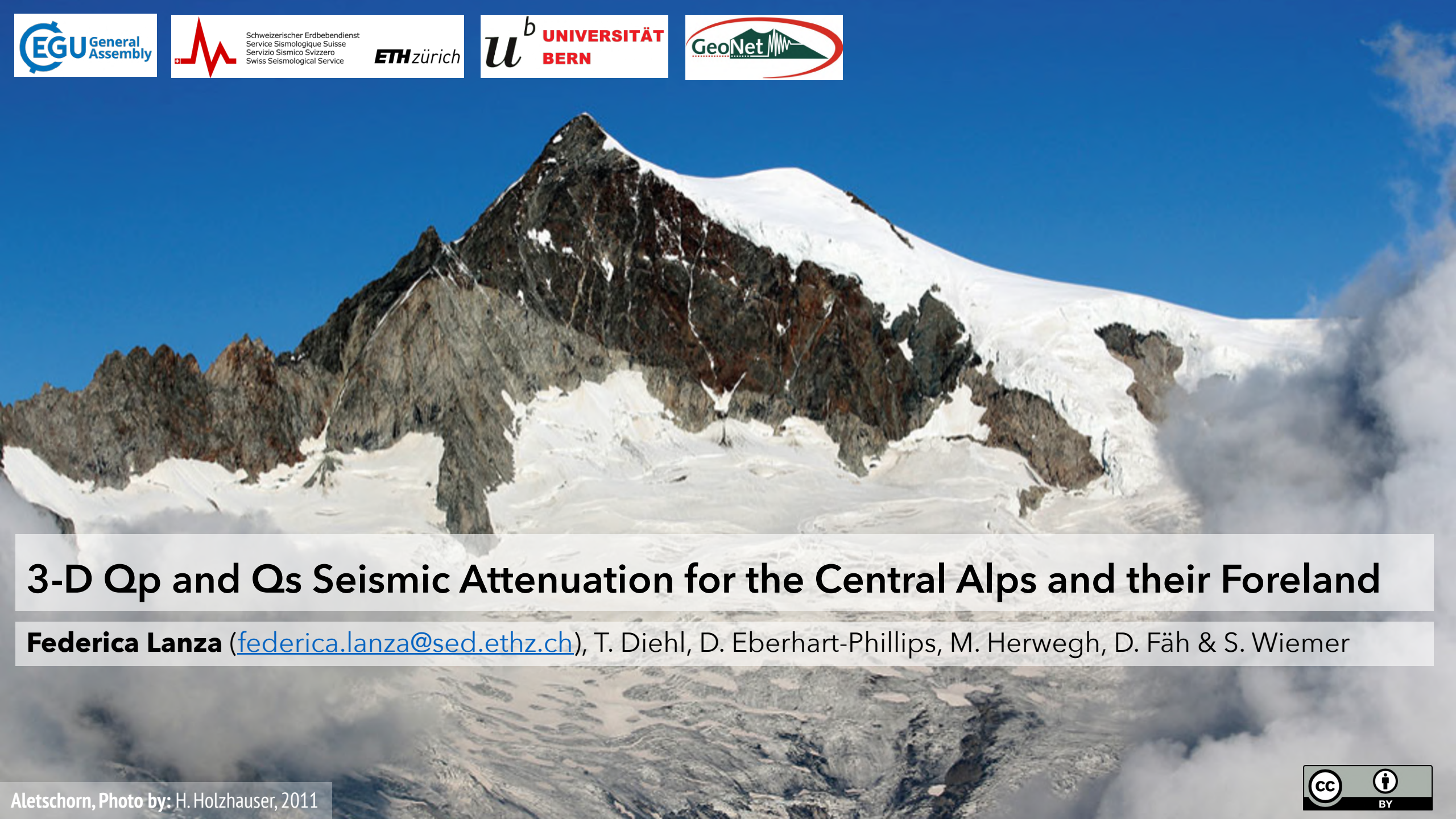


3-D Qp and Qs Seismic Attenuation for the Central Alps and their Foreland

Federica Lanza (federica.lanza@sed.ethz.ch), T. Diehl, D. Eberhart-Phillips, M. Herwegh, D. Fäh & S. Wiemer

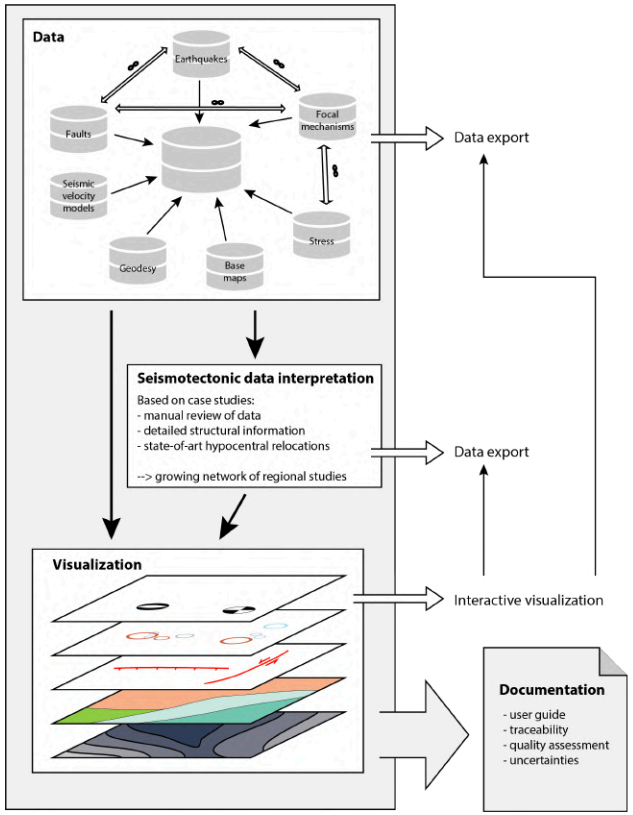
Aletschorn, Photo by: H. Holzhauser, 2011

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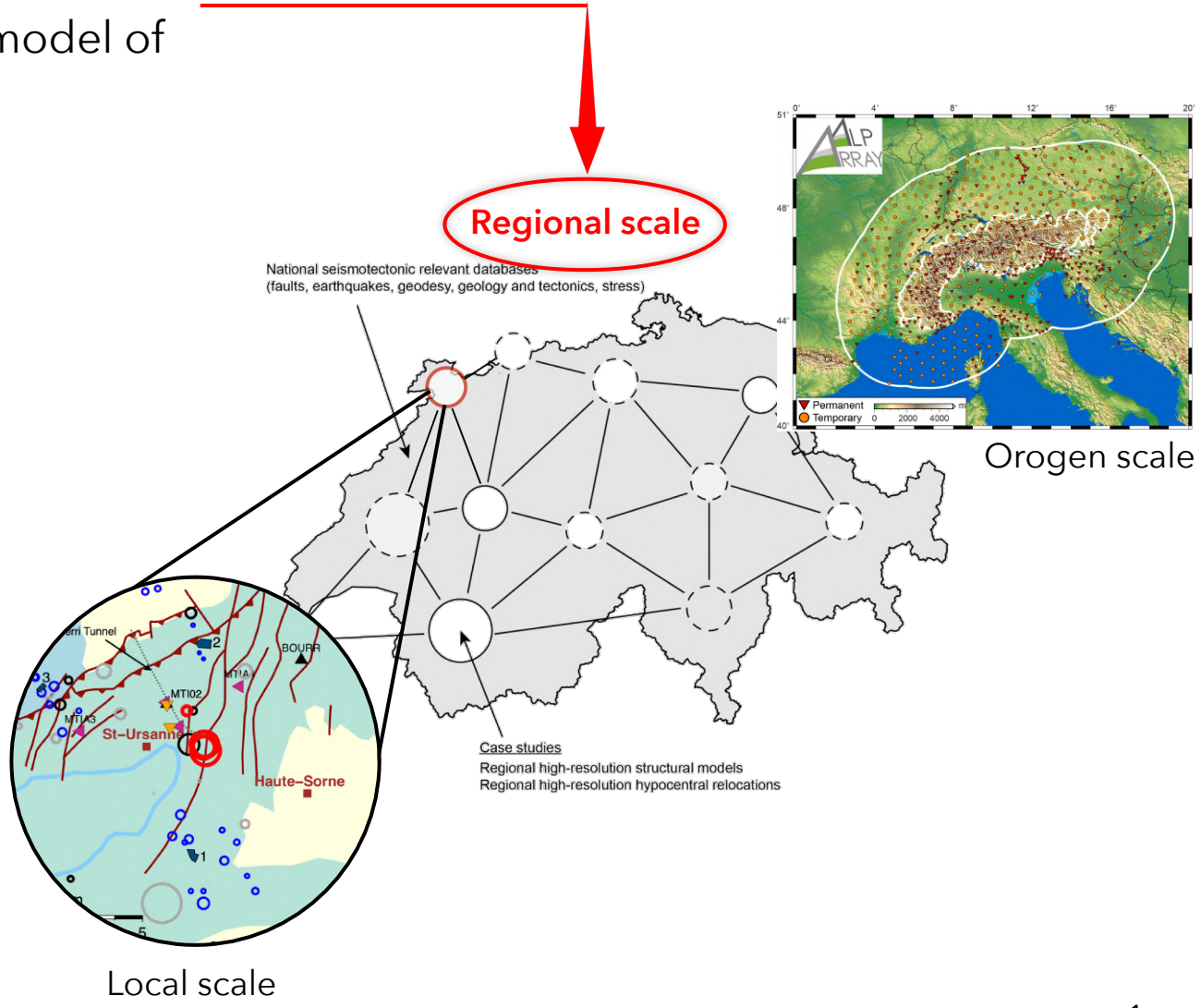
Introduction

This study is a contribution to the **SeismoTeCH project** which aims at advancing our understanding of seismotectonic processes in Switzerland. Here we present the first 3-D attenuation model of the upper crust for the Central Alps and their Foreland.

SeismoTeCH project



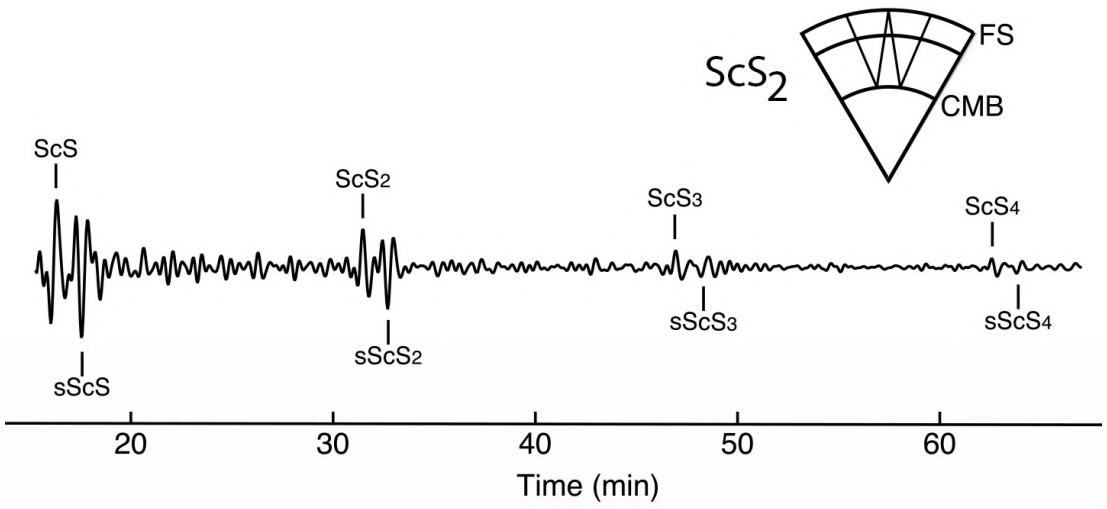
- Joint project between University of Bern, SED, and Swisstopo, funded by the Swiss Geophysical Commission (SGPK).
- Combine:
  - Hypocenter locations,
  - Velocity, Q models,
  - Focal mechanisms and moment-tensors,
  - Faults,
  - Geodetic data,
  - In-situ/regional stress data
- Interactive database



Seismic Attenuation

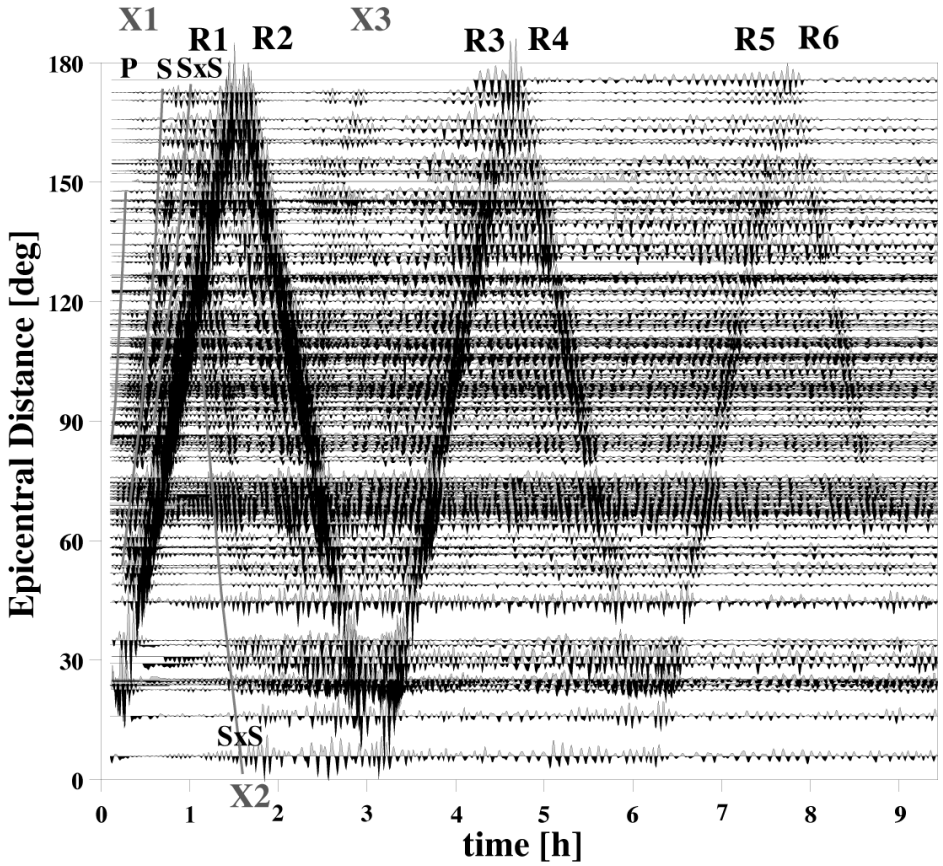
In a perfectly elastic medium, the total energy of the wavefield is conserved. **Seismic (anelastic) attenuation** is the absorption of seismic energy, or the deviation from perfect elasticity.

Body waves



Coutier & Revenaugh [2006]

Surface waves



Widmer & Laske [2007]

Seismic Attenuation Mechanisms

- Attenuation is usually expressed by the **quality factor Q** which describes the **inverse of attenuation**: i.e., high Q regions have low attenuation.

$$\frac{1}{Q} = \frac{\Delta E}{2\pi E}$$

$E = maximal\ energy\ in\ the\ cycle$

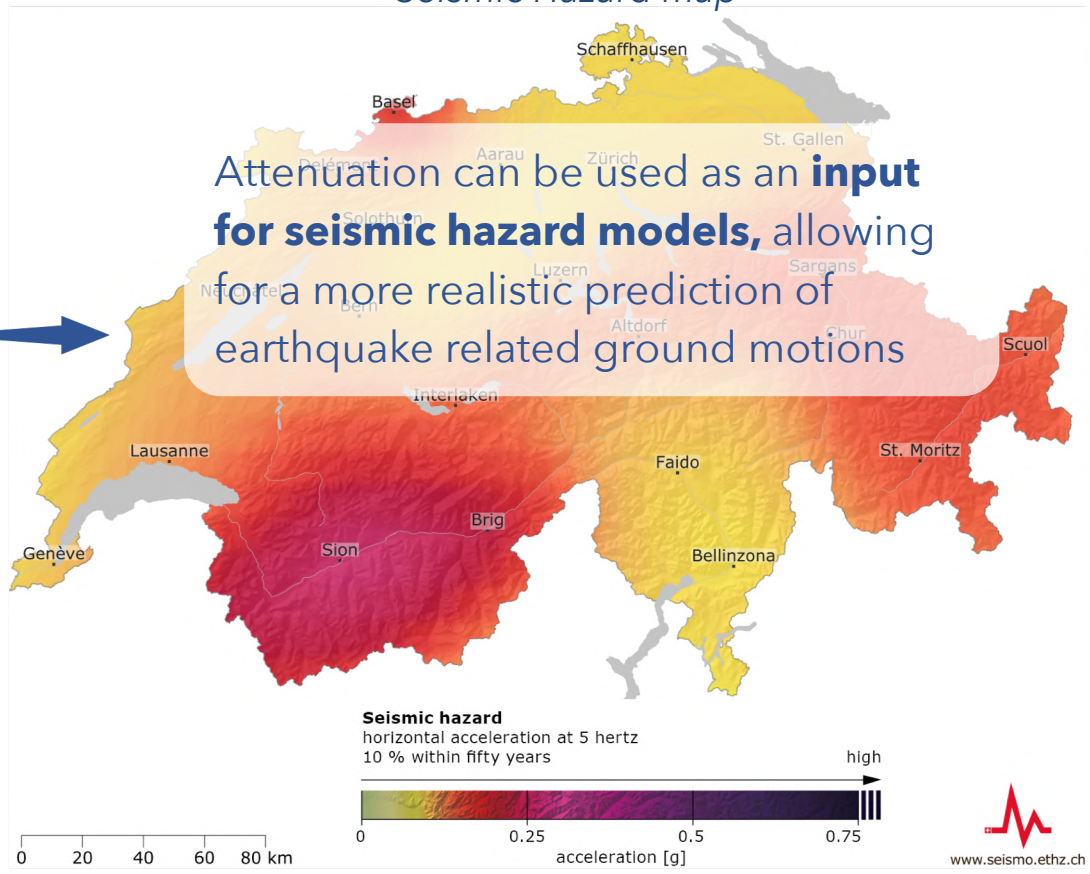
$\Delta E = loss\ of\ energy\ in\ the\ cycle$

- Q patterns may differ from patterns in seismic velocity and may provide new insights into the material properties of a region. Dominant factors in Q variations are due to:

  Cracks, grain boundary sliding phenomena, pore pressure:
  - Q decreases for increased porosity.
  - Q decreases for zones of distributed fractures.
  - Q decreases for high strain zones (grain size reduction)
  - Q decrease for high fluid pressure, but
  - Q increases for high confining pressure (cracks close).

  Rock type:
  - High Q for metamorphic rocks
  - Moderately-to-high Q for limestone, basalt;
  - Moderate-to-low Q for sandstone

Seismic Hazard map



Fitting t* Spectra

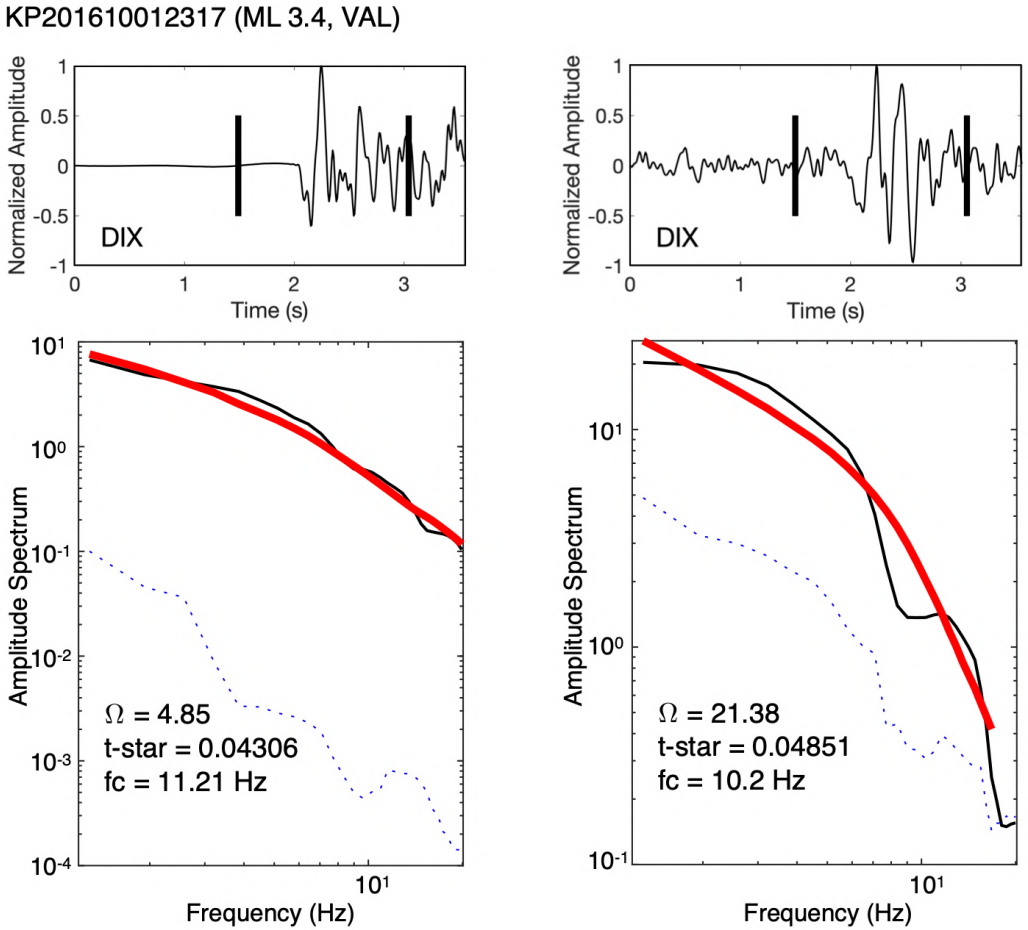
From local earthquake data, attenuation is determined by fitting spectra for the **parameter *t**. Considering the whole path attenuation, and when Q and V vary spatially, *t** is calculated using equation (1); hence, data from local earthquakes are amenable to inversion for 3D Q. *t** is related to Q by equation (2).

$$t^* = \int_{ray} ds/[Q(s) * V(s)] \qquad \textbf{(1)}$$

$$\ln[\mathrm{A}(f_i)] = \ln(\Omega_0) + \ln[S(f_i)] - \ln\left[1 + \left(\frac{f_i}{f^c}\right)^2\right] + (-\pi f_i t^*) \qquad \textbf{(2)}$$

where $\mathrm{A}(\mathrm{f_i})$ = observed amplitude spectra at frequency $\mathrm{f_i}$
Ω_0 = low-frequency plateau amplitude
$\mathrm{f^c}$ = corner frequency
$\mathrm{S(f_i)}$ = site response term at frequency $\mathrm{f_i}$

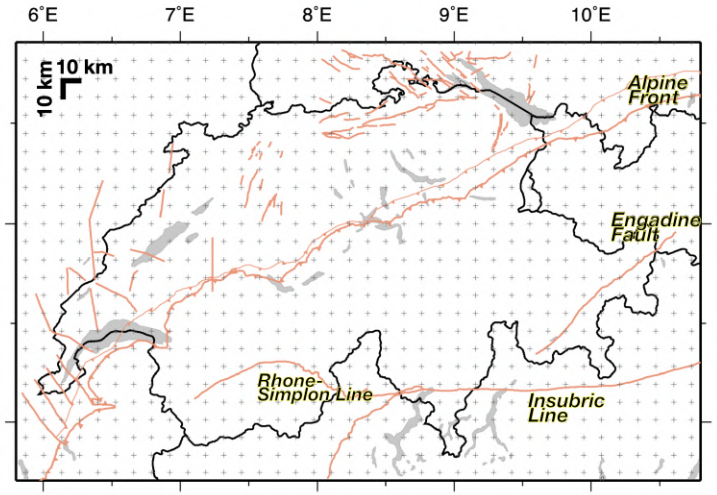
- Here, t* are calculated using a simultaneous joint inversion scheme for attenuation, source parameters, and site response for all events and stations.
- **Frequency-independent** approximation in the *t** calculation is assumed.



Body wave (P, S) Attenuation Tomography

Data source: frequency-independent t* values (integrated value of 1/Q along the ray path)

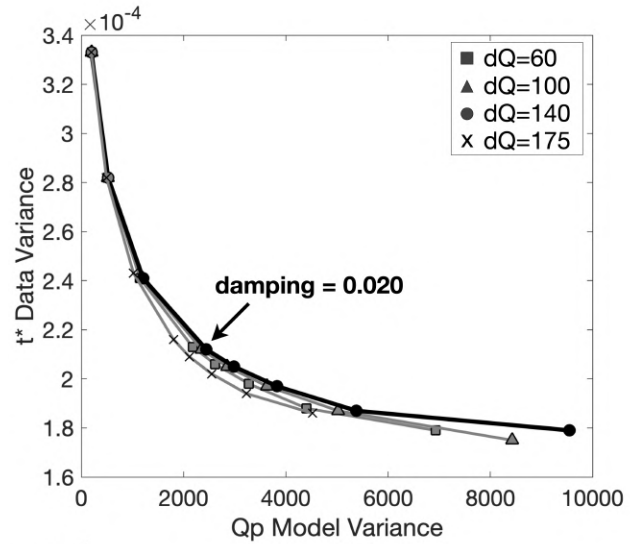
(1)



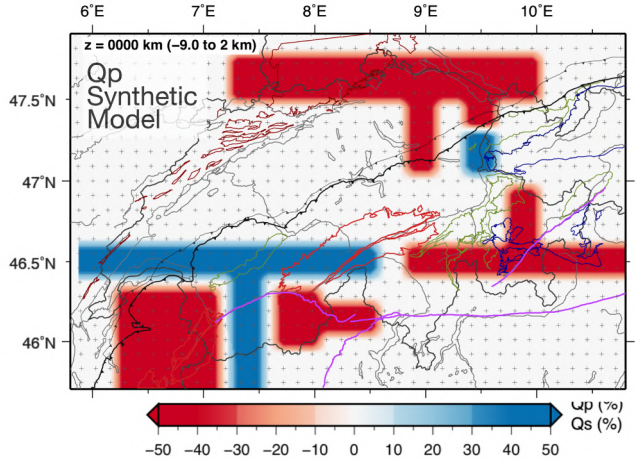
Inversion Method:

1. Regular horizontal grid spacing of 10 x 10 km and a vertical spacing of 4-5 km).
2. Optimal damping values from multi-iteration trade-off curves (L curves).
3. Synthetic tests to attest resolution in addition to Derivative Weighted Sum (DWS) and Spread Function obtained directly from the inversion.

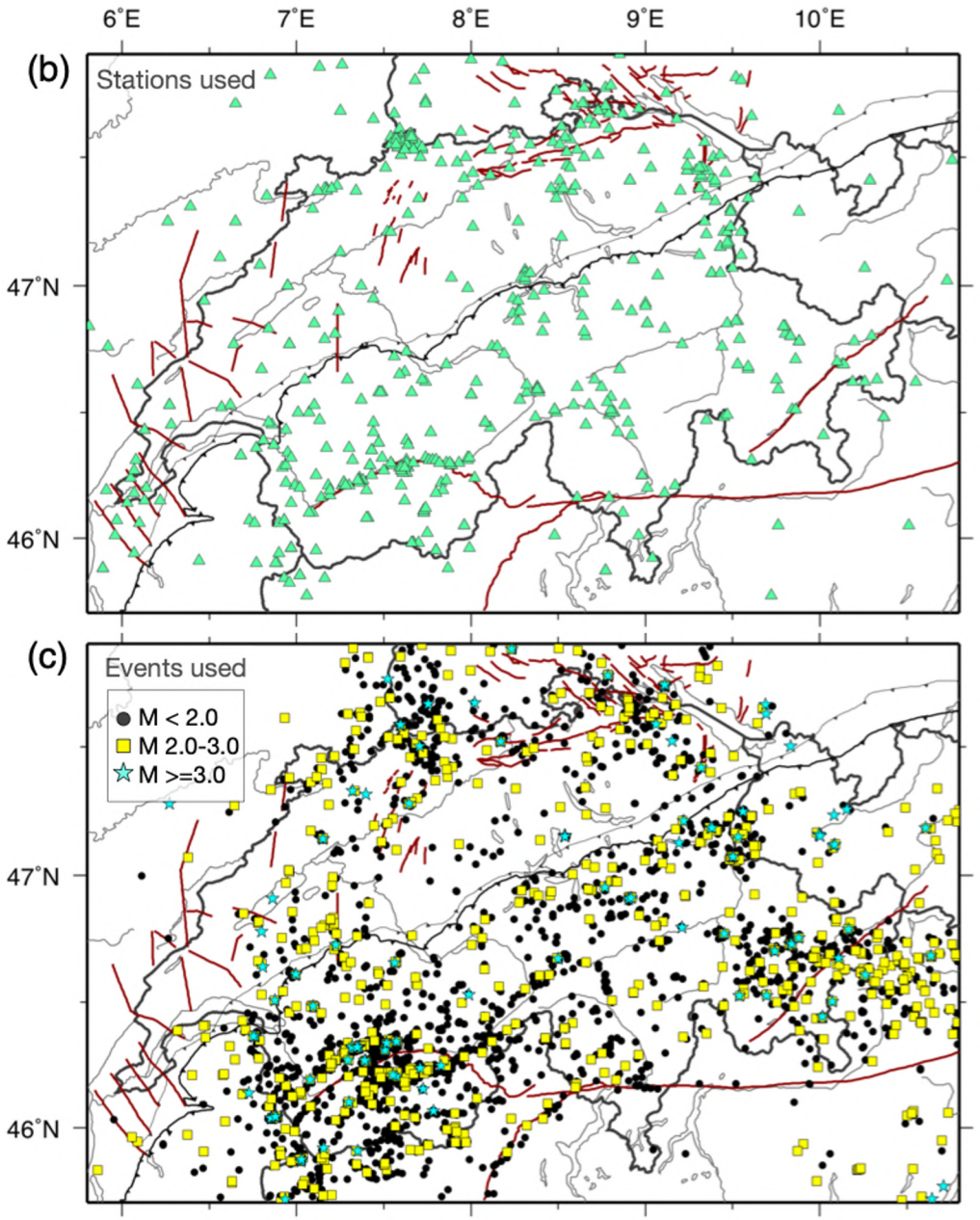
(2)



(3)

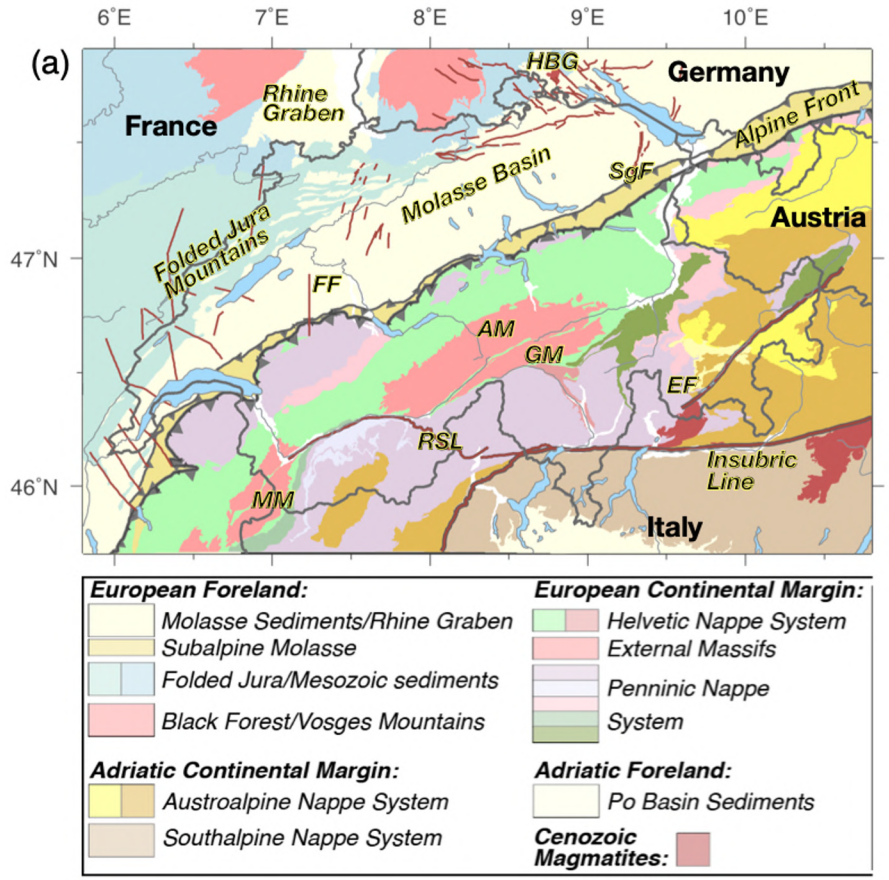


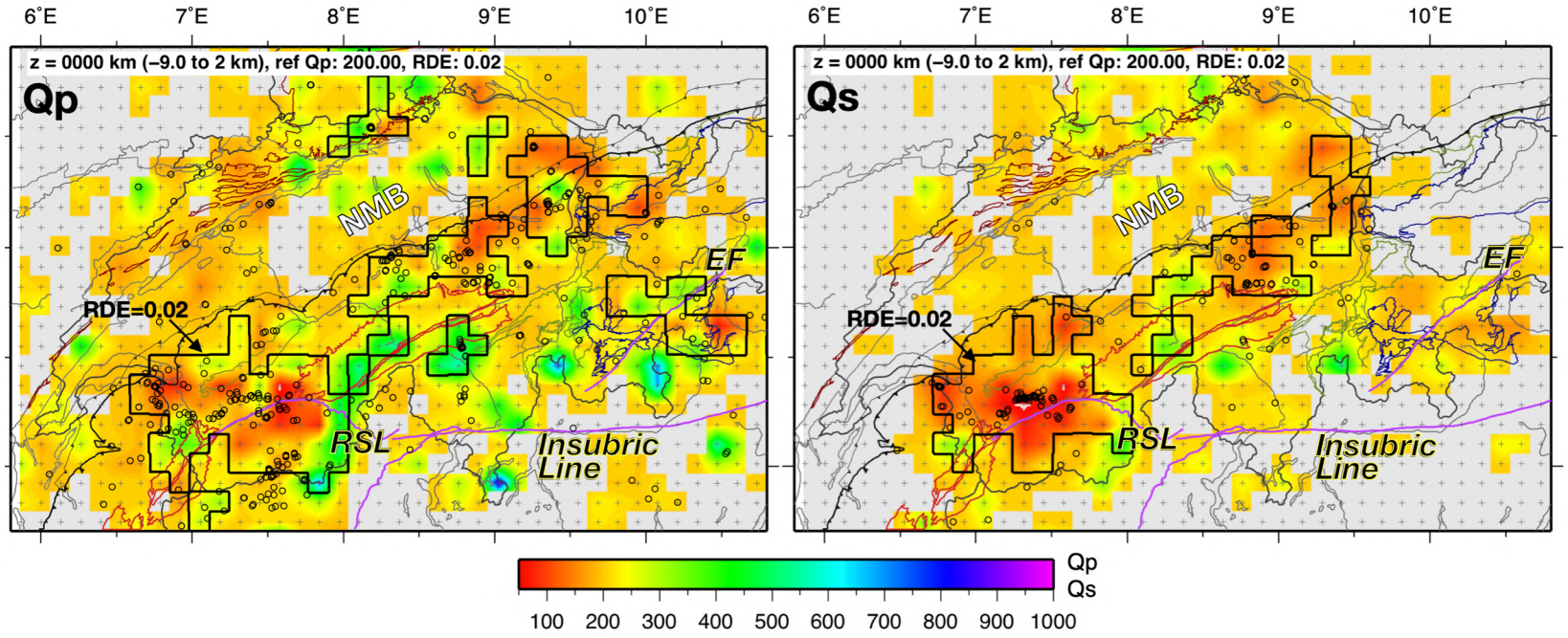
Data



- 637 stations (CH backbone network plus other temporary networks and foreign stations)
- 4,192 distributed earthquakes recorded on permanent and temporary stations for the period 2002-2020. All events have been previously relocated with the most recent Pg-Sg velocity model (Diehl et al. 2021, submitted → **vPICO TS7.8, EGU21- 2902**).
- 14,945 *t** observations for S waves (measured on best picked horizontal channel) and 49,368 *t** observations for P waves

Preliminary Qp, Qs model at depth slice 0 km (**sensitivity: -2.5 to 2 km**)



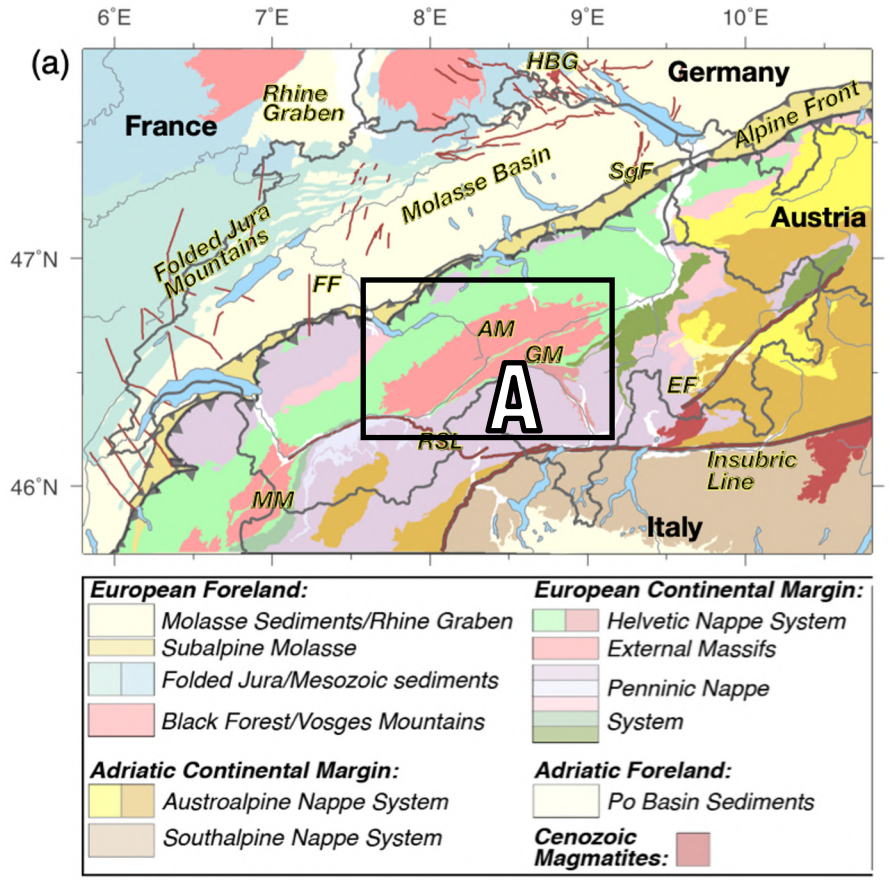


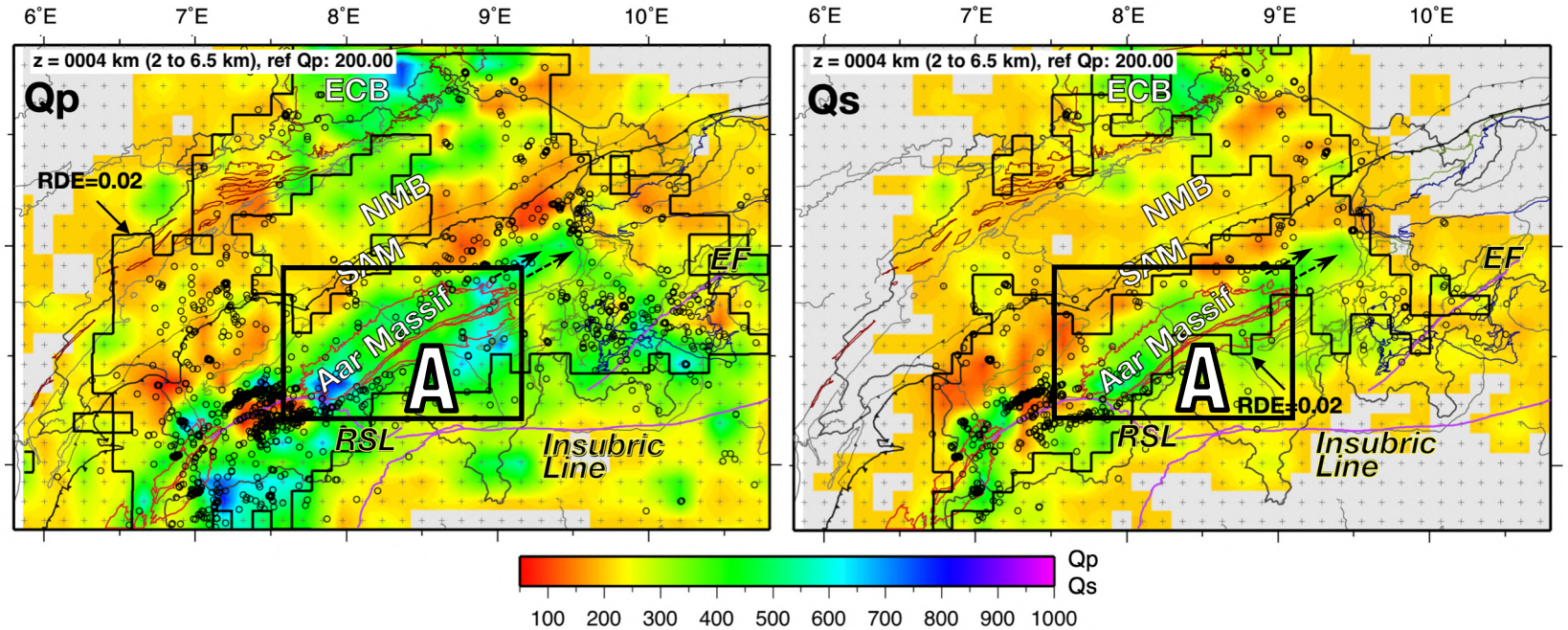
AM: Aar massif, **ECB**: European Crystalline Basement, **EF**: Engadine fault, **FF**: Fribourg fault zone, **GM**: Gotthard massif, **HBG**: Hegau-Bodensee Graben, **MM**: Mont Blanc massif, **NMB**: Northern Molasse Basin, **RSL**: Rhone-Simplon line, **SAM**: Subalpine Molasse, **SgF**: St. Gallen fault zone.

- Main observed features:

In the resolved part of the model (within black lines, RDE > 0.02) we observed low Q which is most likely related to the sedimentary covers. Correspondent high Vp/Vs ratio and low Vp also would indicate a correlation with the rock type in the Helvetic Nappes and/or presence of fluids.

Preliminary Qp, Qs model at depth slice 4 km (**sensitivity: 2 to 6.5 km**)



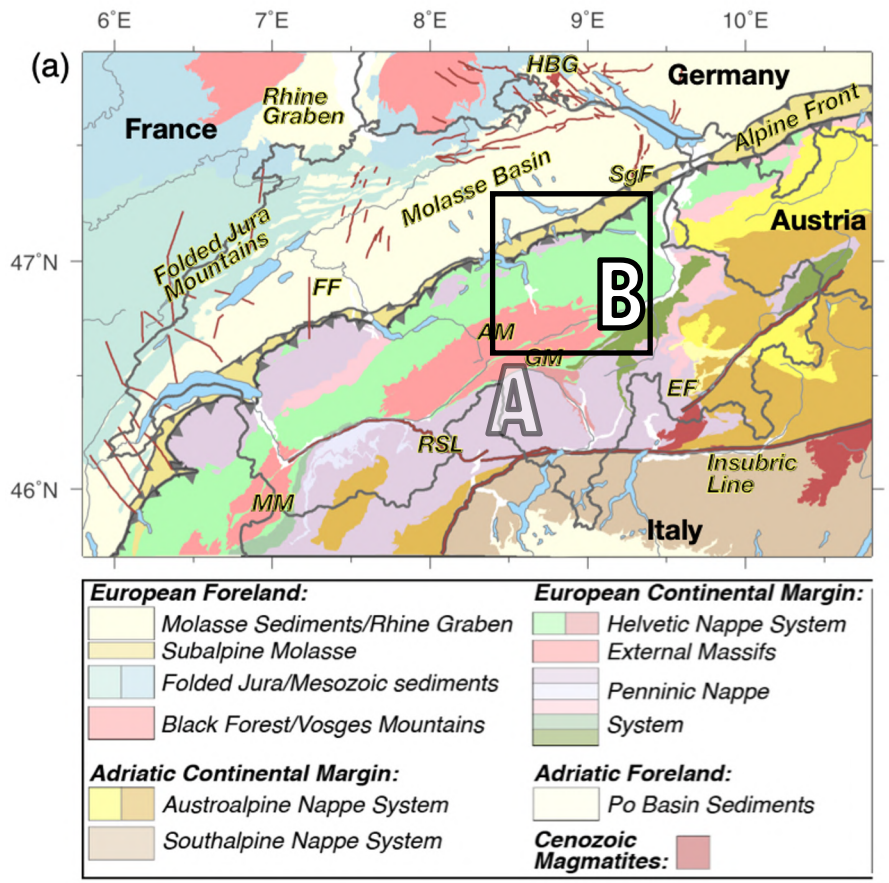


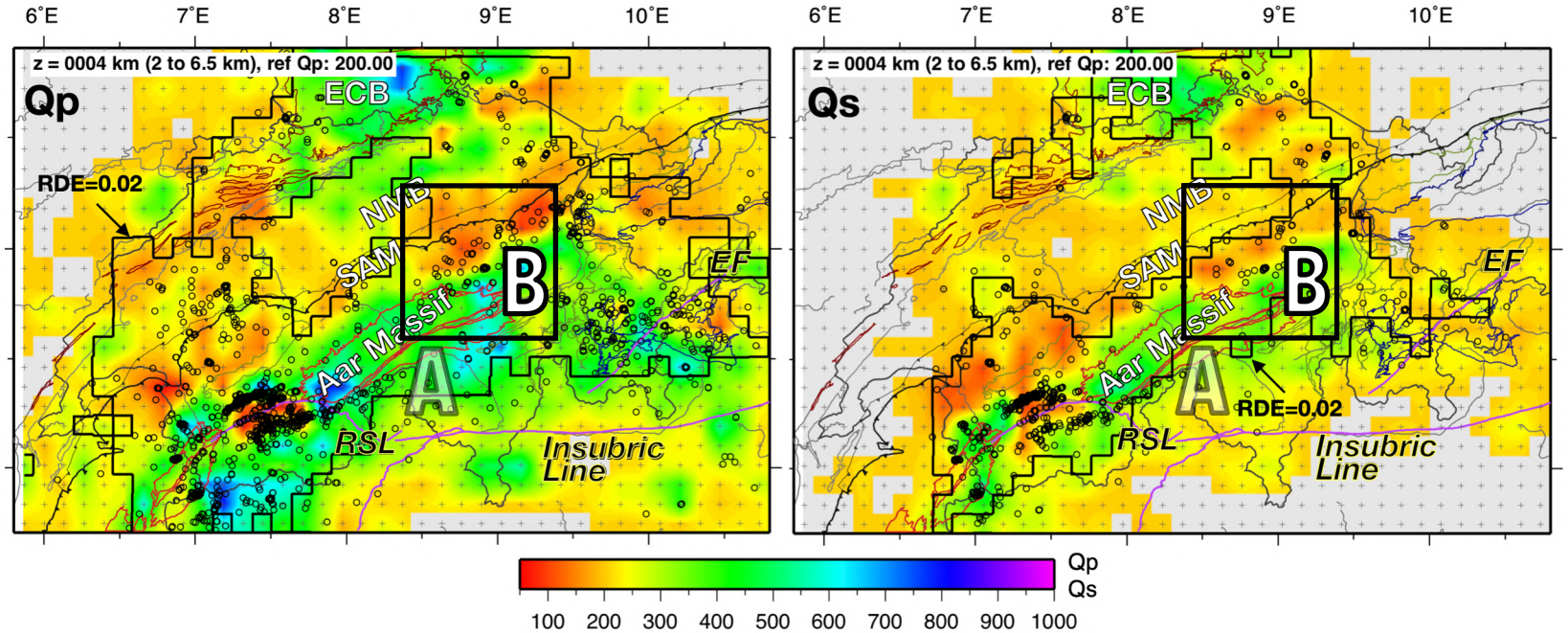
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- Main observed features:

A) Aar Massif. The moderate-to-high Qs and Qp (400-800) along with low Vp/Vs ratio and high Vs could be indicative of metamorphic processes leading to different Vp/Vs compared to the basement in the foreland (ECB), and possibly suggest the continuation of the massif further to the northeast (black arrows).

Preliminary Qp, Qs model at depth slice 4 km (**sensitivity: 2 to 6.5 km**)



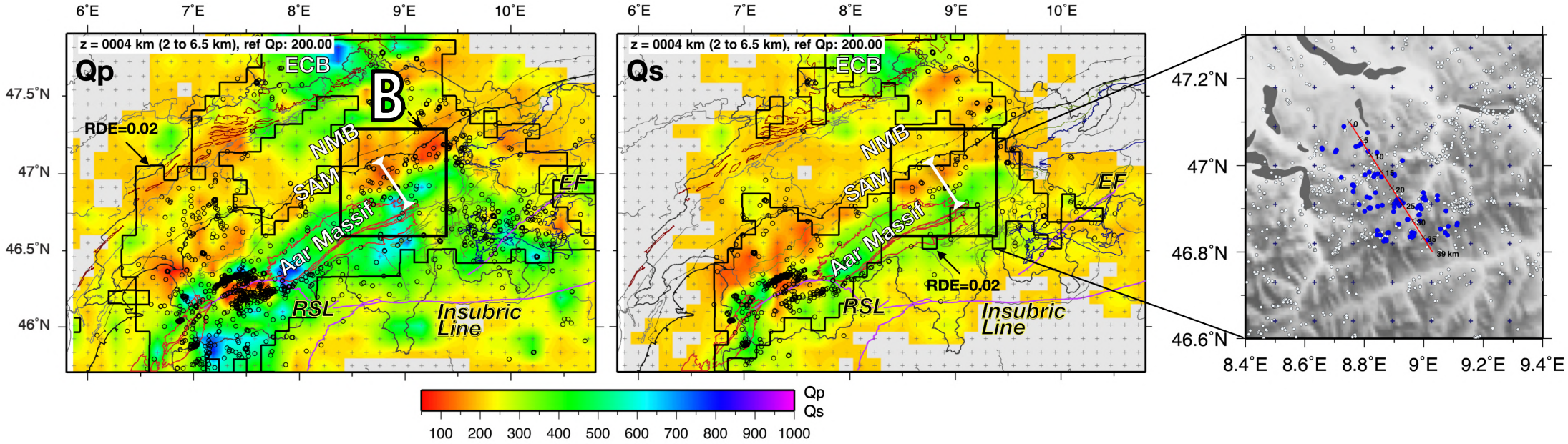


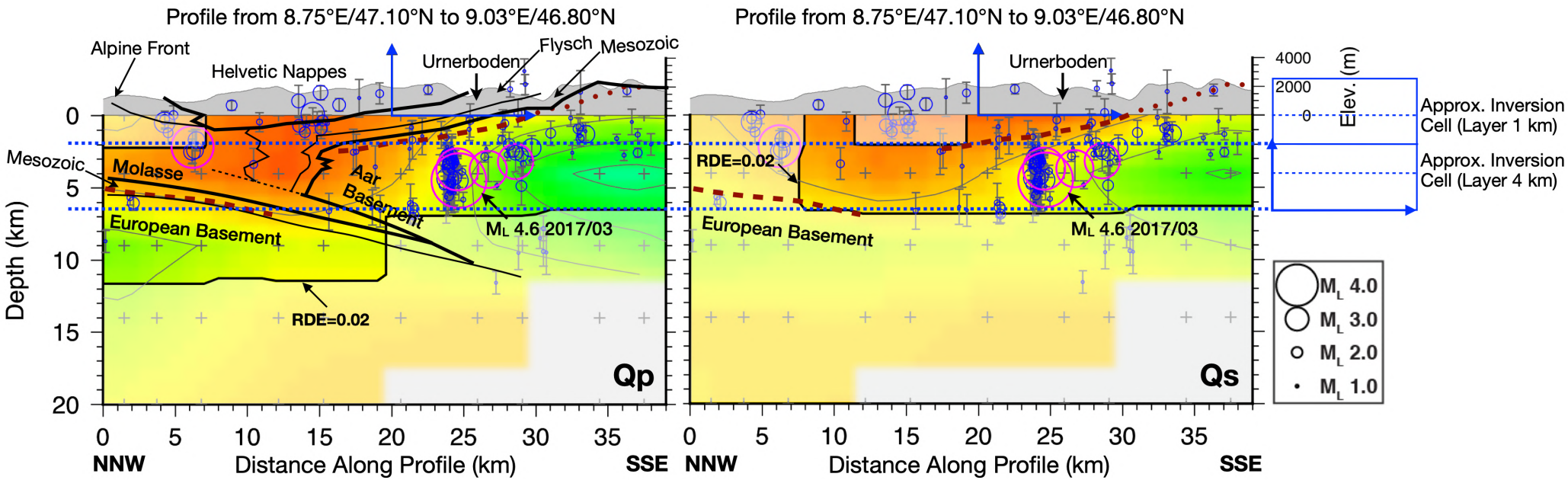
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- Main observed features:

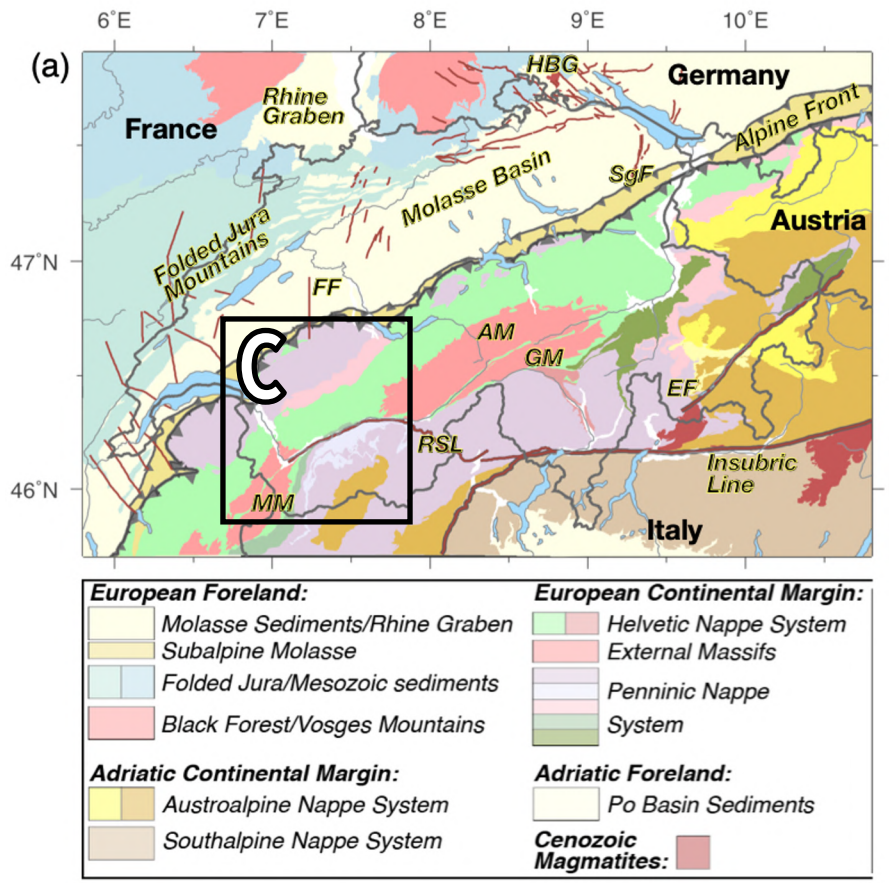
B) Subalpine Molasse. A low Q crustal block is bounded by moderately-to-high Q regions, where low Q areas coincide with the sediments of the Subalpine Molasse, and high Q regions outline the crystalline basement towards north and the crystalline Aar Massif to the south.

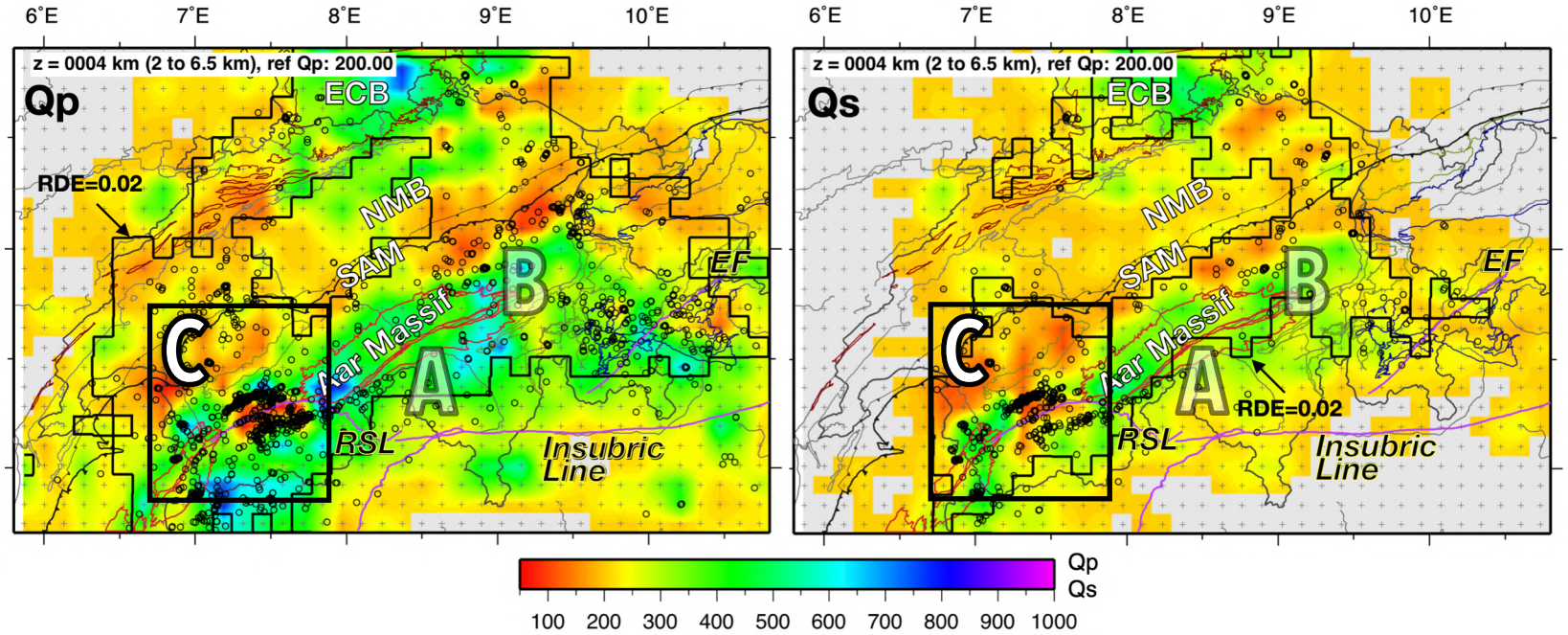
Preliminary Qp, Qs model at depth slice 4 km (**cross section: Urnerboden**)





Preliminary Qp, Qs model at depth slice 4 km (**sensitivity: 2 to 6.5 km**)



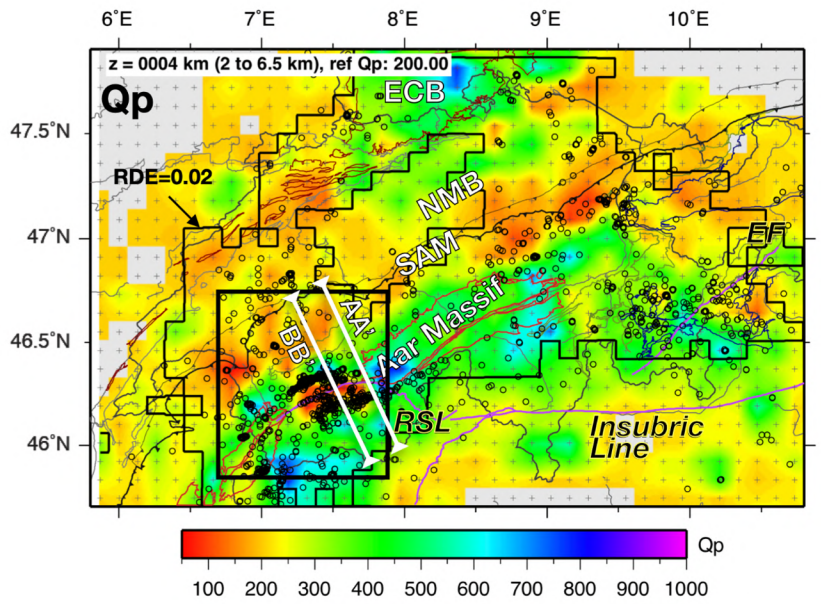


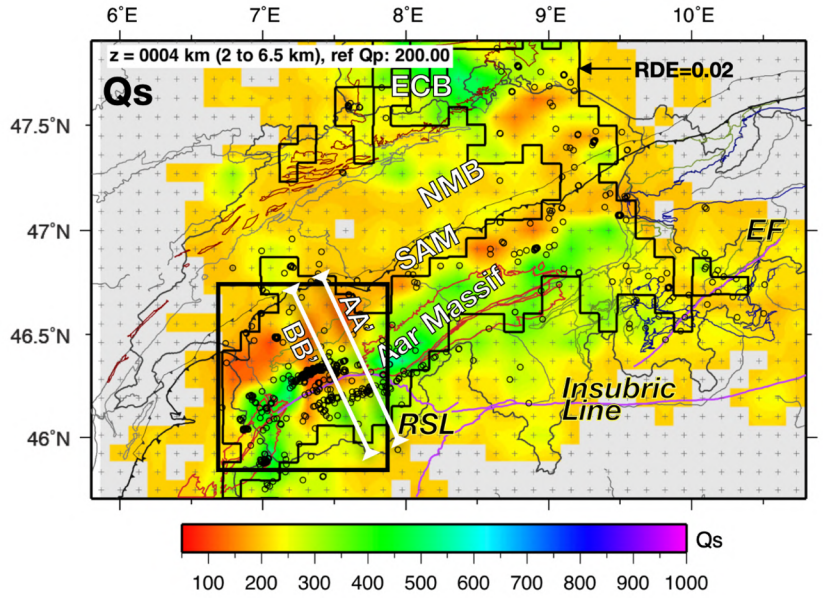
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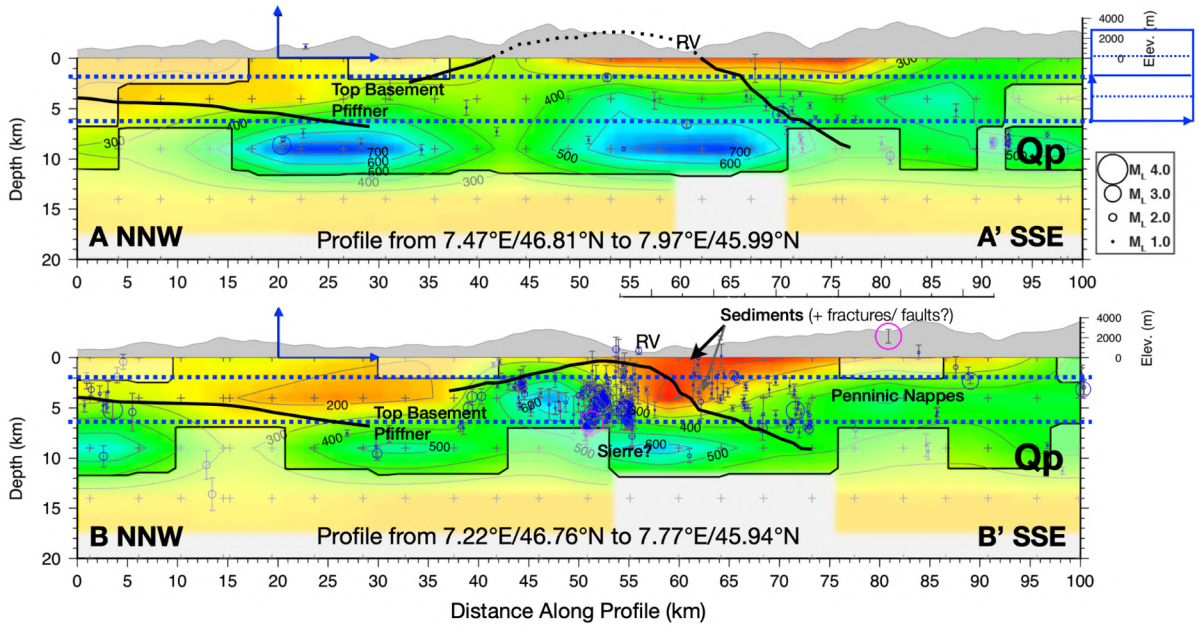
- Main observed features:

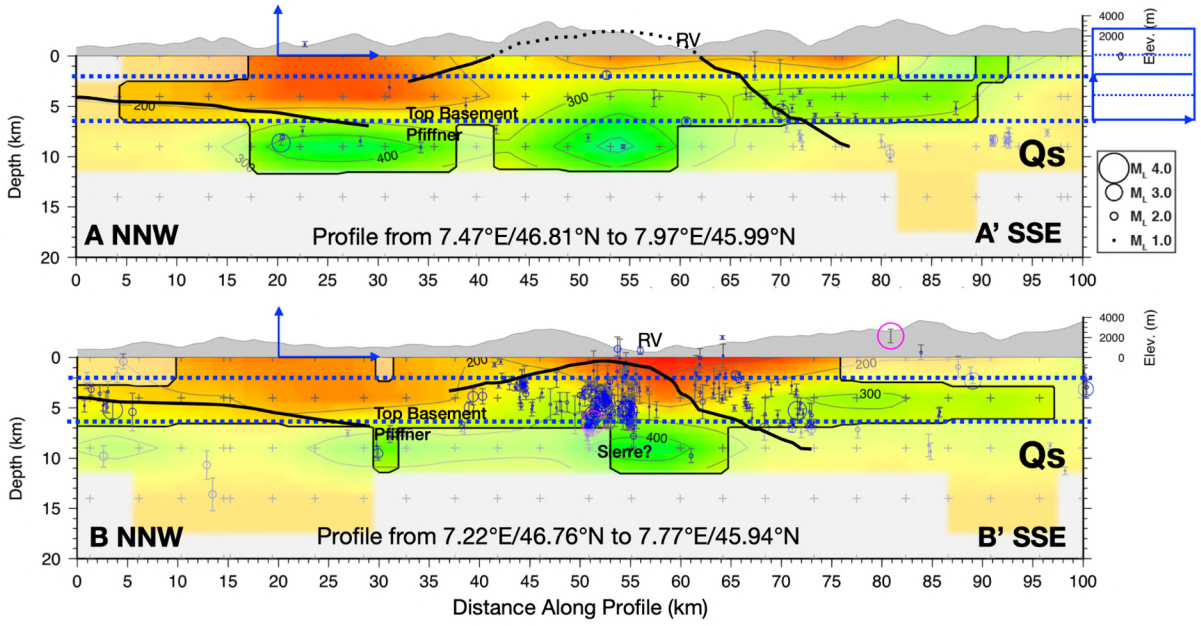
C) Rhone Valley. Both Qp and Qs are low (<150). This region hosts the most presently seismically active fault zones with an elevated number of small magnitude events. Low Q here could indicate enhanced damage related to the Rhone Simplon Line. In addition, we observe a strong correlation between Q and the lithology (sediments /basement).

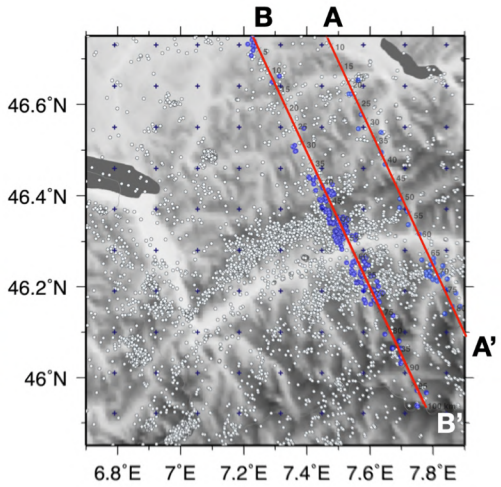
Preliminary Qp, Qs model at depth slice 4 km (**cross sections: Rhone Valley**)



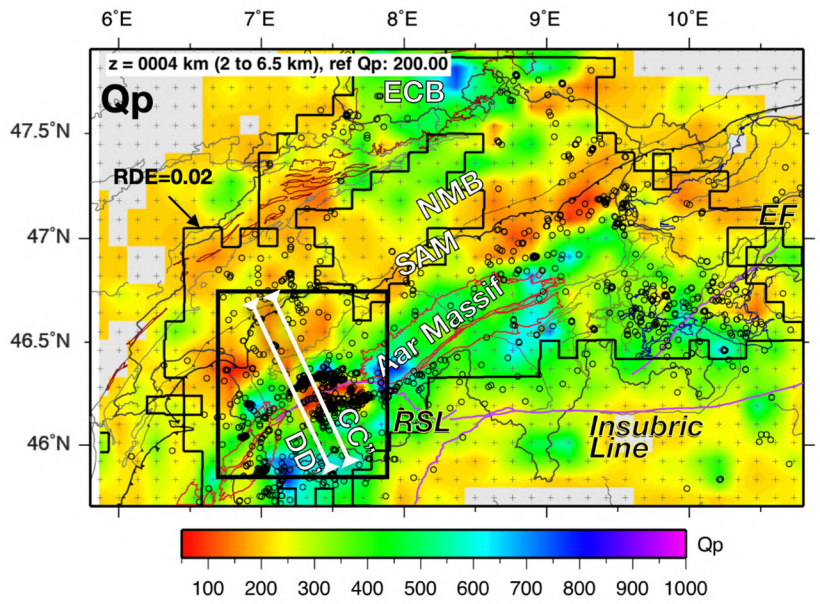


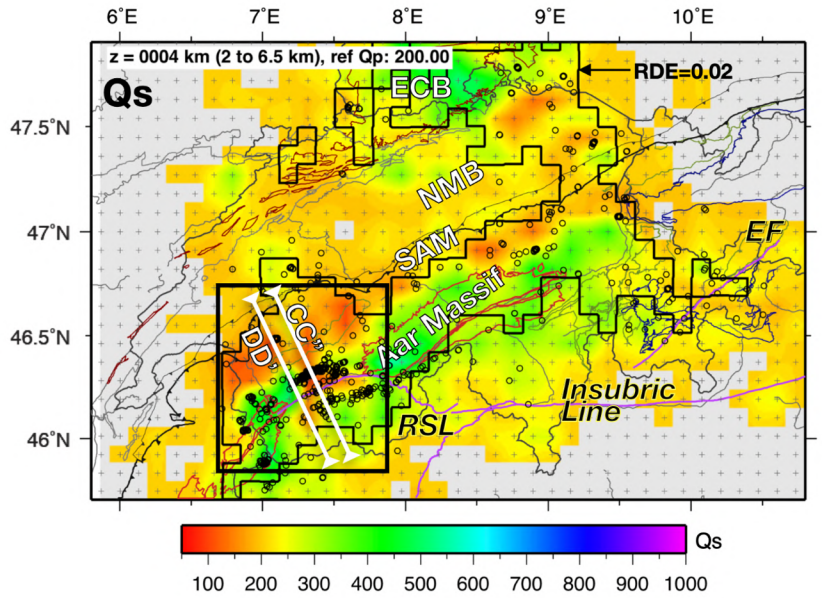


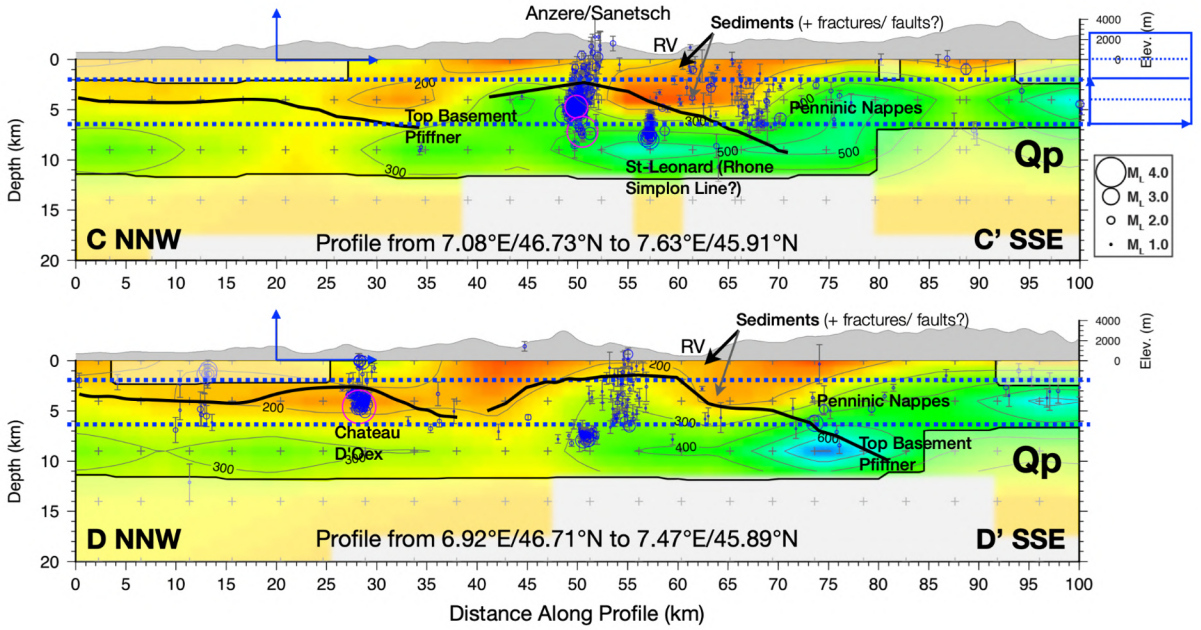


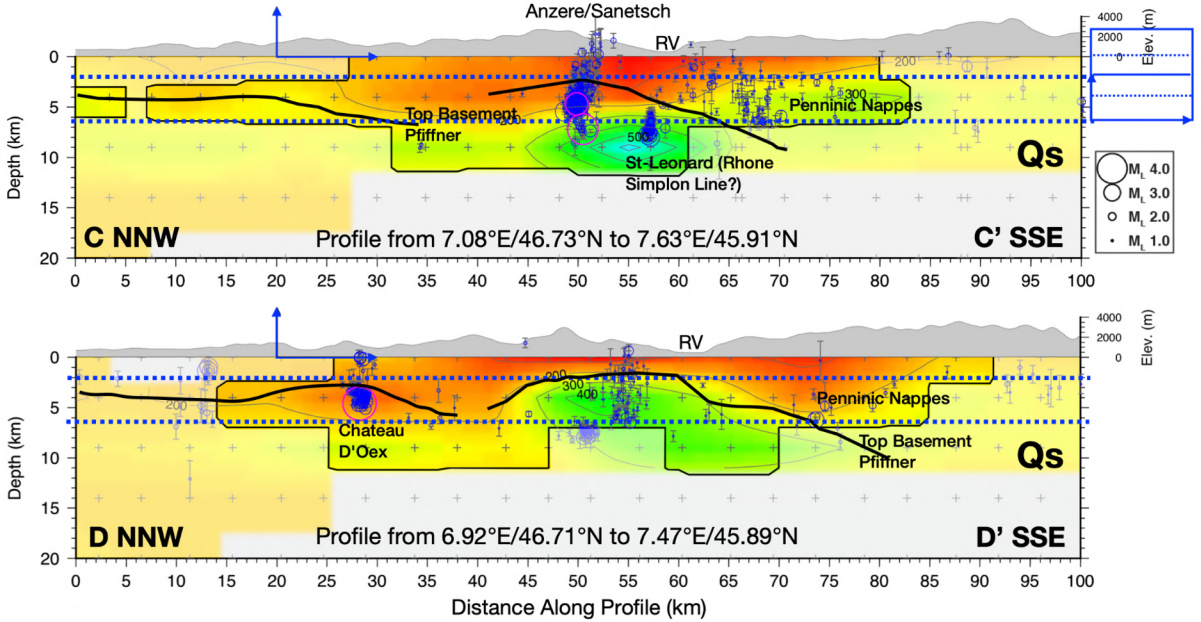


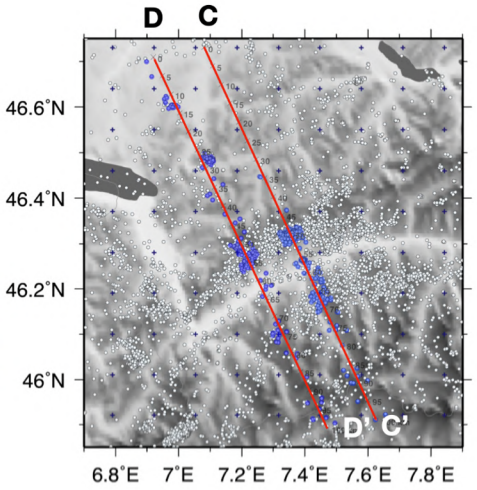
Preliminary Qp, Qs model at depth slice 4 km (**cross sections: Rhone Valley**)



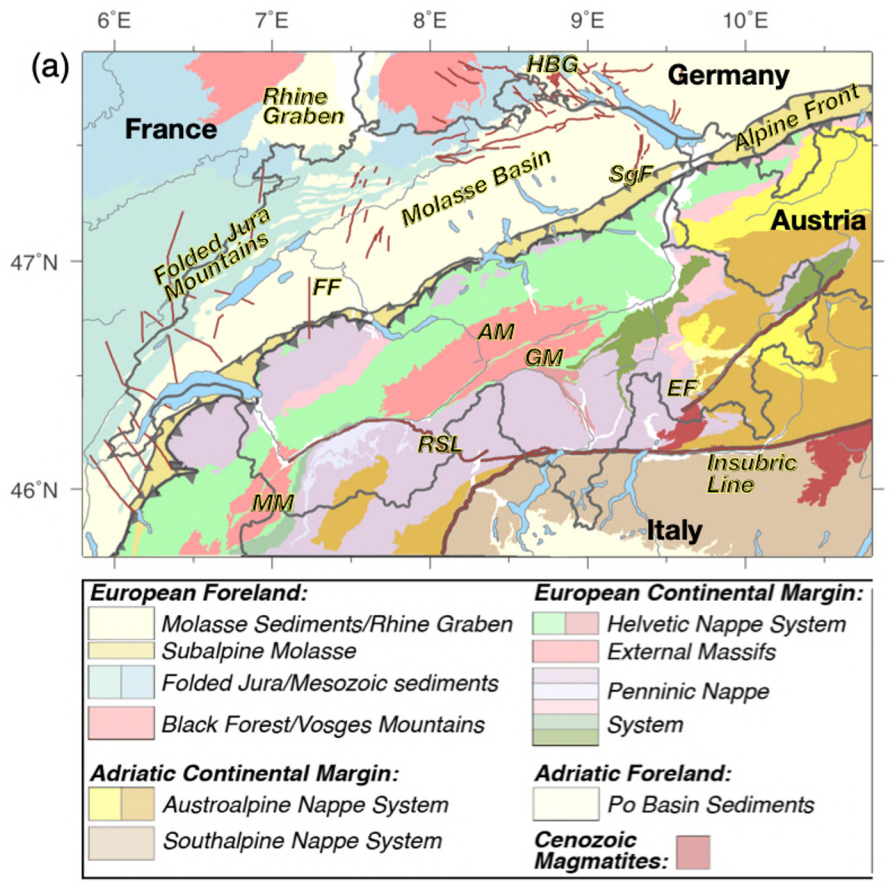


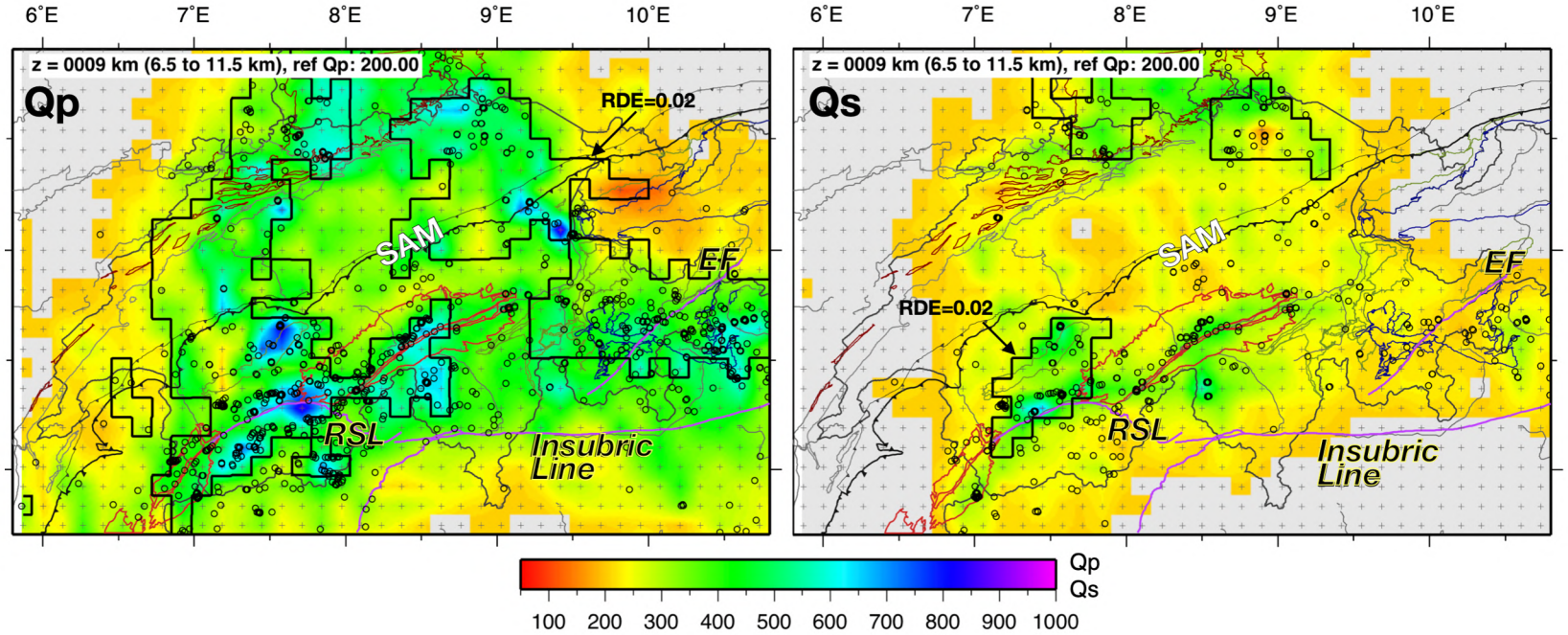






Preliminary Qp, Qs model at depth slice 9 km (**sensitivity: 6.5 to 11.5 km**)



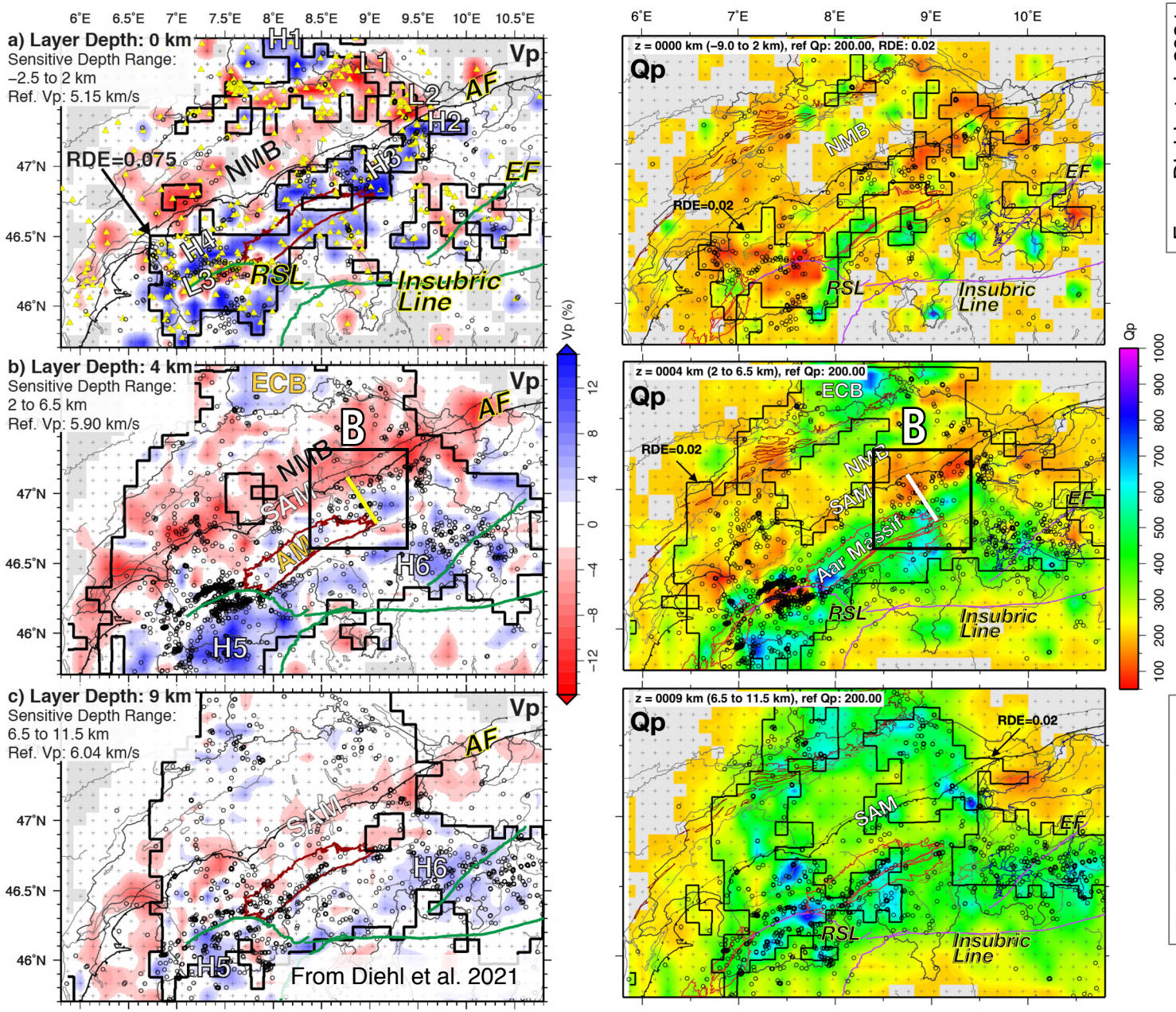


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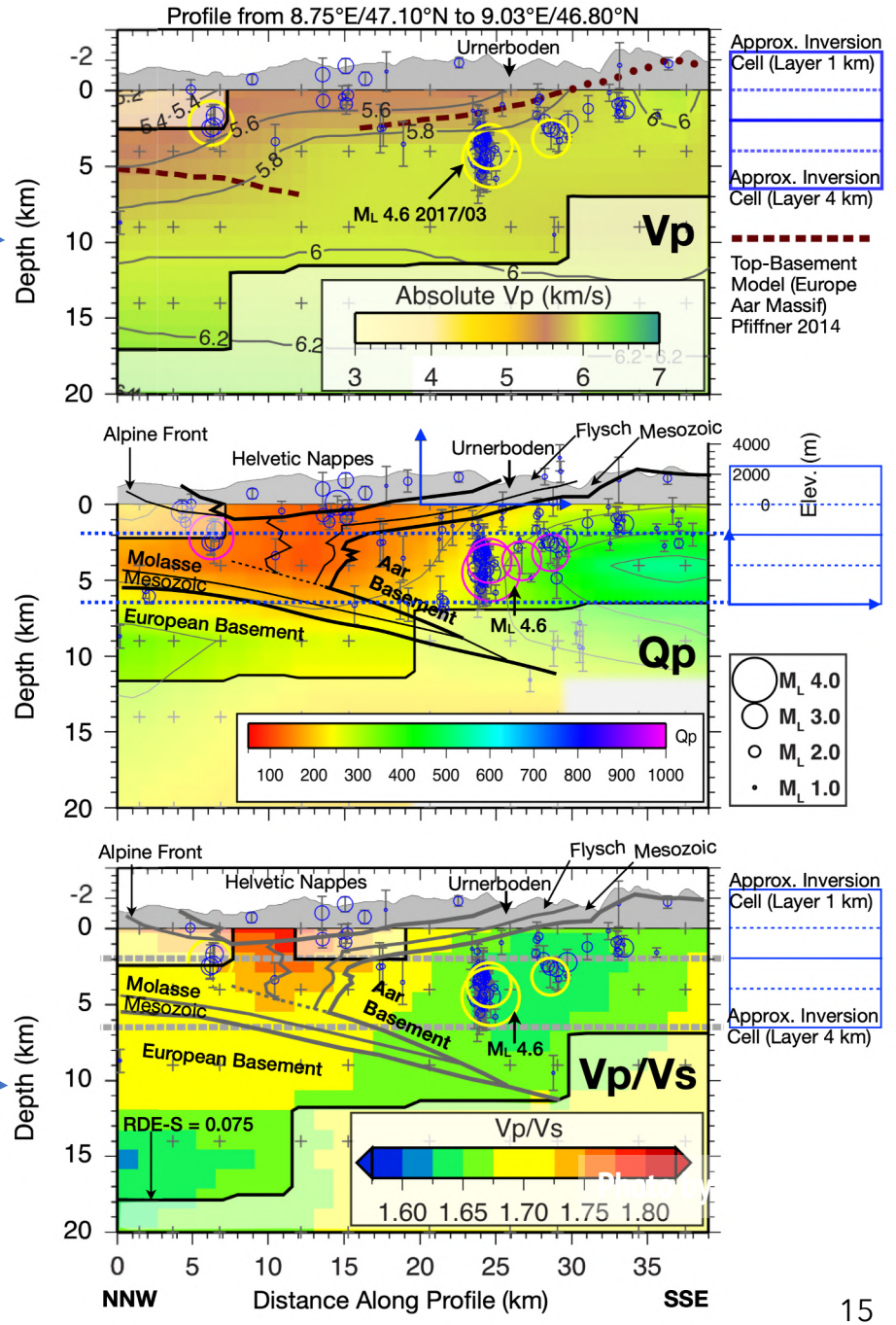
- Main observed features:

In the resolved part of the model (within black lines, RDE > 0.02) we observed medium-to-high Q which at this depths is most likely related to the crystalline basement.

Comparison Vp – Qp - Vp/Vs: Urnerboden

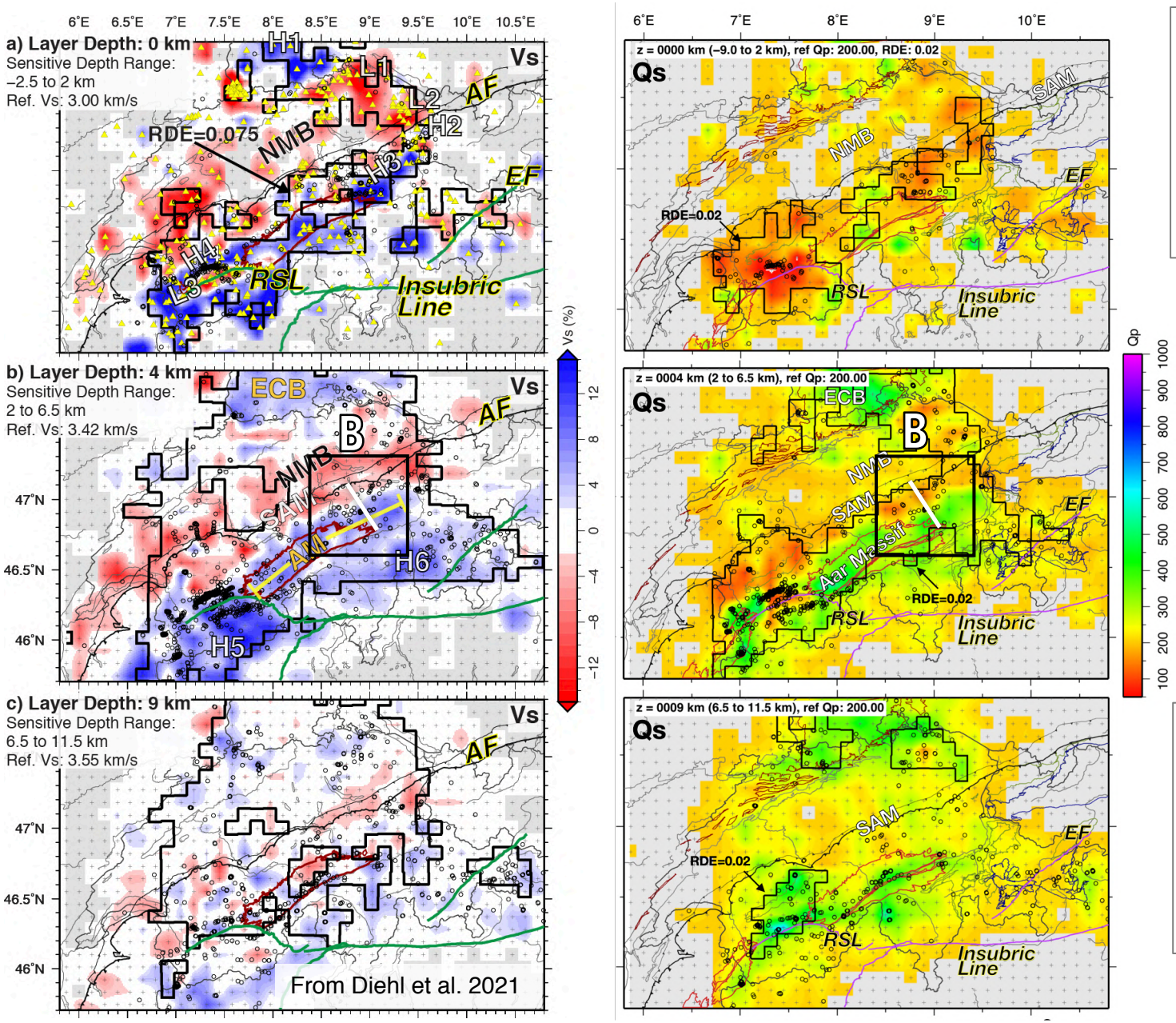


From Diehl et al. 2021

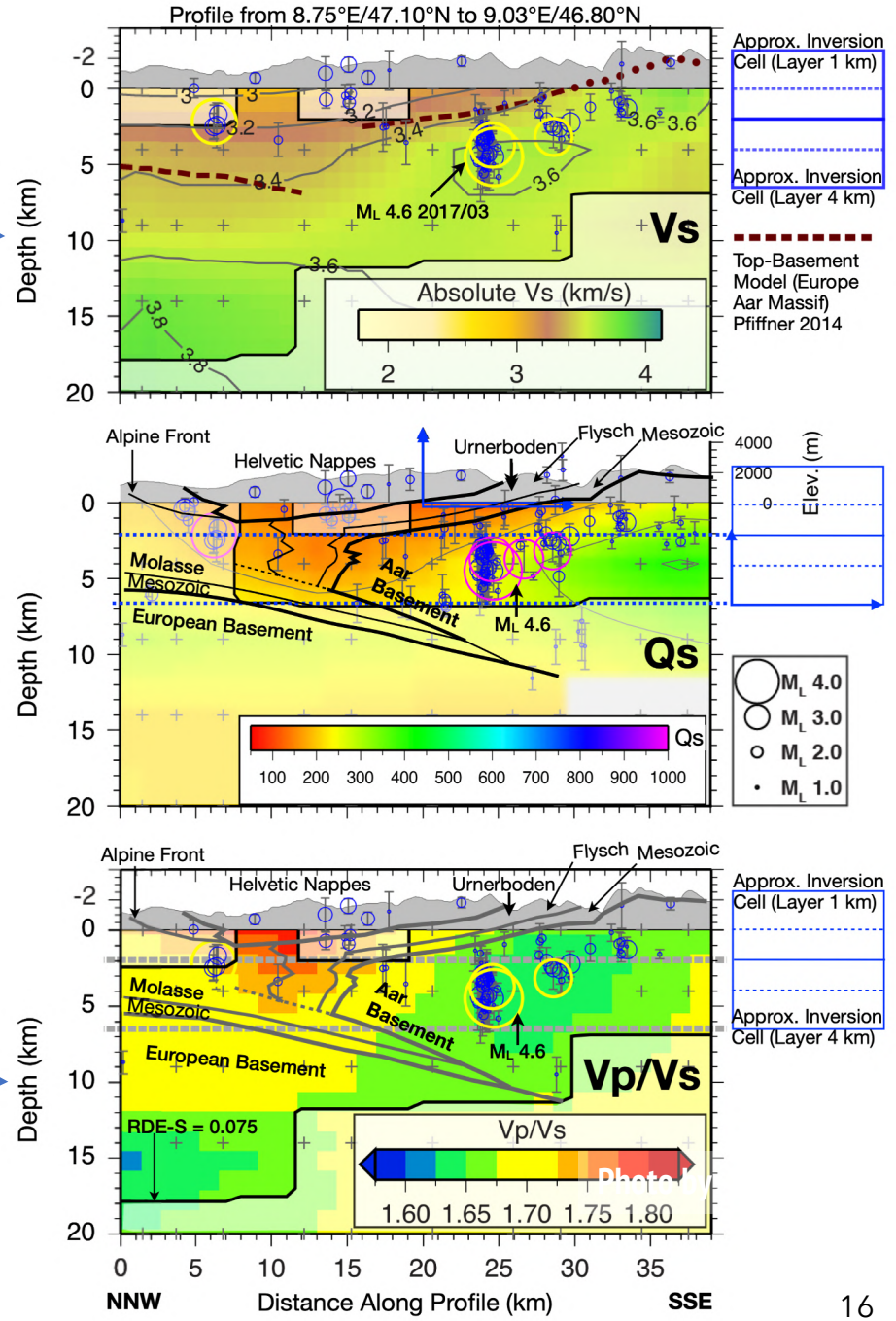


From Diehl et al. 2021

Comparison Vs – Qs - Vp/Vs: Urnerboden

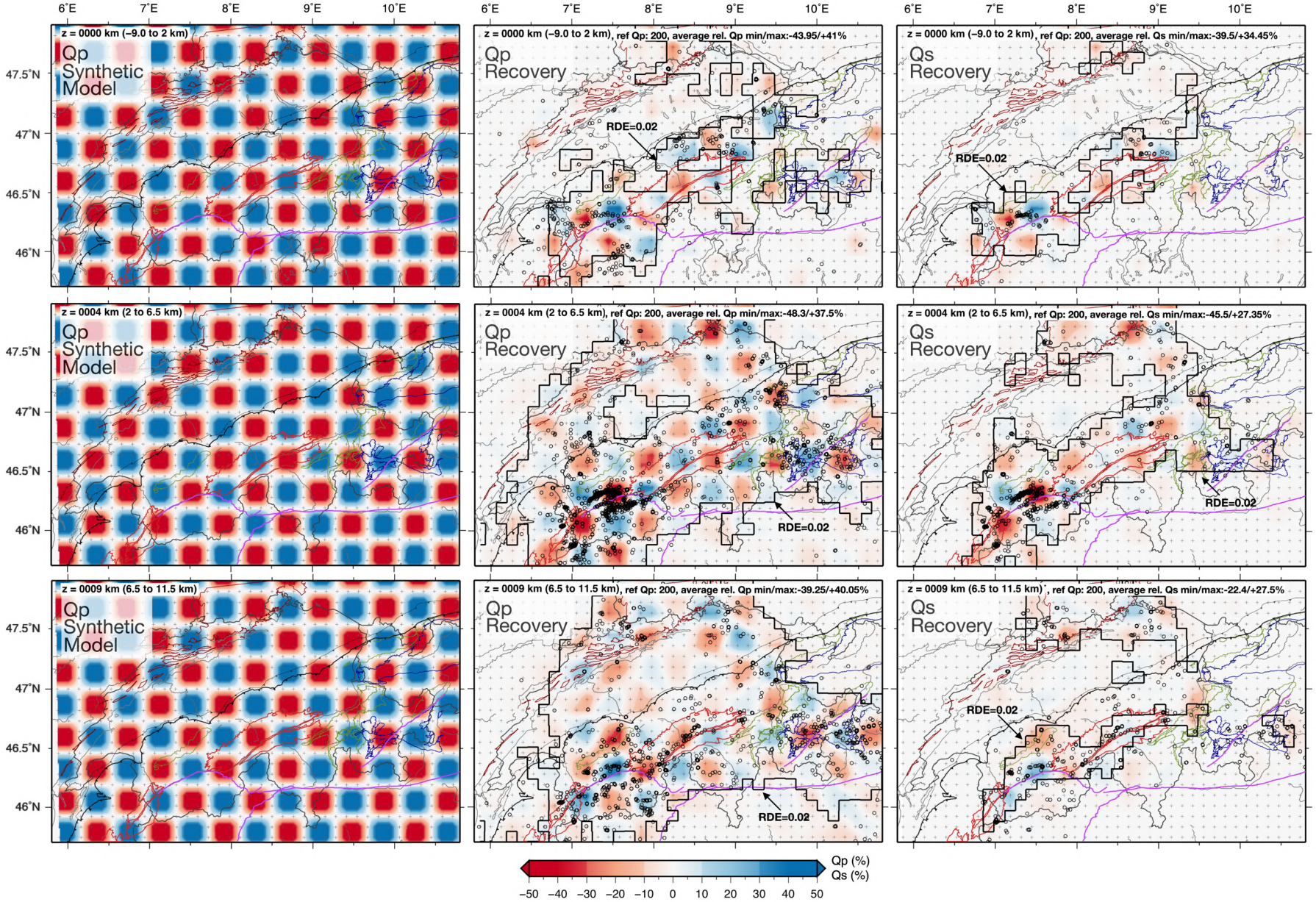


From Diehl et al. 2021



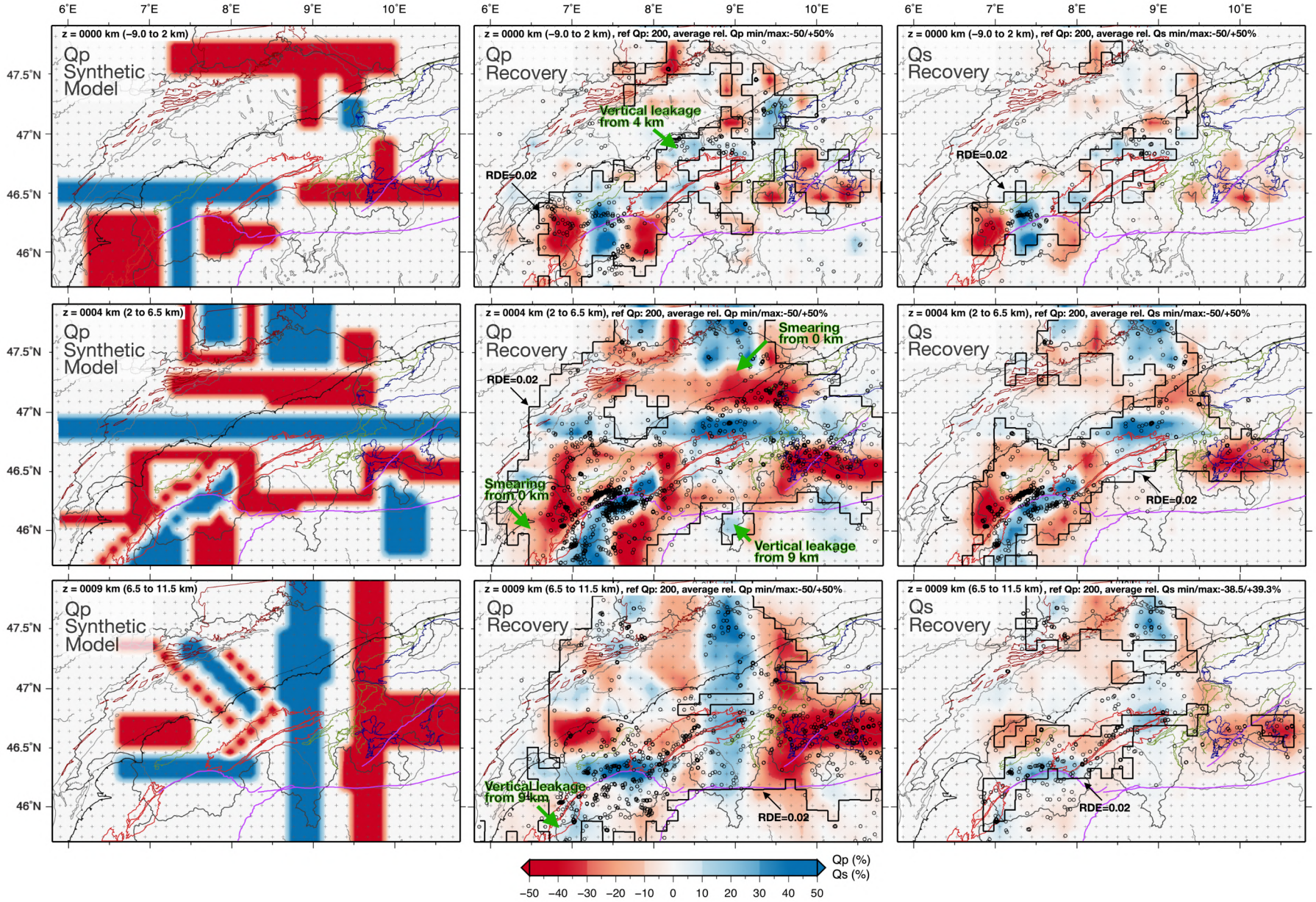
From Diehl et al. 2021

Synthetic Tests and Resolution (checkerboard)



Synthetic checkerboard tests to assess the sensitivity and resolution of both Qp and Qs tomography models. Left: synthetic model at different depths. Center and right: corresponding structures recovered by the inversion for Qp and Qs respectively. The starting 1-D homogeneous Q models is perturbed by alternately adding and subtracting 50% Q anomalies to a homogeneous model with Q value of 200.

Synthetic Tests and Resolution (continued)



Synthetic tests to assess the sensitivity and resolution of both Qp and Qs tomography models. Left: synthetic model at different depths. Center and right: corresponding structures recovered by the inversion for Qp and Qs respectively using the same source-receiver geometry as for the real data. The same anomalies were also tested in Diehl et al. 2021 (submitted to JGR) for assessing the resolution of their Vp and Vs models)

Future Work

Directions under consideration towards further model improvements include:

- Dataset enrichment (expansion of the Qs t* data).
- **Gradational inversion scheme** to reduce any undefined Q in the model (a.k.a. reduce the spottiness of the image) so that the results could be then used in rheological models.
- Finer grid (5 x 5 km) for high resolution areas (i.e., Rhone Valley).

Thank you for stopping by!