[EGU25-3239] Assessing the Impact of Seismic Anisotropy on Estimates of Lower Continental Crust Bulk Composition: Insights from the Ivrea-Verbano Zone

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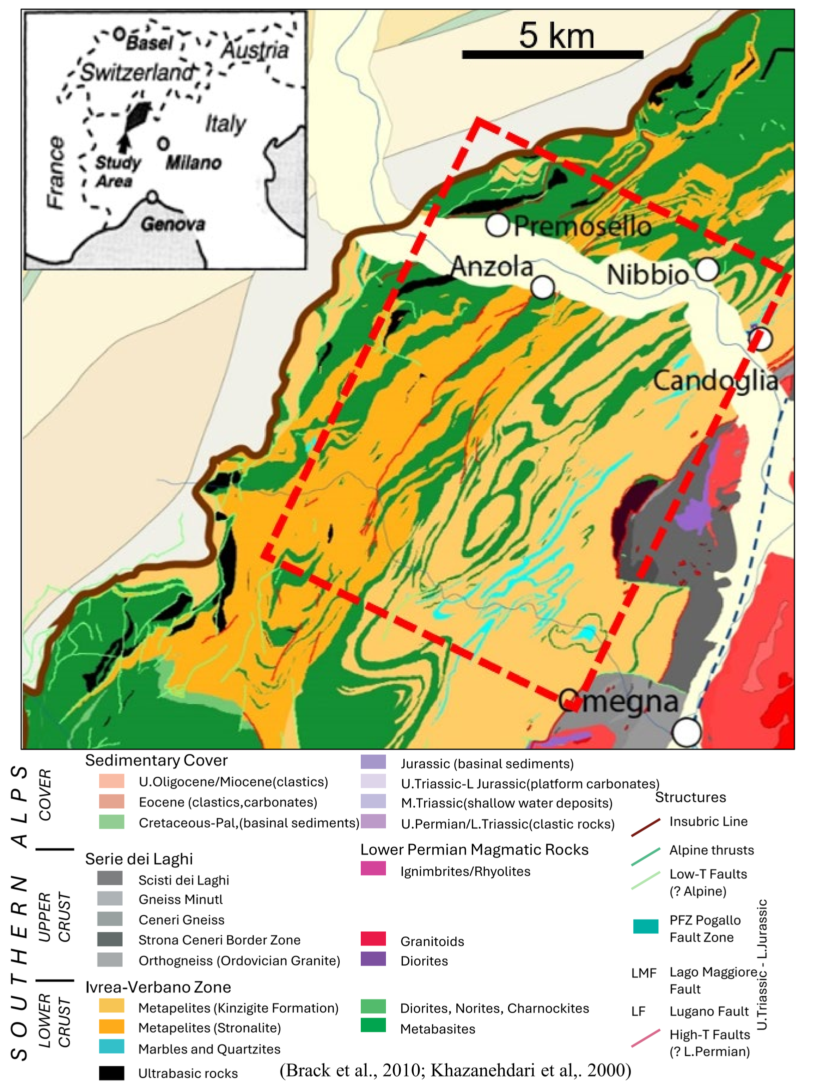
Motivation

Knowledge of the structure and composition of the lower continental crust is essential for understanding the dynamic and geochemical evolution of the Earth's lithosphere-asthenosphere system (e.g., Hacker et al., 2015). Most of our information on the lower continental crust is based on controlled source wide-angle seismic experiments, for which the direction of wave propagation in the target region is largely sub-horizontal (e.g., Christensen and Mooney, 1995; Prodehl and Mooney, 2012). Following the common practice of interpreting such data in an isotropic framework, too high P-wave velocities may therefore be inferred in a TI-type environment. This, in turn, could result in an interpretational bias of the lower crustal bulk composition towards the mafic side (e.g., Brittan et al., 1996, 1997; Jones et al., 1999). TI-type anisotropy can arise from the sub-horizontal alignment of anisotropic minerals and/or from layering. The Ivrea Zone corresponds to an archetypal outcrop of lower continental crust consisting mostly of interlayed metamafic and metapelitic rocks and thus lends itself to the systematic exploration of this problem. To assess the likely importance of lower crustal anisotropy in Ivrea-type lower continental crust, we use a Monte Carlo procedure to comprehensively analyze a range of stochastically layered canonical models. The individual layers are parameterized based on published laboratory measurements from pertinent rock samples (e.g., Fountain, 1976; Burke et al., 1990; Burlini and Fountain, 1993; Barruol and Kern, 1996; Khazanehdari et al., 2000; Barberini et al., 2007; Adero, 2020).

Geological Setting



❖To a first approximation, the outlined central part of Ivrea Zone can be conceptualized as an interlayering of metapelitic and metamafic lithologies

❖This interlayering is expected to cause seismic anisotropy at the macroscopic scale, that is, at wavelengths that are larger than the layer thicknesses

❖Additionally, intrinsic anisotropy at the microscopic scale arises due to the presence of aligned anisotropic minerals, such as mica, amphibole, and pyroxene

Methodology

Monte Carlo Simulation of Ivrea-type Lower Crust

① Classify laboratory measurements of seismic properties and SiO_2 content on samples from the Ivrea Zone: Lithology bucket → Bucket 1: Metapelites + Bucket 2: Metamafics

② Randomly draw layer thickness from a hyperbolic distribution based on ICDP DIVE boreholes DT-1B and DT-1A — Layer thickness 1-200m

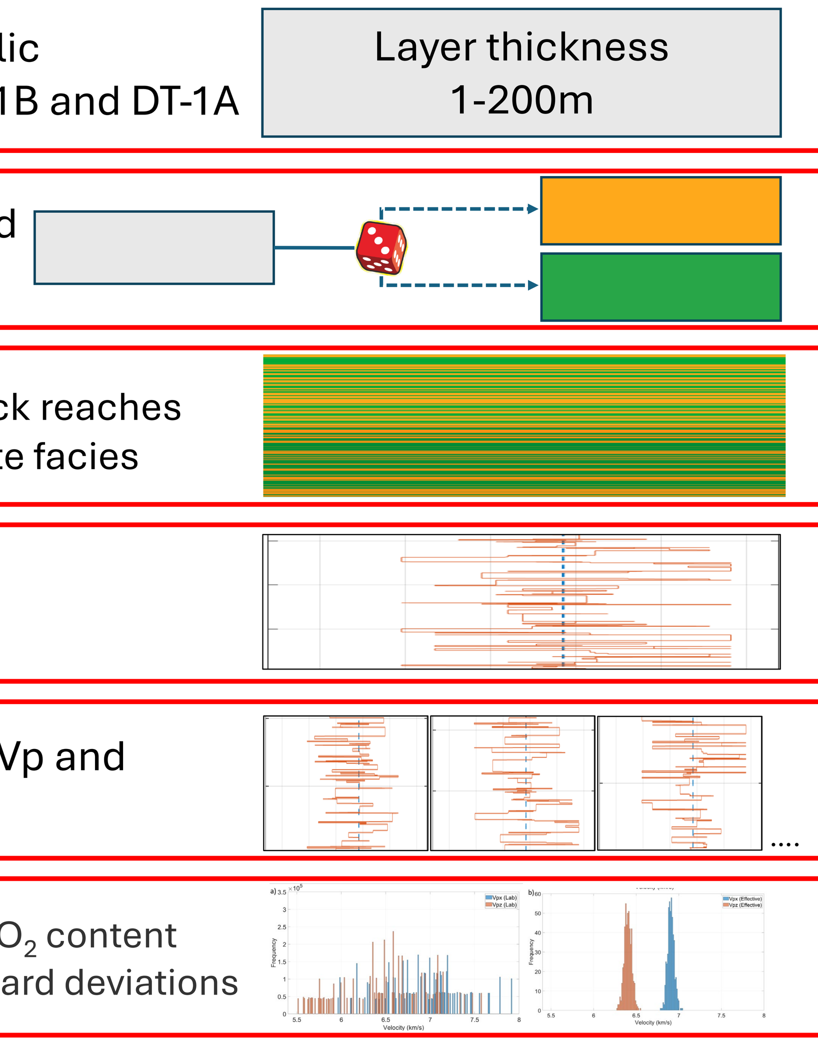
③ Randomly determine whether layer is populated from bucket 1 or bucket 2

④ Repeat ② - ③ until thickness of layer stack reaches 5 km in both the amphibolite and granulite facies

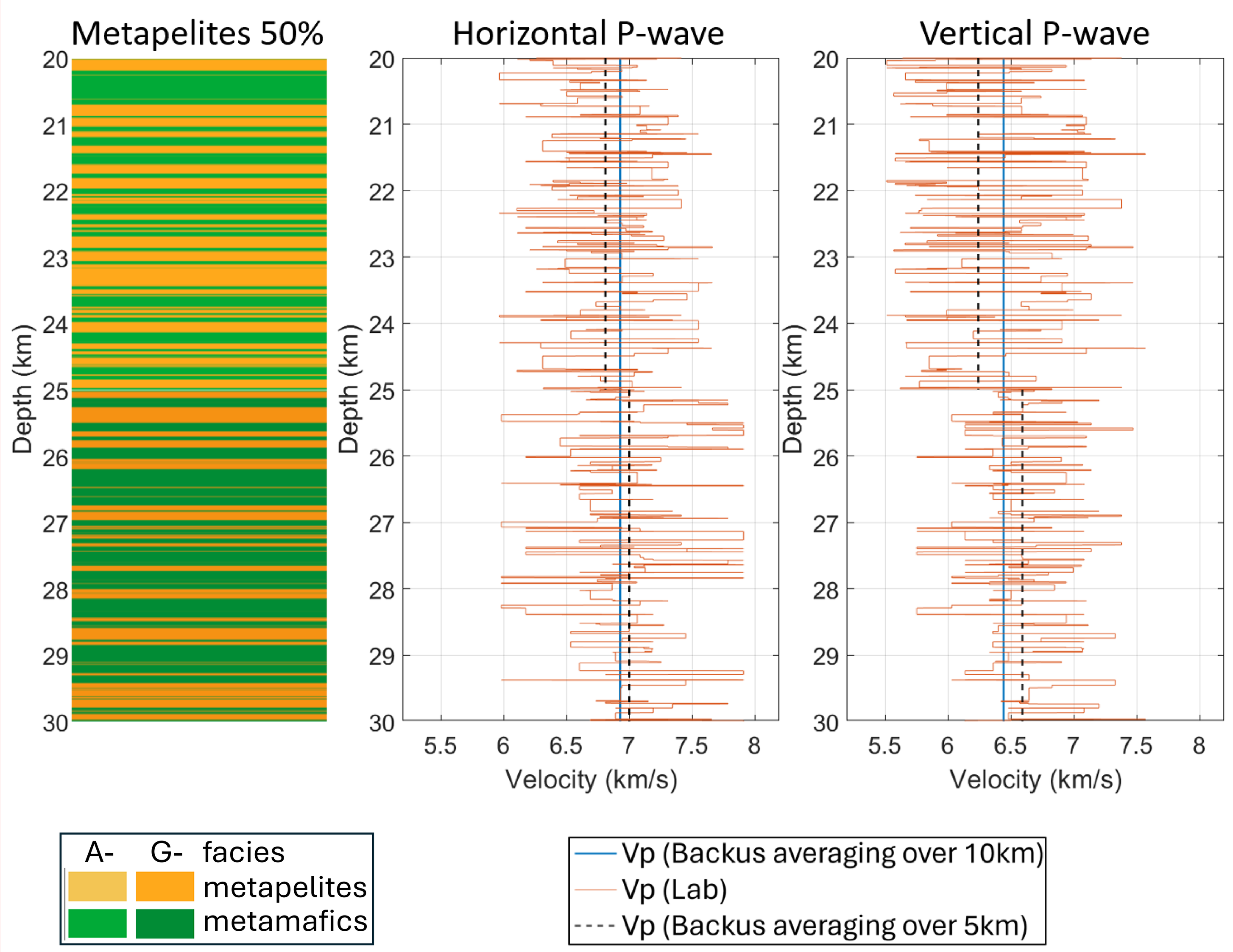
⑤ Perform P/T correction and Backus averaging

⑥ Repeat ② - ⑤ until the mean values of Vp and Vs reach convergence.

⑦ Representative distributions of Vp, Vs, density and SiO_2 content allowing for the estimation of mean values and standard deviations

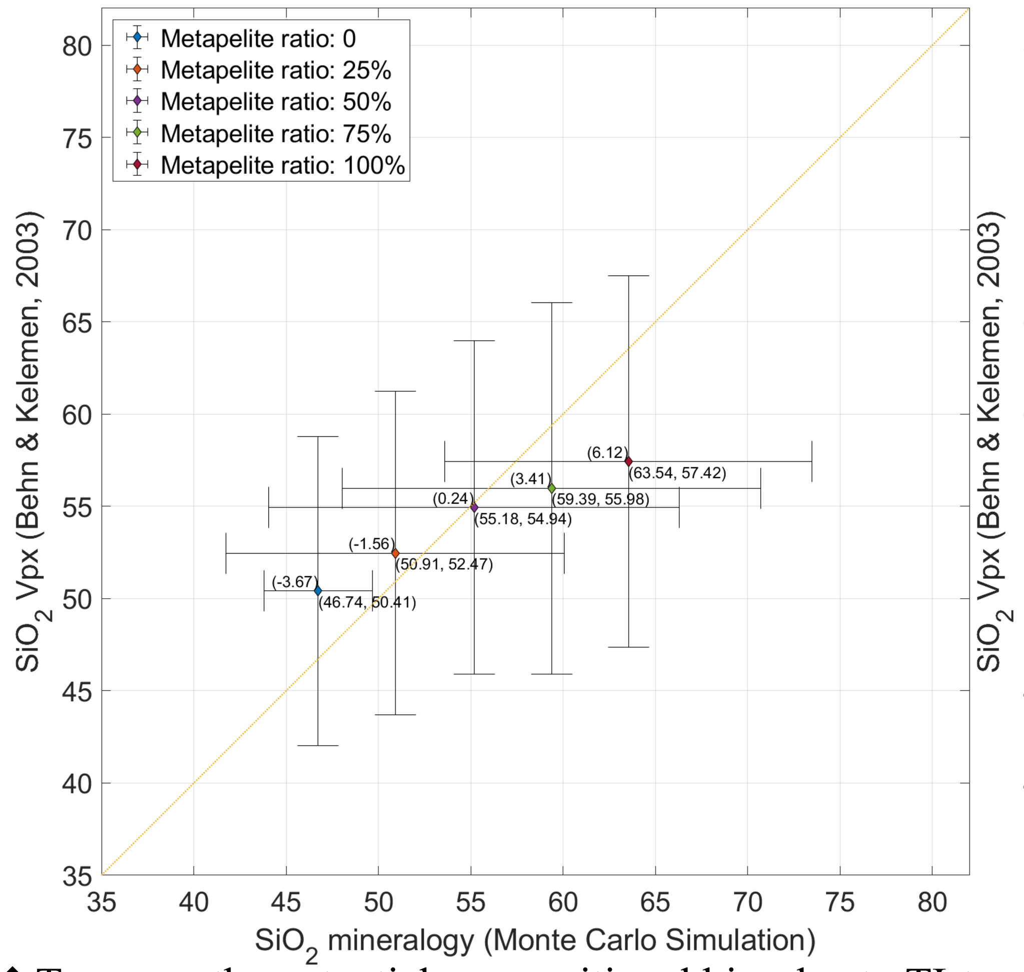


Inner Loop of Monte Carlo Simulation

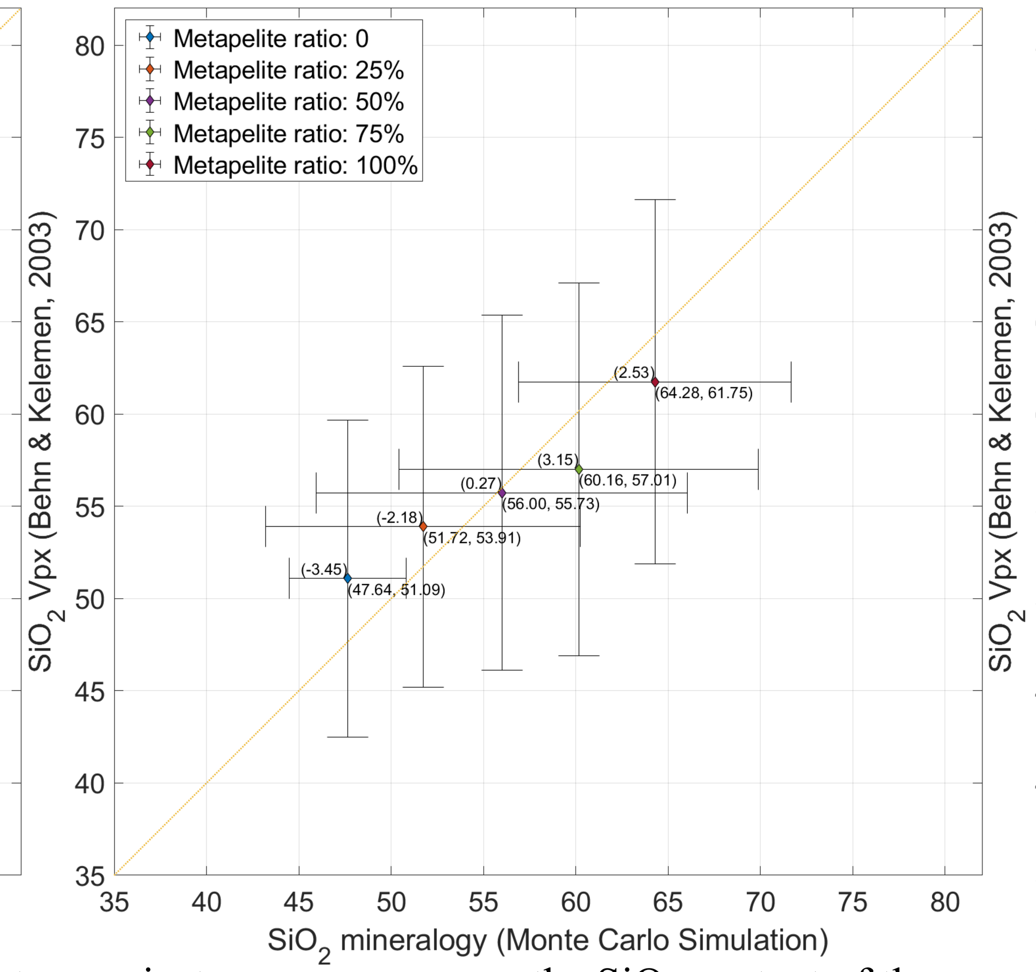


Results: Observed vs Predicted SiO_2 Content

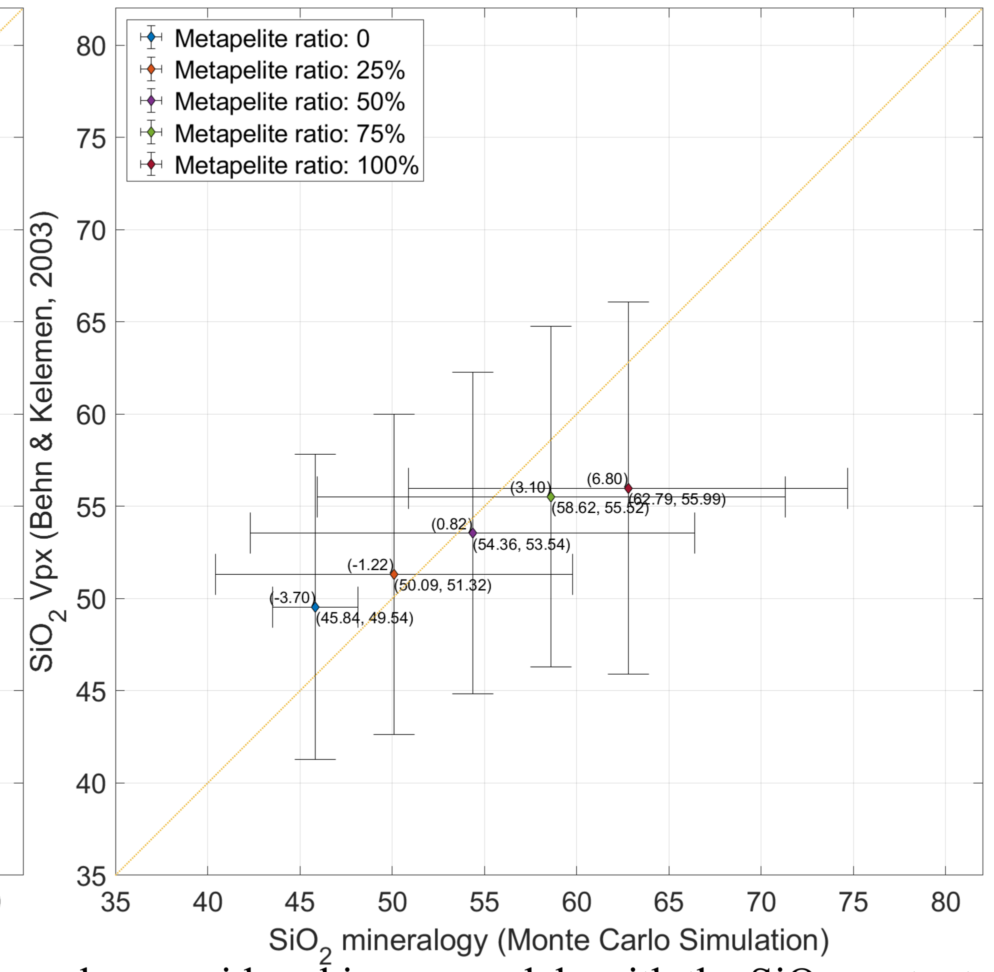
Average Ivrea-type lower crust: amphibolite and granulite facies



Amphibolite facies



Granulite facies



❖To assess the potential compositional bias due to TI-type anisotropy, we compare the SiO_2 content of the samples considered in our models with the SiO_2 content predicted by the geochemical model of Behn and Kelemen (2003) based on the inferred lower crustal P-wave velocities. To this end, we consider the entire compositional range prevailing in the central Ivrea Zone ranging from predominantly metamafic to predominantly metapelitic lithologies.

❖For Ivrea-type lower crust as whole, our results indicate that the SiO_2 content is substantially underestimated, of order of 6 to 7%, for predominantly metapelitic compositions and moderately overestimated, of the order of 3 to 4%, for predominantly metamafic compositions. The pronounced mafic bias of the metapelitic end-member scenario is governed by the formation of garnet in the granulite facies and hence unrelated to anisotropy. Conversely, the felsic bias for the metamafic end-member scenario, which persists both in the amphibolite and granulite facies, remains unclear at this point.

❖We therefore conclude that TI-type anisotropy, as it prevails in Ivrea-type lower continental crust, does not lead to a systematic mafic bias in the estimation of the bulk composition of the lower continental crust. Such biases seem to be limited to metapelitic end-member compositions and largely unrelated to seismic anisotropy.

❖These results are based on the assumption of a warm geotherm. They do, however, retain their overall validity for a normal geotherm.

Conclusions

We have explored the seismic anisotropy of Ivrea-type lower continental crust based on 1D stochastically layered models and assessed the potential implications for estimations of lower crustal bulk composition based on seismic wide-angle measurements. A key result of our work is that estimations of the SiO_2 content based on seismic wide-angle measurements are not systematically biased towards the mafic side due to the presence of anisotropy. Except for end-member metapelitic lower crustal compositions, our results indicate that the SiO_2 content inferred from seismic wide-angle velocities is reasonably realistic. For metamafic end-member compositions, we observe a consistent felsic bias of moderate magnitude, the origin of which is as of yet unknown.

Acknowledgements

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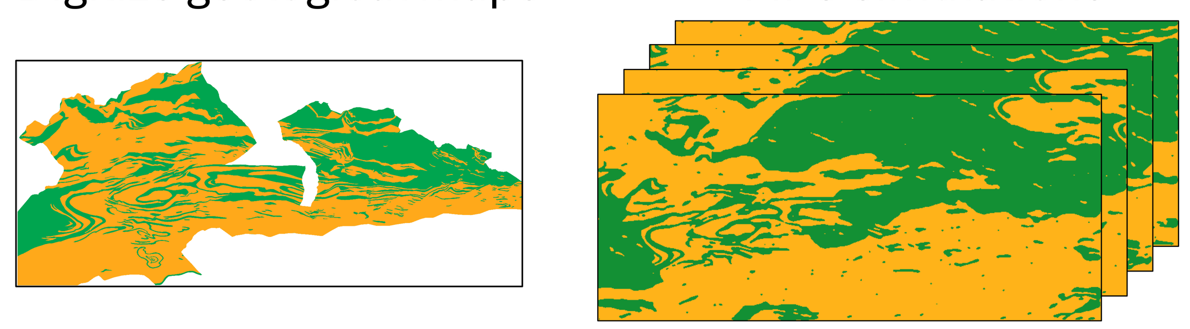
References

Outlook



❖While the 1D layered lower crustal models with TI-type anisotropy considered so far represent a reasonable first-order abstraction, the actual structure and anisotropy prevailing in the Ivrea Zone are much more complex.

❖To address this problem, we digitize all high-quality maps available for the central Ivrea Zone (e.g., James, 2002) and use them as training images for corresponding structural models based on multi-point statistics (MPS) (e.g., Gravey and Mariethoz, 2020).

❖MPS-based stochastic models are populated with seismic velocities accounting for generic anisotropy governed by the local orientations of the foliation.

❖The seismic response of these models is assessed by generating wide-angle synthetic seismic reflection profiles using a finite-difference solution of the generically anisotropic elastodynamic equations.

➢ [EGU25-3693] Wed, 30 Apr, 09:05–09:15 (CEST) Room 0.16
A new seismic model of Ivrea-type lower continental crust accounting for realistic structural complexity, spatial variability, and generic anisotropy