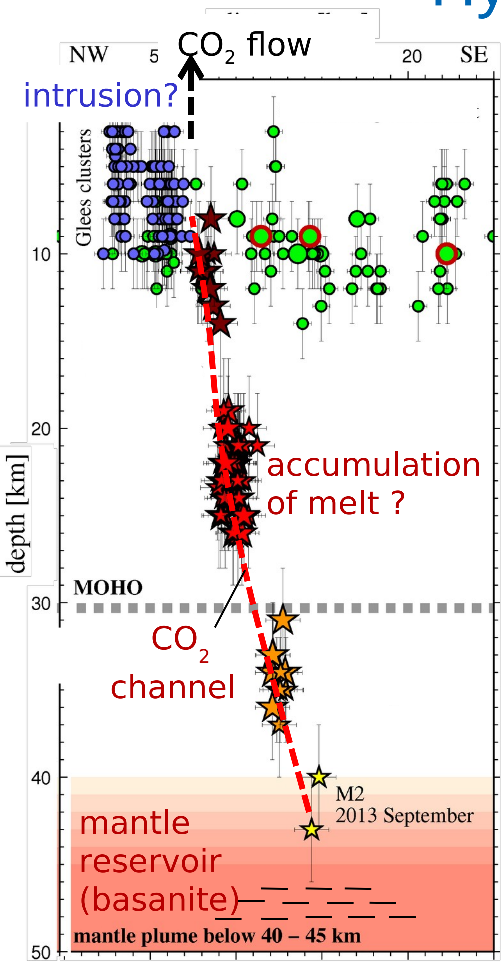
Laacher See Volcano (LSV): VEI 6 eruption 13 ka

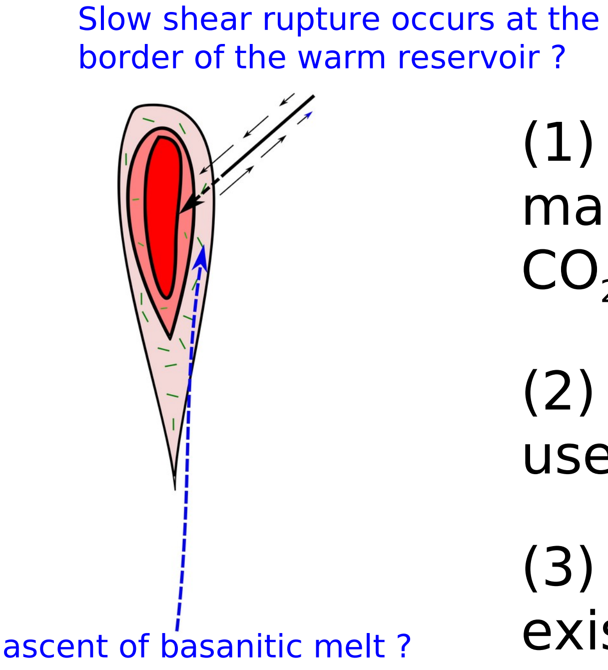
- since 2013: >260 deep low freq. (DLF) earthquakes in 4 depth cluster
- since 2016: local uplift transient at Glees between LSV and W

Moment release of DLF in crust and mantle (2013-2022)



Hypothesis on DLFs generation mechanism





(1) DLF earthquakes indicate that magmatic fluids ascent through CO_2-channel

(2) Channel may occasionally be used by basanitic melts(≈60 m/d?)

(3) Reaction and heating of the existing melts may increase pressure, which can induce bursts of DLF earthquakes

Measures to improve monitoring: Multiparameter station in the Eifel

1. Glees

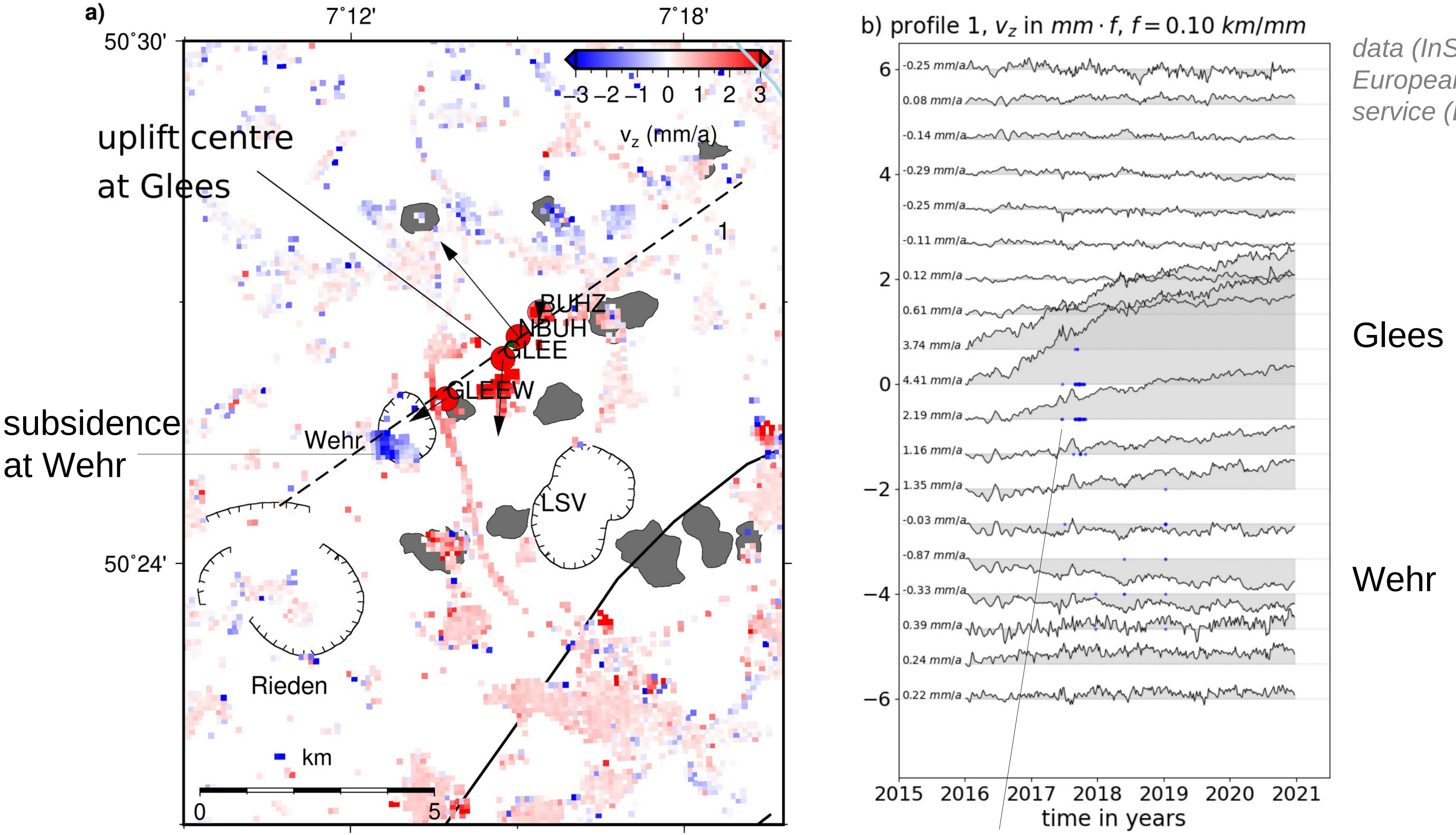
2. Buchholz Probstei

3. Mendig airport

- GNSS
- Corner reflectors
- Seismometer (borehole)
- Tilt meter
- Fluid monitoring
- Gravity measurement point

MoU between GFZ, Geological and Geodetic Surveys of RLP

Ground velocity (v_z) shows localized uplift at Glees since ~2017

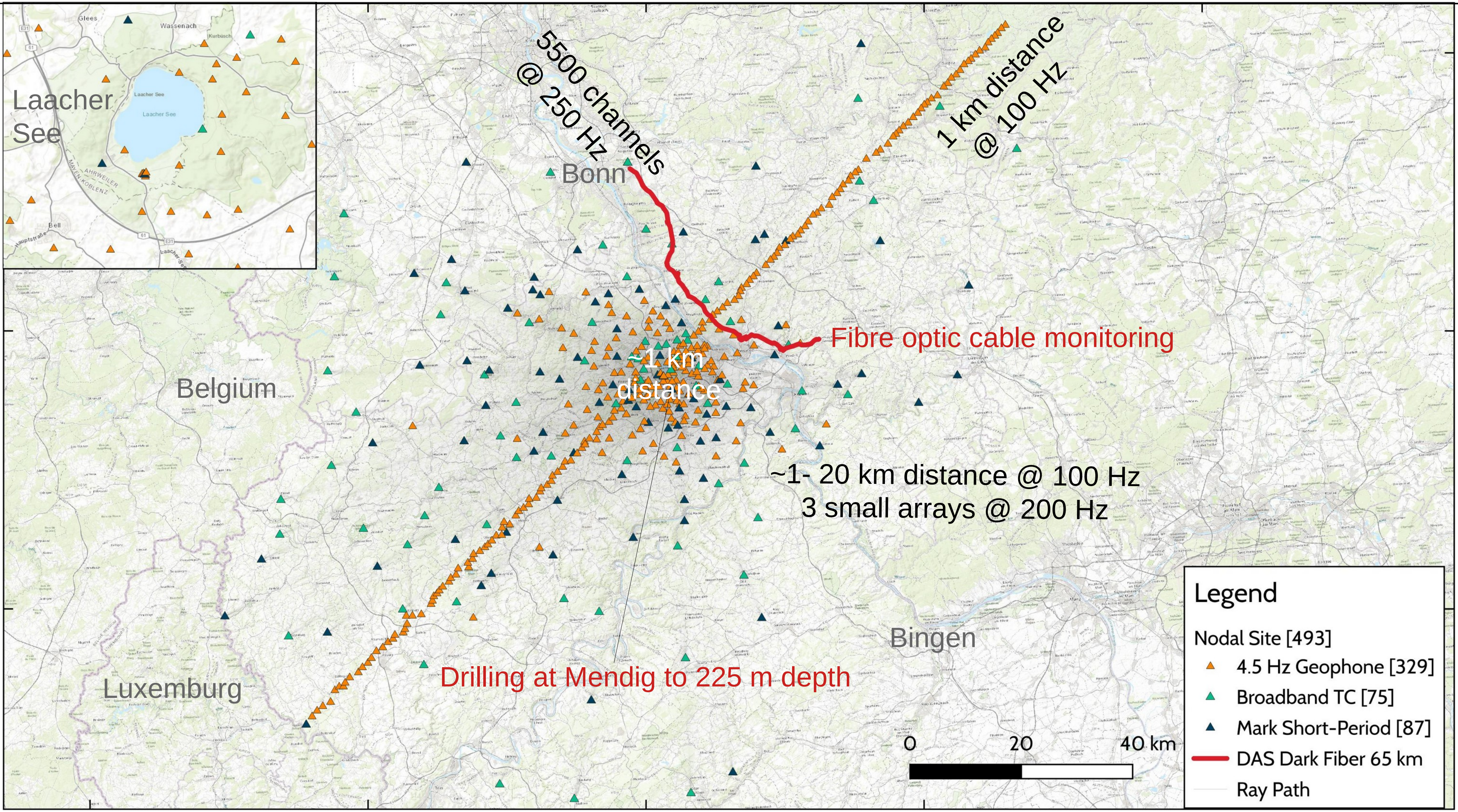


data (InSAR-based) from European Ground Motion service (EGSM)

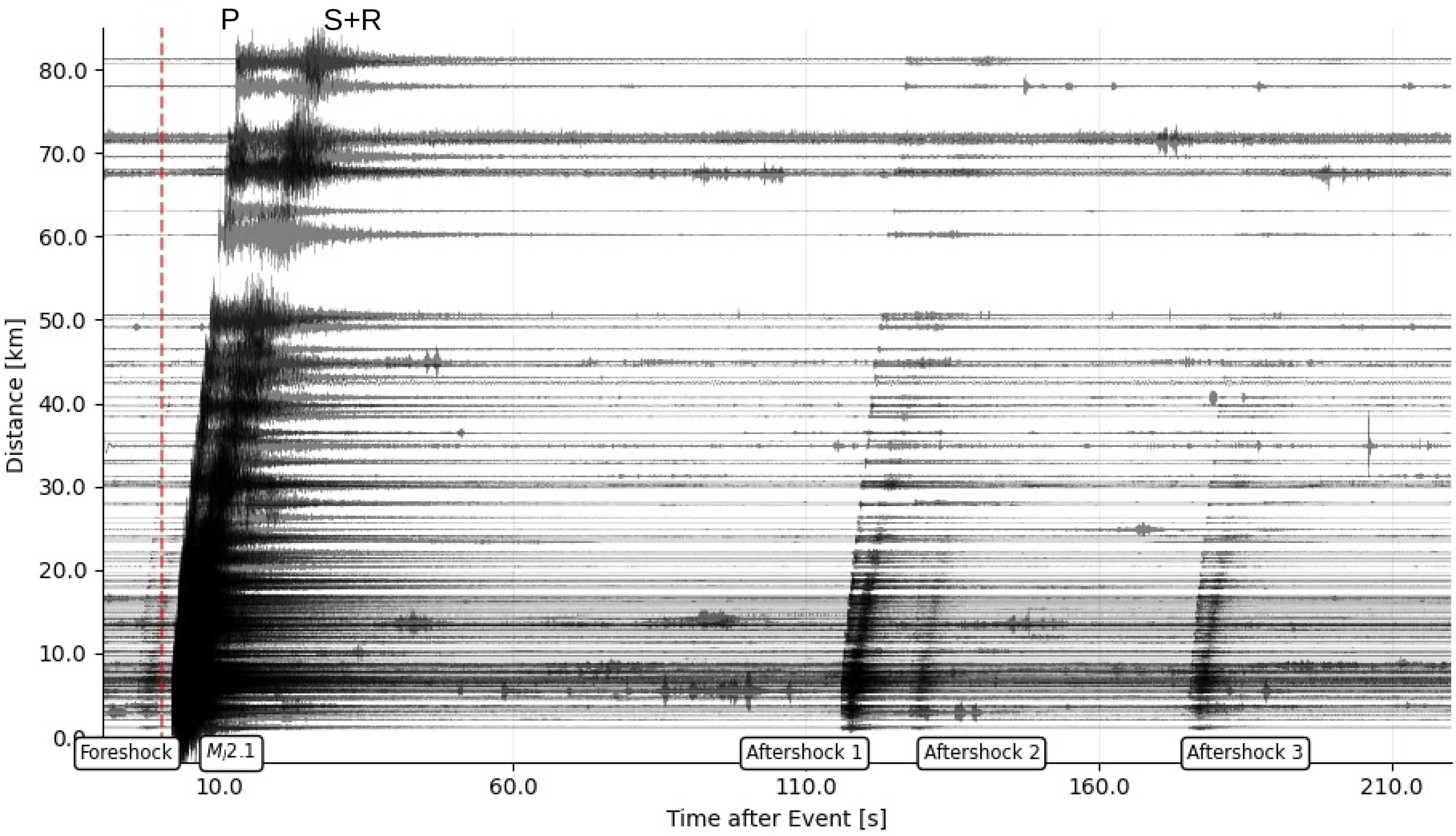
blue dots: earthquakes

figure from Deng et al., in review

The Eifel Large-N experiment: resolving transcrustal magmatic systems



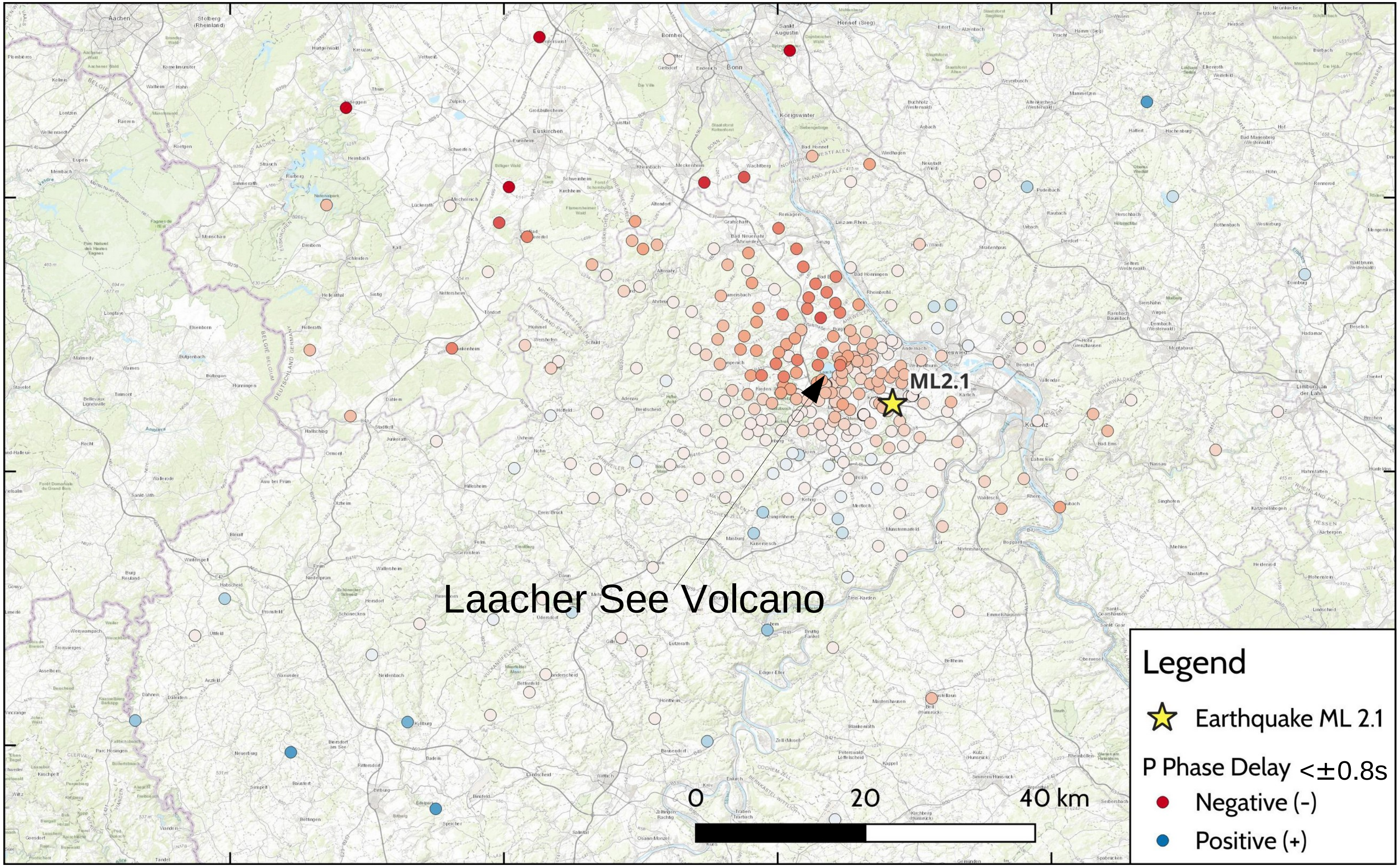
Example: earthquakes sequence at Plaidt, ~12 km depth



Large delay times of rays through upper crust beneath the Laacher See

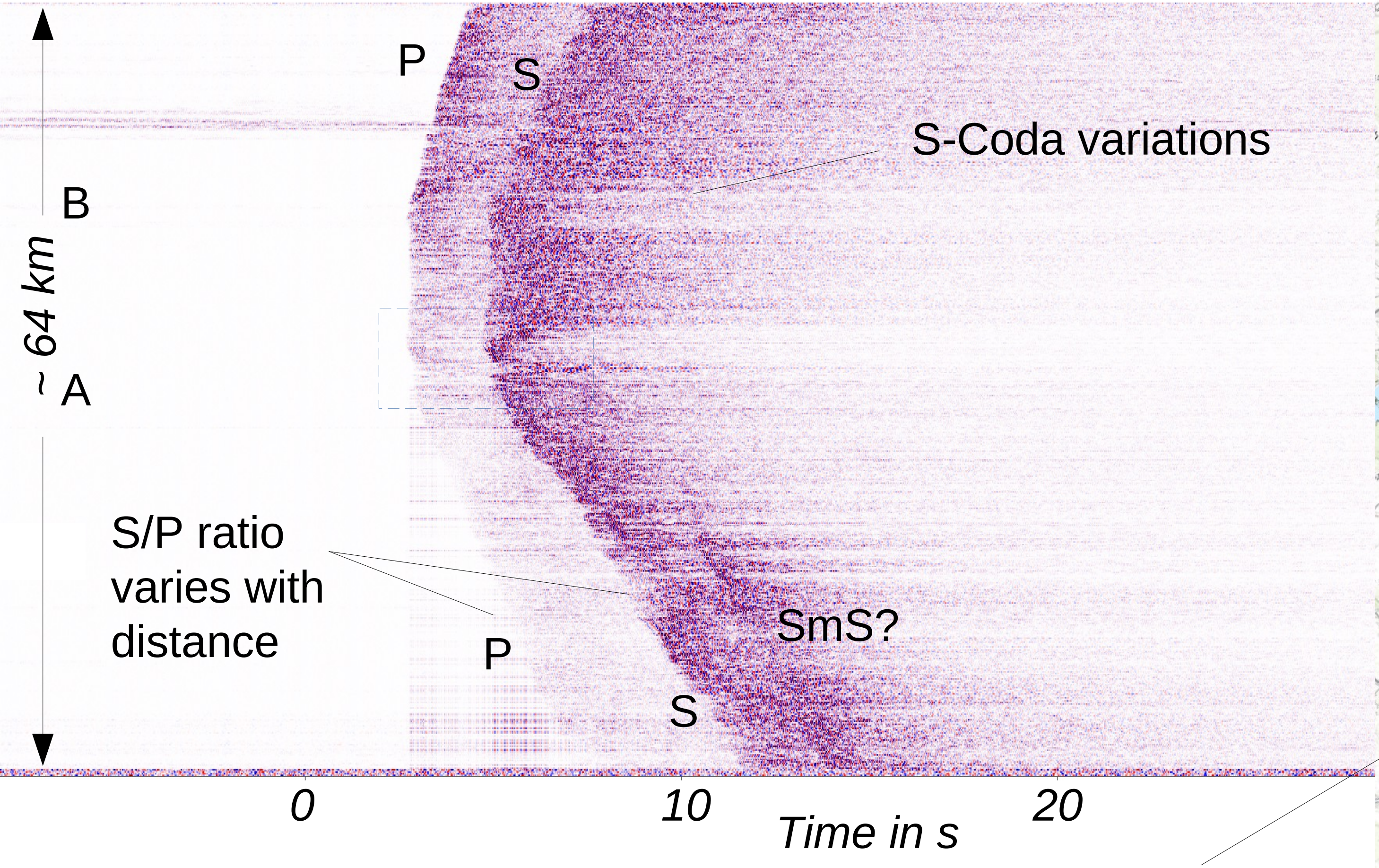
P-picks estimated with “SeisBench” (Münchmeier et al.) *based on PhaseNet*

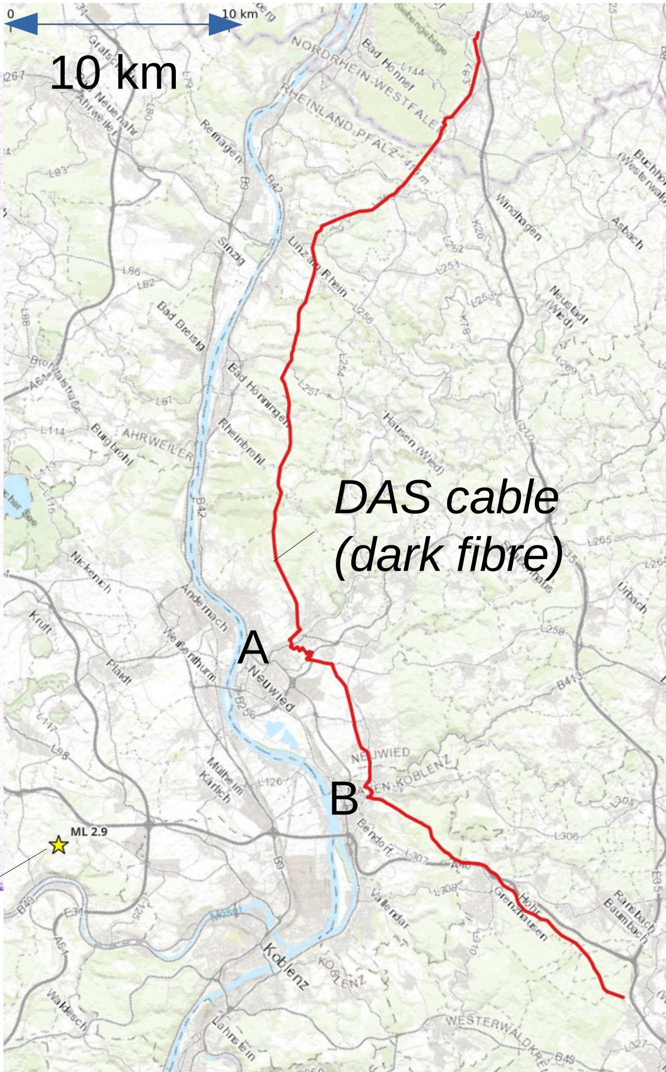
Earthquake (M 2.1) in 12 km depth



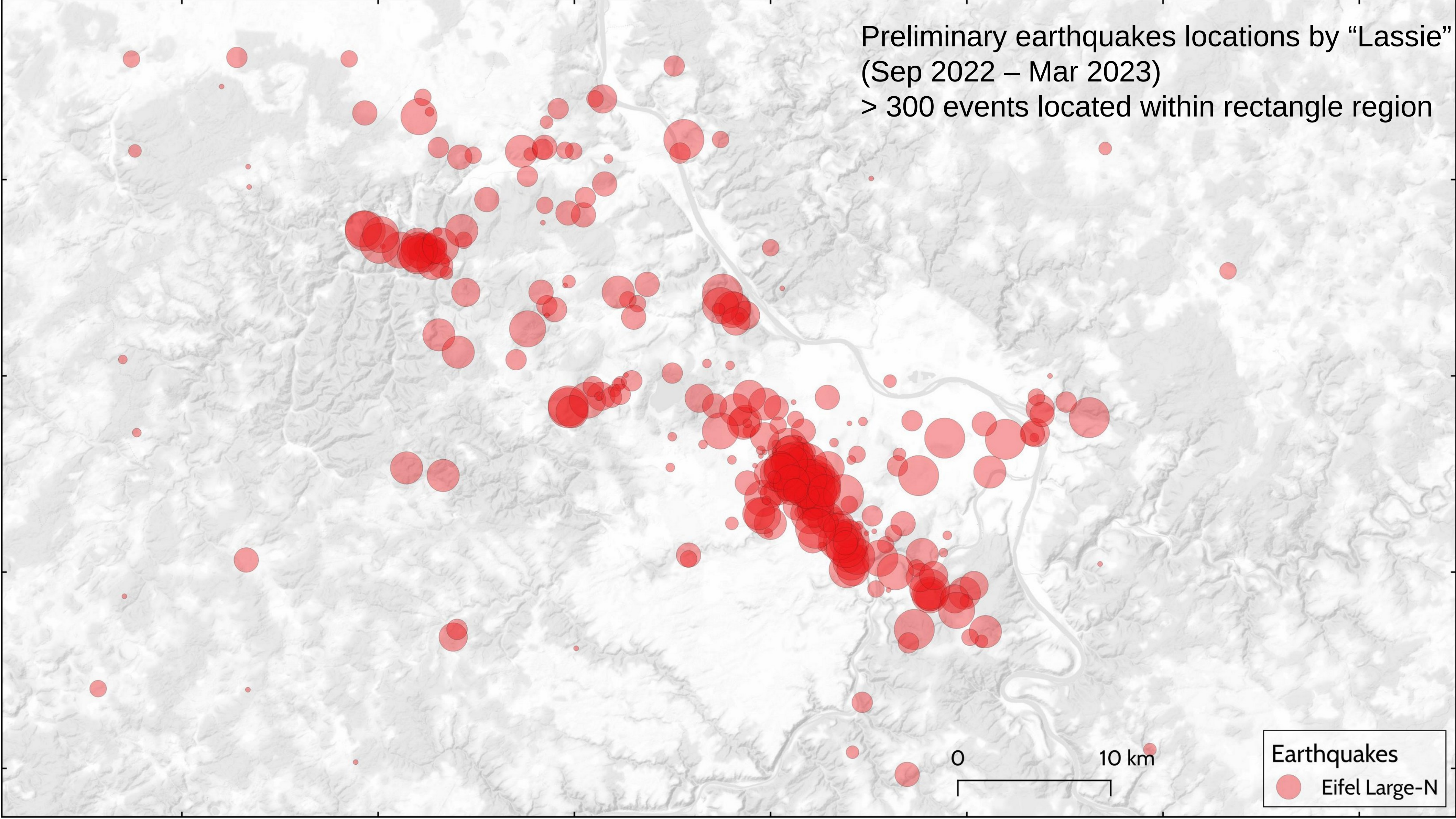
Ml 2.9 earthquake recorded on 64 km long fibre optic cable (DAS)

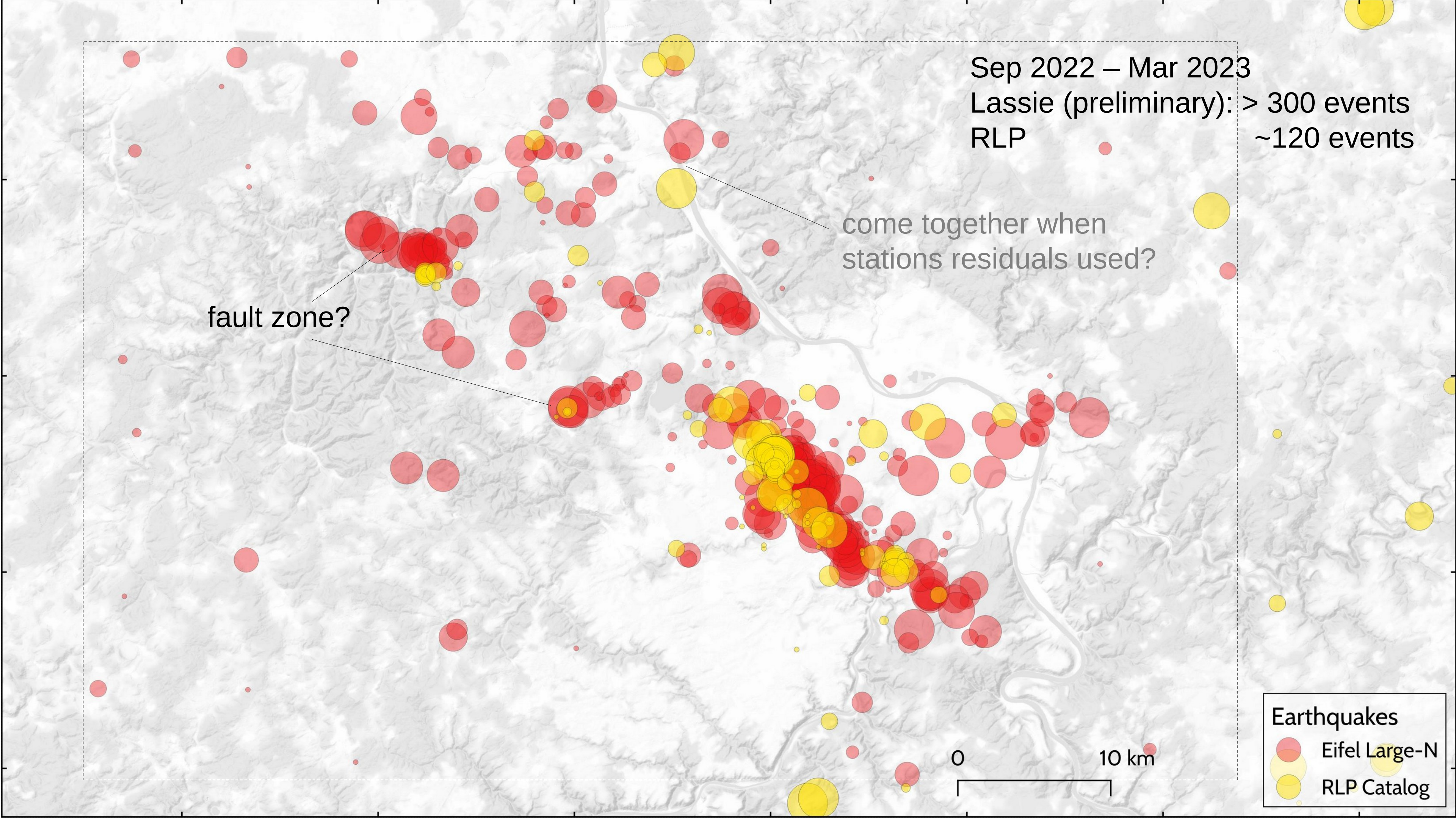
5500 channels (Δx=~12 m), @250 Hz, strain rate, filtered @ 10Hz





18. April 2023, Ml 2.9, ~12 km

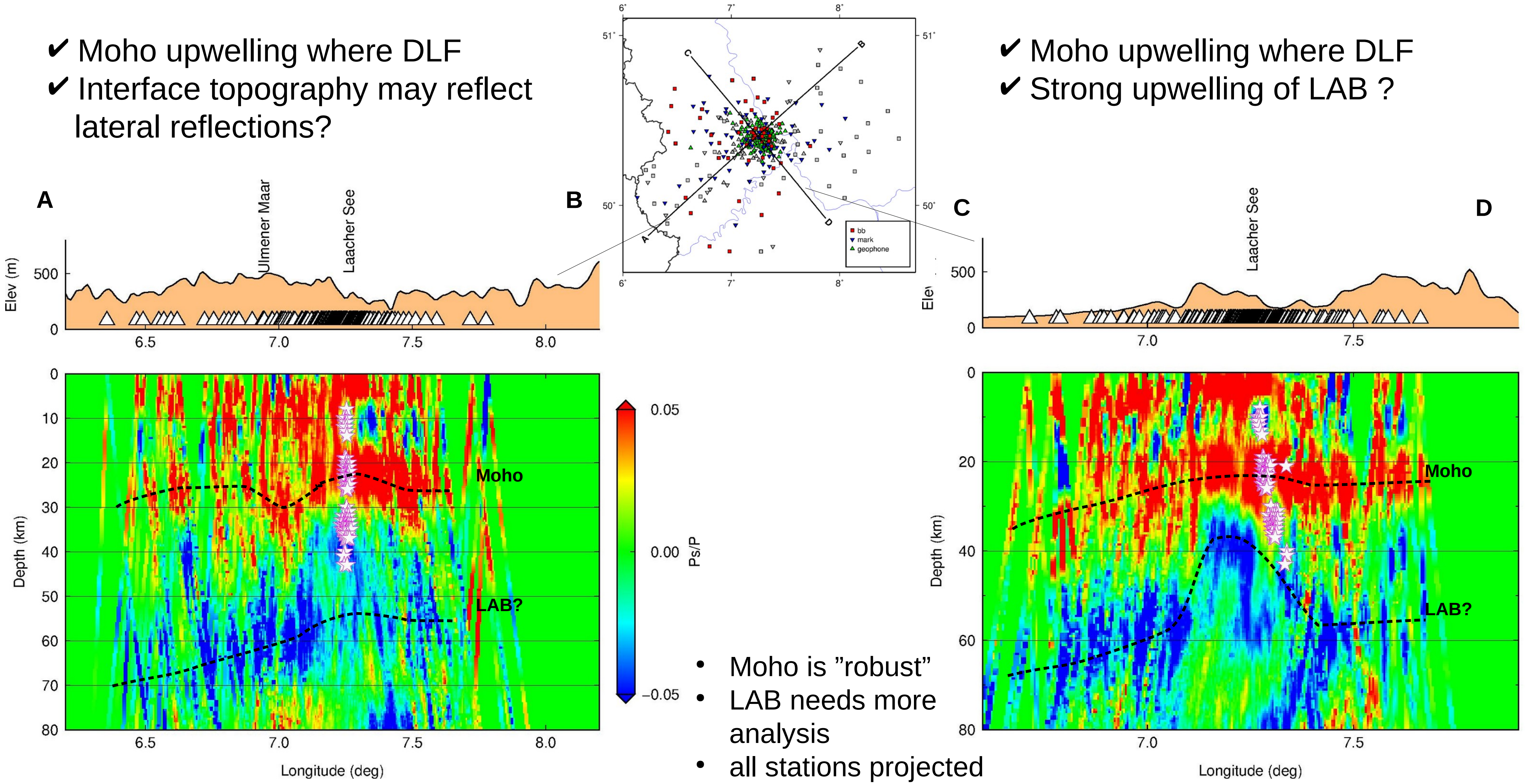

Preliminary earthquakes locations by “Lassie”
(Sep 2022 – Mar 2023)
> 300 events located within rectangle region
0
10 km
Earthquakes
Eifel Large-N


Sep 2022 – Mar 2023
Lassie (preliminary): > 300 events
RLP ~120 events
come together when
stations residuals used?
fault zone?
0
10 km
Earthquakes
Eifel Large-N
RLP Catalog

Deeper structure (by receiver functions, preliminary)

✔ Moho upwelling where DLF
✔ Interface topography may reflect lateral reflections?

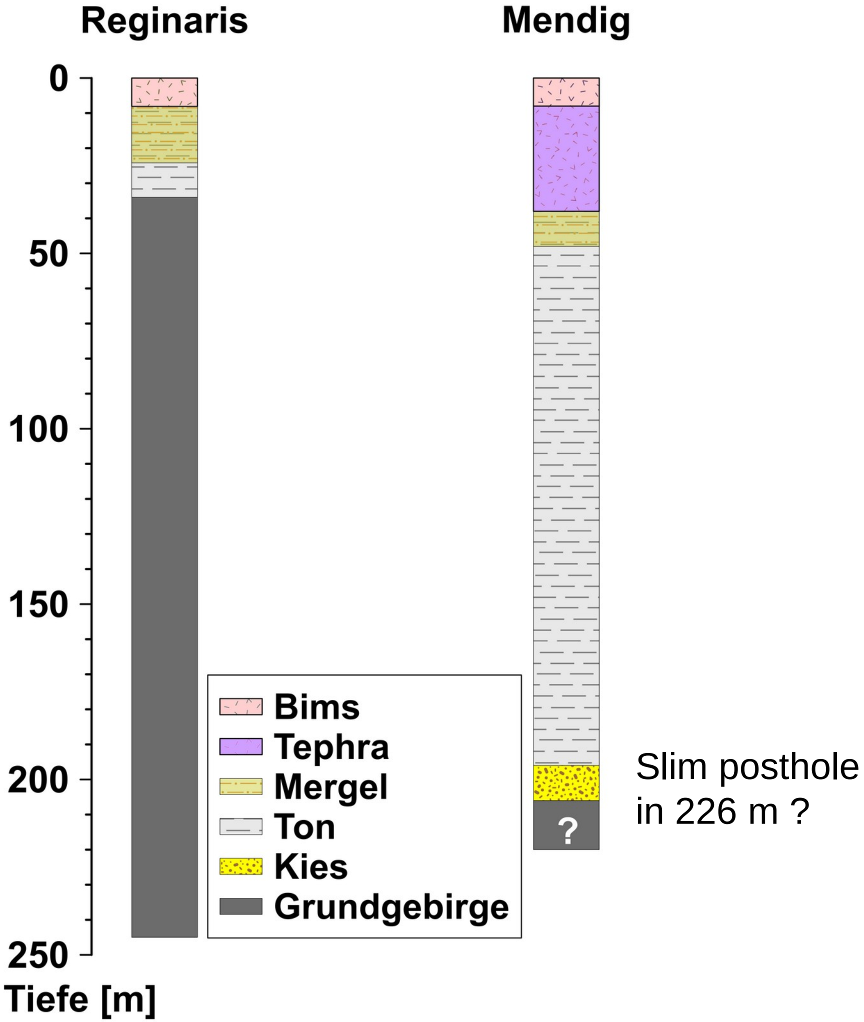
✔ Moho upwelling where DLF
✔ Strong upwelling of LAB ?



- Moho is ”robust”
- LAB needs more analysis
- all stations projected

What next – drilling into a phonolitic reservoir ?

First scientific well (220 m) close to Laacher See to improve seismic montoring



Planned scientific drilling with ICDP: key questions

- Improve fundamental understanding of magmatic transport and storage
- Better assessment of primary and secondary volcanic hazards
- Advance volcano engineering (geothermal energy, extraction of critical/rare elements)
- Use as natural lab to study mineral exchange by CO_2 flushing

Interested ? Register to the planned ICDP workshop 3-5 December 2023

https://www.icdp-online.org/projects/by-continent/europe/eifel-germany/workshops

Summary

- Quaternary volcanoes beneath the Eifel show latent activity in its magmatic system
- Anomalies in lower crust and at Moho indicate possible accumulation of partial melts
- Newest mineral diffusion studies indicate persistent inflow of fresh melts into upper crust
- Large-N passive seismological experiment to study transcrustal magmatic system
- ICDP drilling project planned. Workshop **3-5 Dec 2023** in Bad Honnef, Germany