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Continental lithosphere - mosaic of microplates with a rigid mantle lithosphere

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Motto: seismic anisotropy – particularly changes in its 3D orientation in the upper mantle (mantle lithosphere) – a clue in understanding continental plate structure and plate development

CzechGeo/EPOS workshop, Nov 16, 2016, Prague

Passive seismic experiments are designed to bring answers on questions related to specific structural targets in different provinces

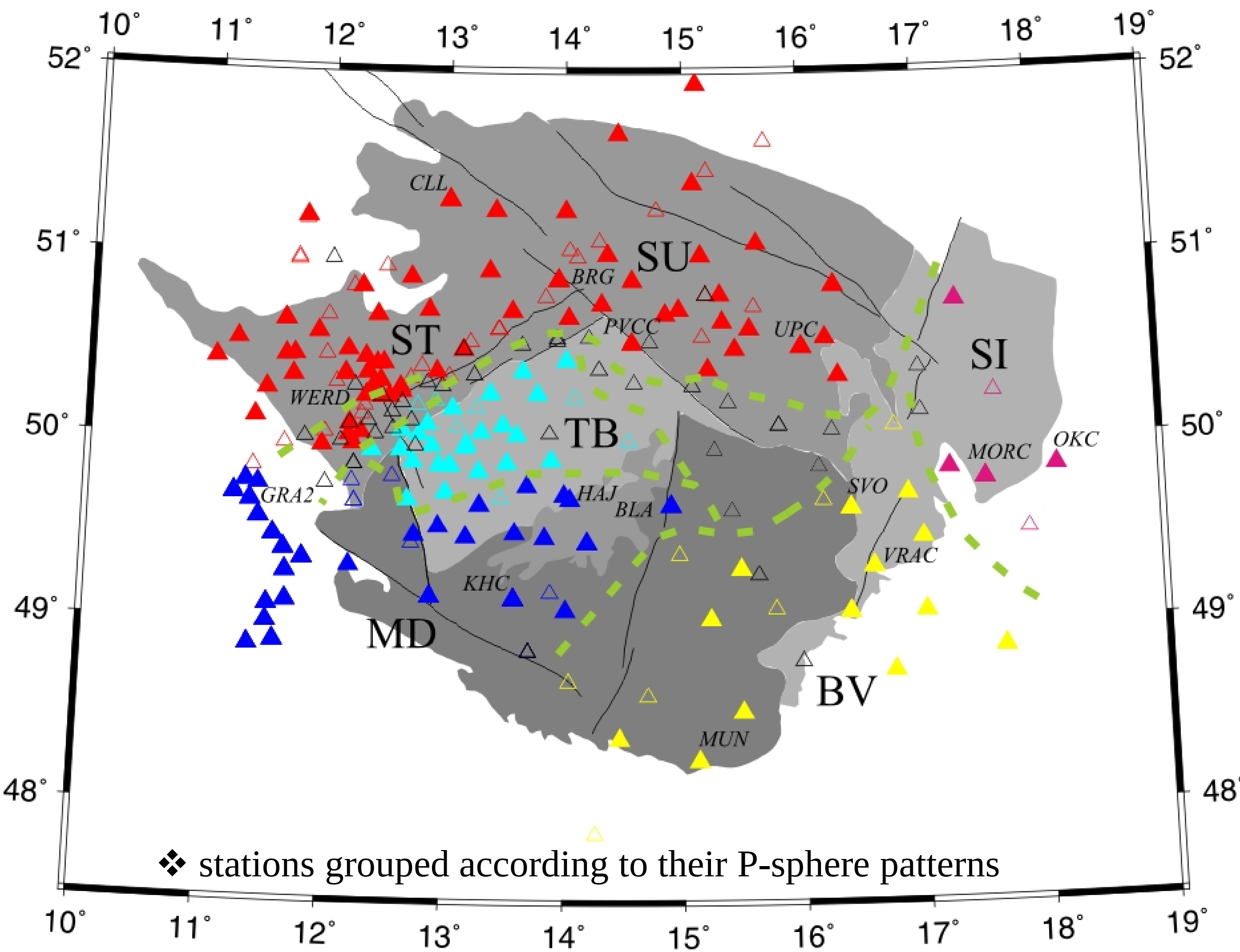
tools to study upper mantle fabrics – **body-wave anisotropy** evaluated from directional dependences of **travel time deviations** of teleseismic P waves and **shear-wave splitting** (analogy of optical birefringence)

BOHEMA experiments – focused on structure of the upper mantle beneath the BM

Similarly to other regions in tectonically different provinces in Europe:

- delimit domains of mantle lithosphere
- domains retain its own fossil fabric
- acc. to character of changes of anisotropic parameters we distinguish orientation of boundaries between the domains – narrow steep, narrow inclined, a transition
- Mapping LAB – lower boundary as a transition between the fossil anisotropy in the mantle lithosphere and anisotropy related to present day flow in the underlying asthenosphere

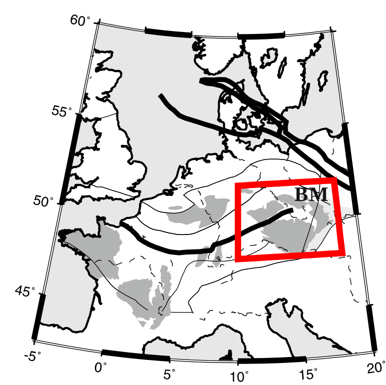
Domains of mantle lithosphere - each with consistent fabric



❖ stations grouped according to their P-sphere patterns

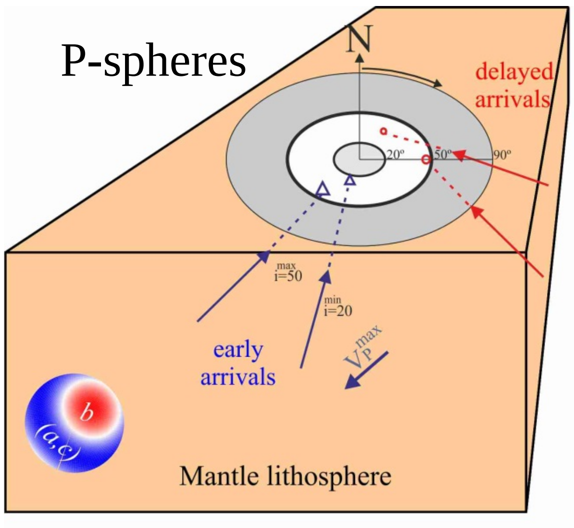
Passive seismic experiments in the BM

Exp'92 *1992 CZ*
MOSAIC 1998-1999 CZ-F
BOHEMA 2001-2003 CZ-F-G
BOHEMA II 2004-2005 CZ
BOHEMA III 2005-2006 CZ
ALPASS 2005-2006 intern.
PASSEQ 2006-2008 intern.
Eger Rift 2007-2011 CZ

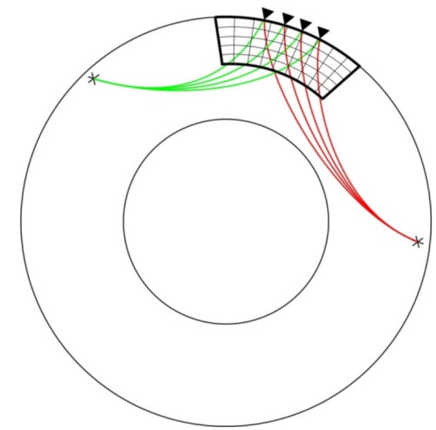


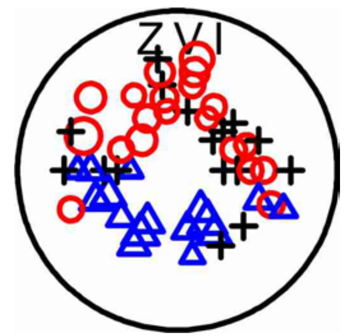
Babuška and Plomerová., Gondwana Res. 2013

Directional variations of relative P-wave travel times



Directional terms of relative residuals





(**-0.5**, 0.5 s)
+ zero (-0.1,01s)

Azimuth-incidence angle dependent terms of relative residuals - in stereographic projection of lower hemisphere

Important – good coverage in BAZ : 0-360º
Incidence angles at Moho: 20º-50º
angels of propagation within mantle lithosphere (epic. distances 20-100)

Waves from SW – faster than from NE, relatively to station directional mean

Bipolar pattern –
consistently faster from one side,
slower form the opposite one

Shear-wave splitting

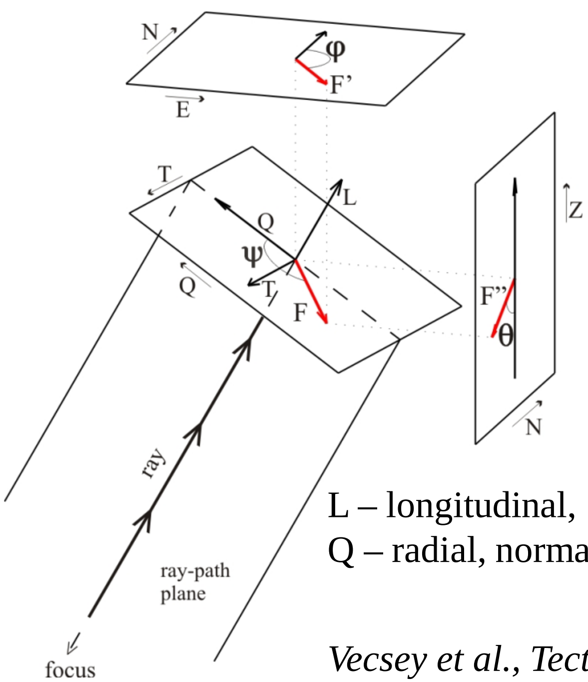
Azimuthal vs. 3D anisotropy

Splitting in 3D

- evaluation generalized into the ray-coordinate LQT system *Šílený and Plomerová , PEPI, 1996*

Reasons:

- splitting parameters depend on back-azimuth
- different splitting parameters for waves from opposite back-azimuth
- seeming incompatibility between high-velocity direction from shear-wave splitting and directional variations of P-wave travel times

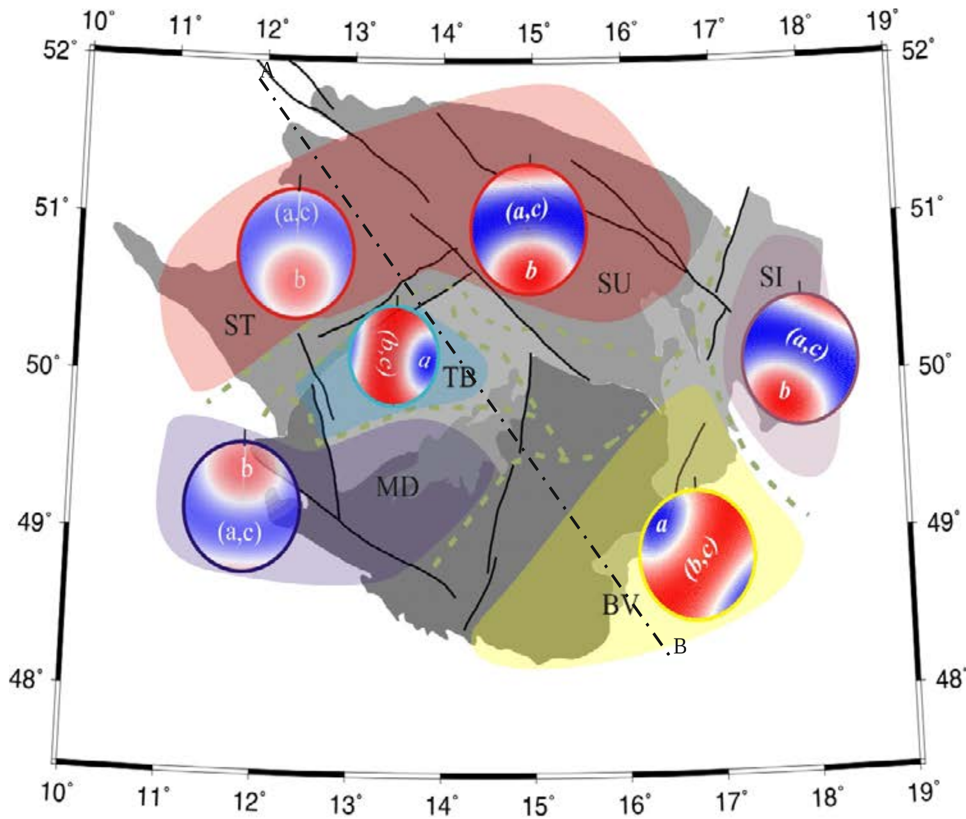


L – longitudinal,
Q – radial, normal to (L-T) plane

Vecsey et al., Tectonophys. 2008

- search for the **fast polarization direction ψ** in the plane (Q-T) perpendicular to the ray path plane (L-Q) of the shear phase.
- A rotation of the coordinate system in the plane (Q-T) by angle ψ, and a time shift δt (s) imposed on the shear-wave components, yield the splitting parameters determined in 3-D.
- the fast polarization direction ψ - defined by two Euler angles – azimuth φ and inclination θ (measured upward from the vertical Z axis oriented downward).

3D self-consistent anisotropic models of BM mantle lithosphere



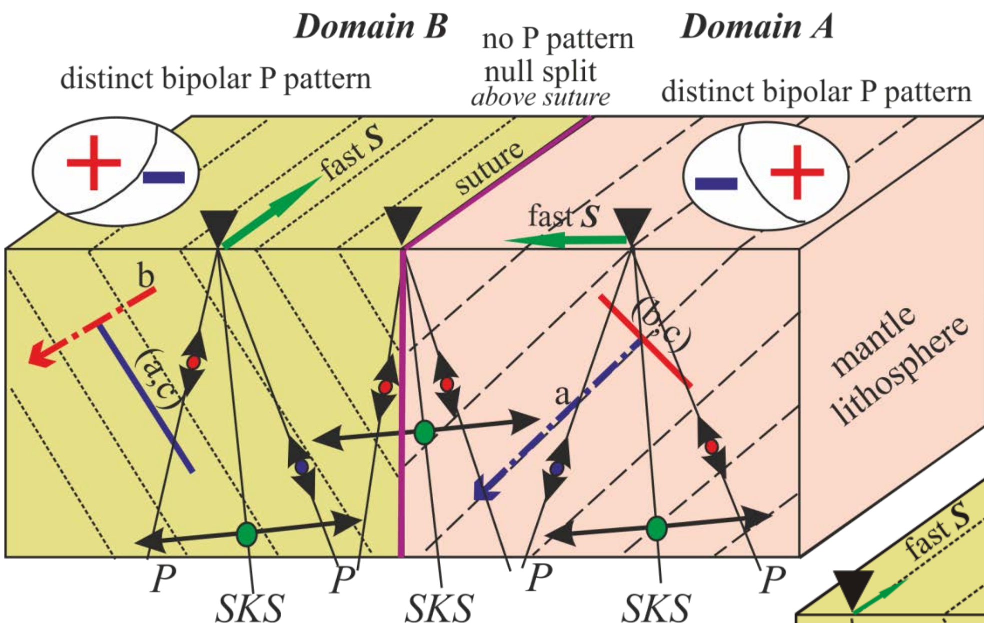
- Each domain of mantle lithosphere is characterized by its own fabric with inclined symmetry axes
- Boundaries of the mantle domains are shifted relative to their crust equivalents
- we interpret the mantle lithosphere fabrics as fossil structure formed during origin of individual mantle lithosphere fragments
- Assumed simple cooling process of forming the lithosphere would result in horizontal layering

Models of domains of the mantle lithosphere with **inclined fabrics** retrieved by **joint inversion of P and S anisotropic parameters**

Babuška and Plomerová, Gondwana Res. 2013

Mantle lithosphere domains with consistent anisotropic signals

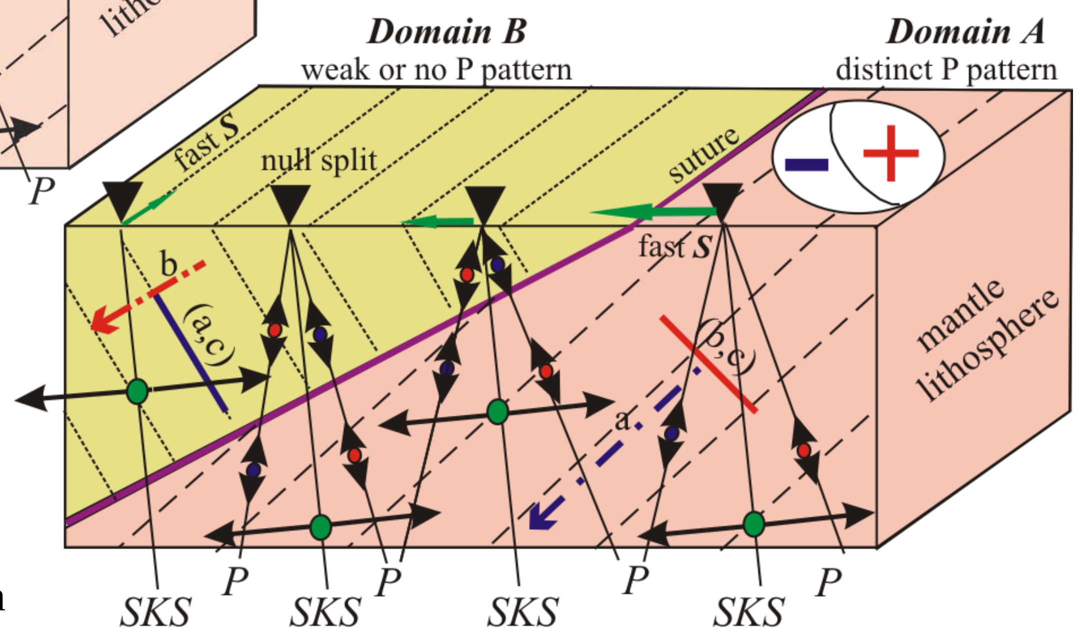
Steep domain boundary



domain boundaries mapped by change of anisotropic signals

Broad transition zone

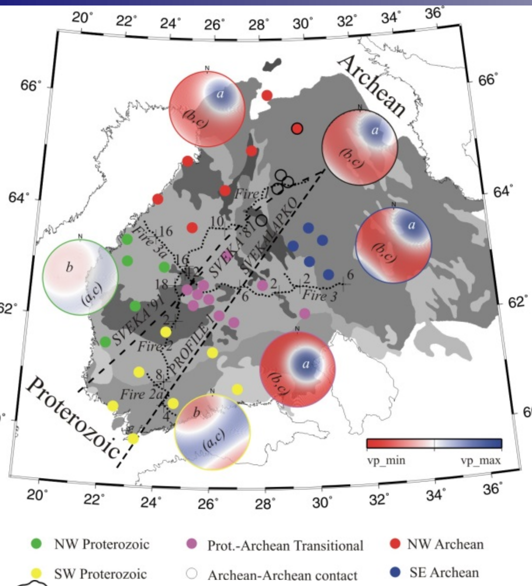
Oblique domain boundary

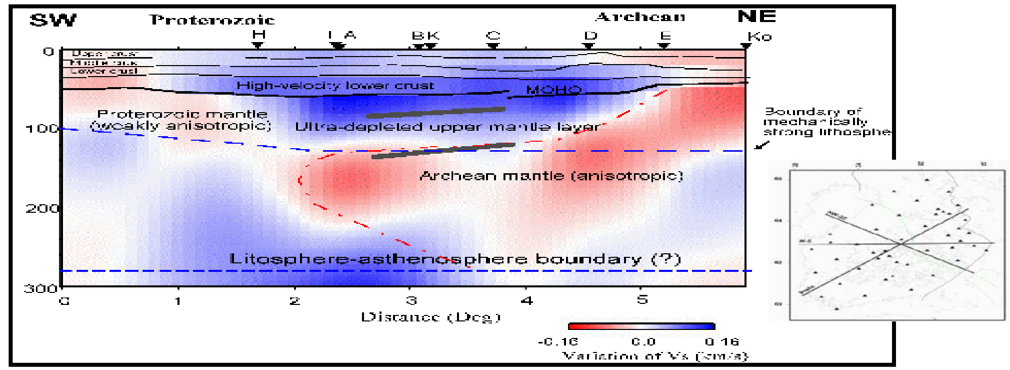


Abrupt changes of the parameters on a short distance

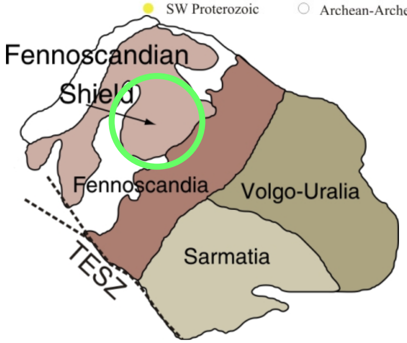
Within each domain - parameters stable; not a product of shearing within a suture

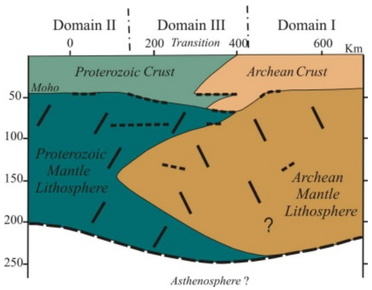
If anisotropy were generated within the suture zones, intensity would decrease with distance from the suture

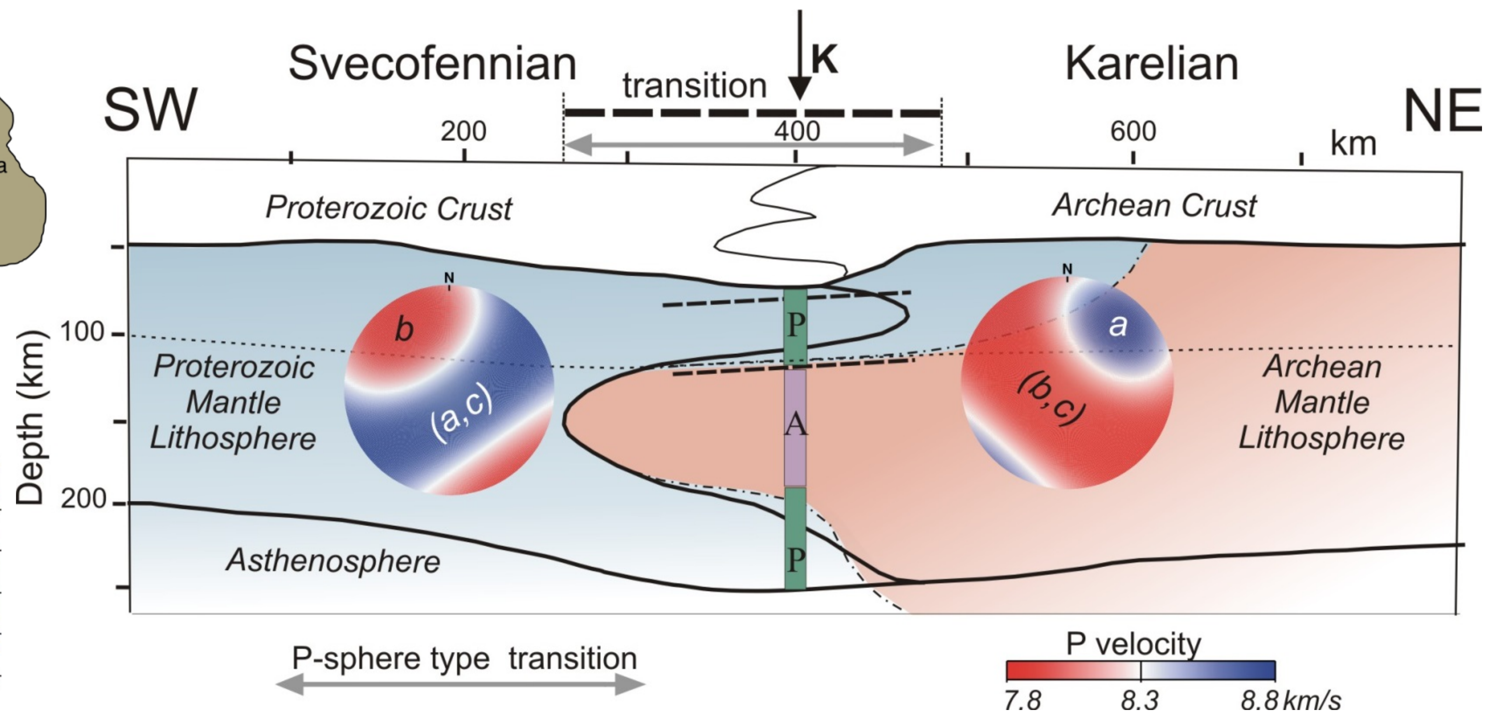




After Funk and Friederich, 2003; Hjelt et al, EDL 2006 in press







Xenolith ages (Peltonen and Bruegmann, 2006)

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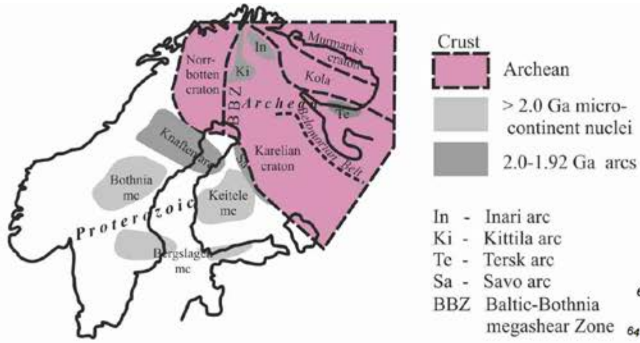
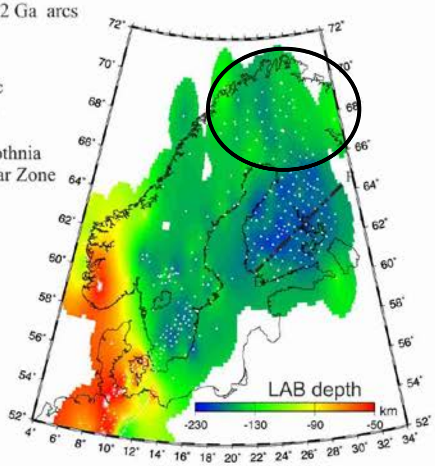
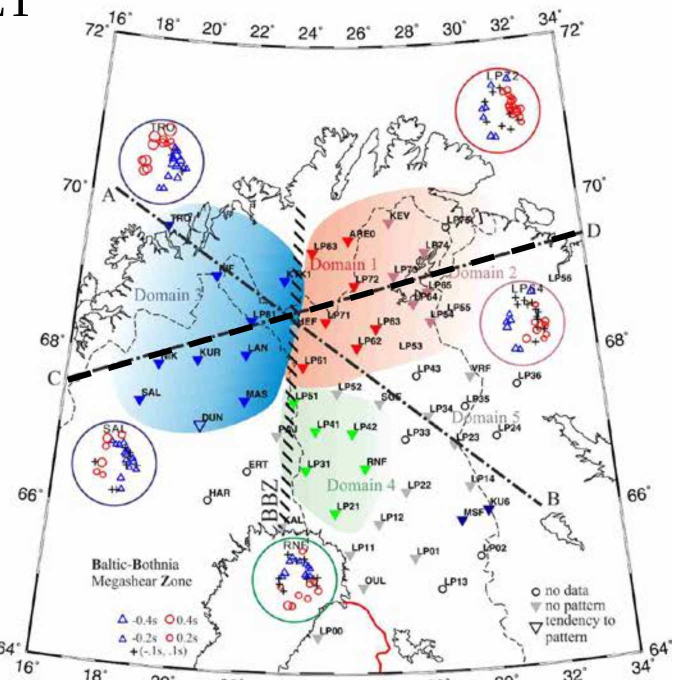
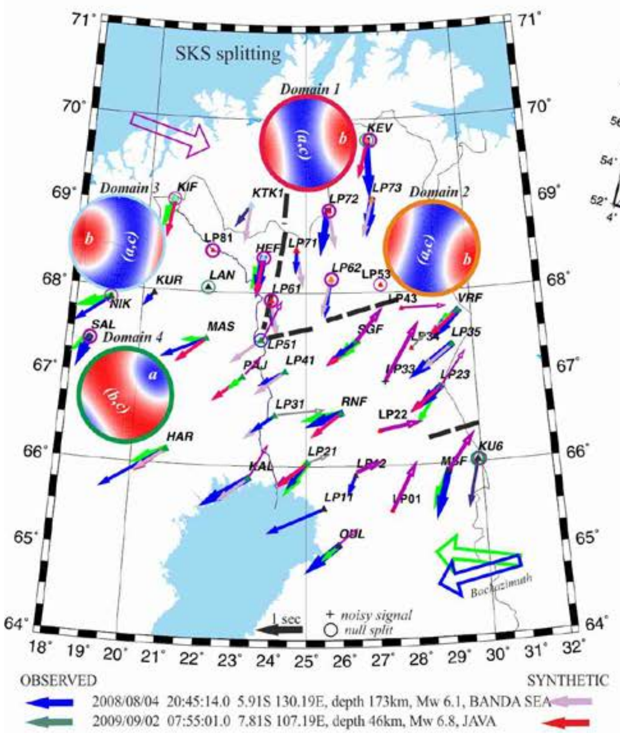
Mantle Lithosphere beneath northern Fennoscandia

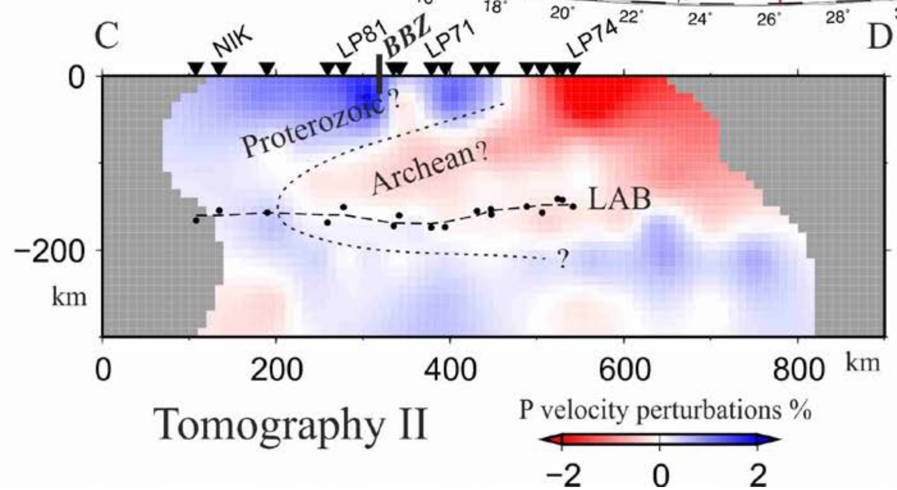


POLENET/LAPNET
2007-2009



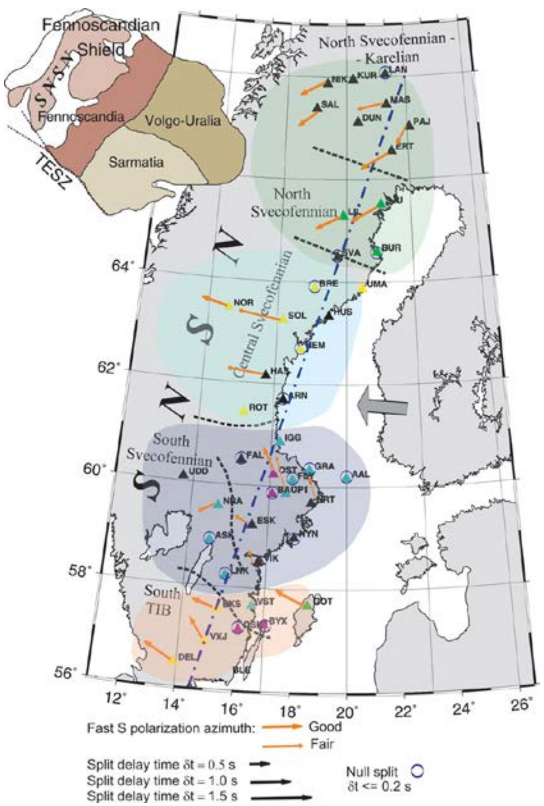


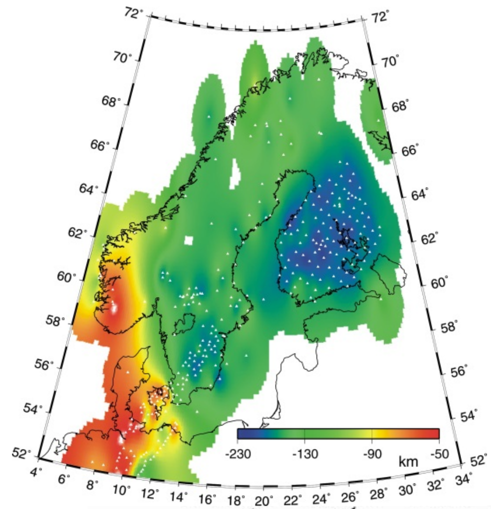




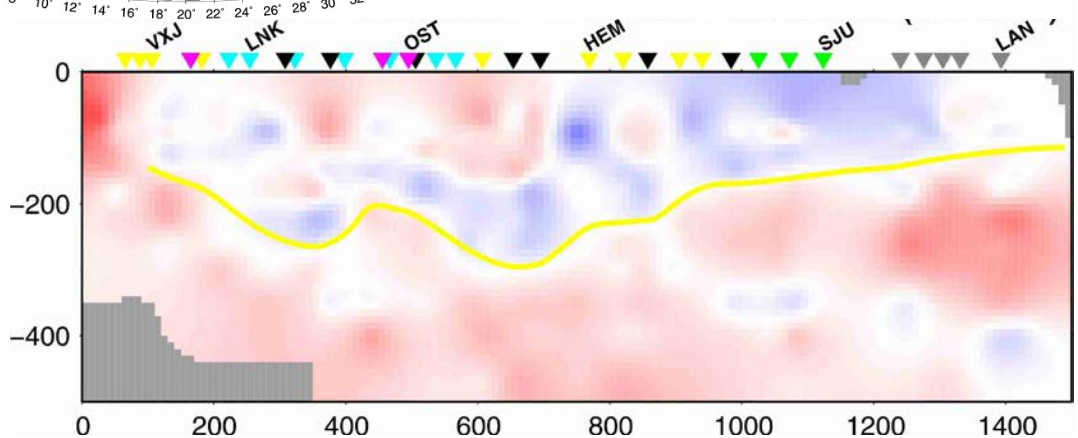
Plomerová et al., Solid Earth 2011

Domains of mantle lithosphere in the Baltic Shield (Svecofennian)





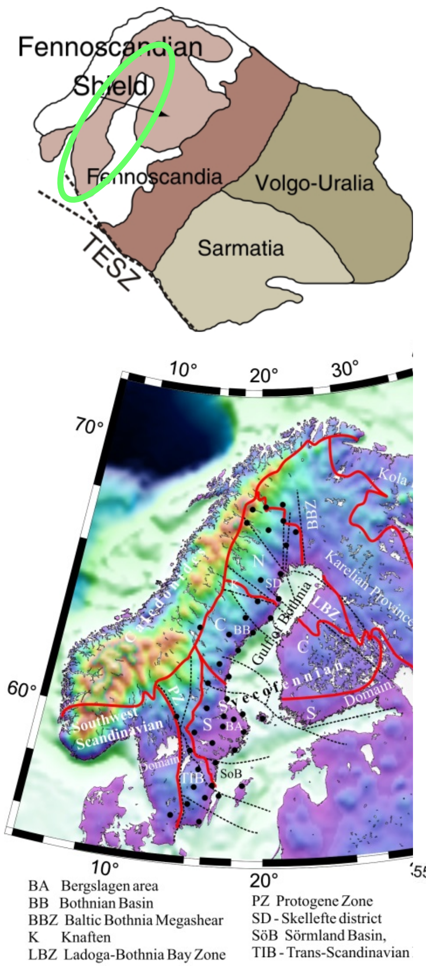
Teleseismic P-wave tomography

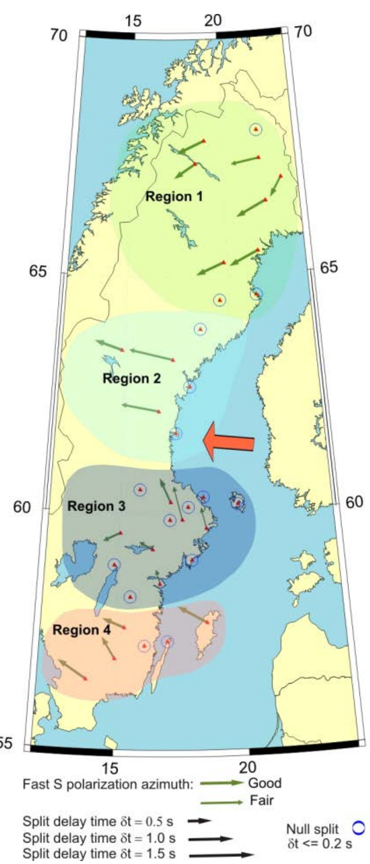


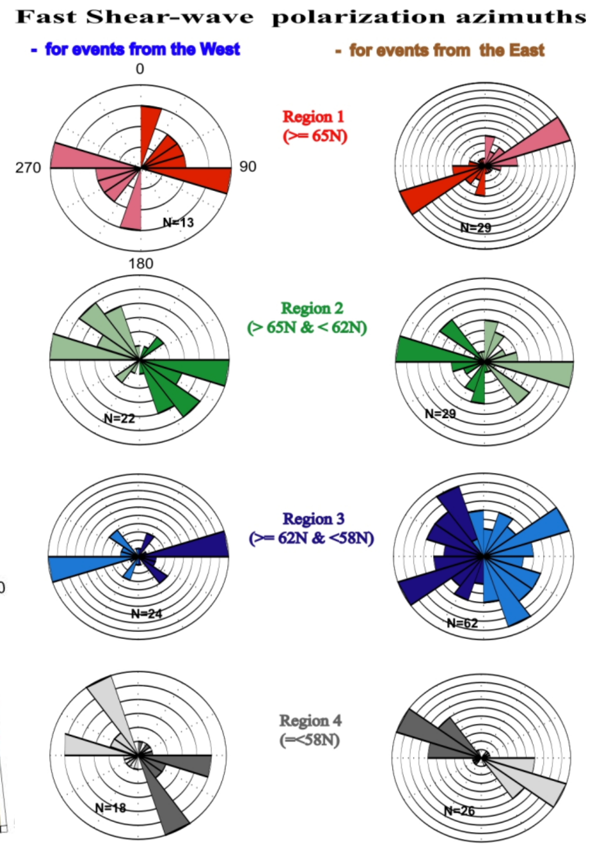
Eken et al., GJI 2012

Lithosphere thinning to the North
(northern Fennoscandia)

Seismic anisotropy of Precambrian Europe - Fennoscandian Mantle Lithosphere







- Different BAZ dependences in each domain
- abrupt changes in parameters - domain boundaries
- domains have their own history and different fossil fabrics, created before they assembled
- **Distinct geographical variations of anisotropic parameters**

Eken et al., Tectonophysics 2010

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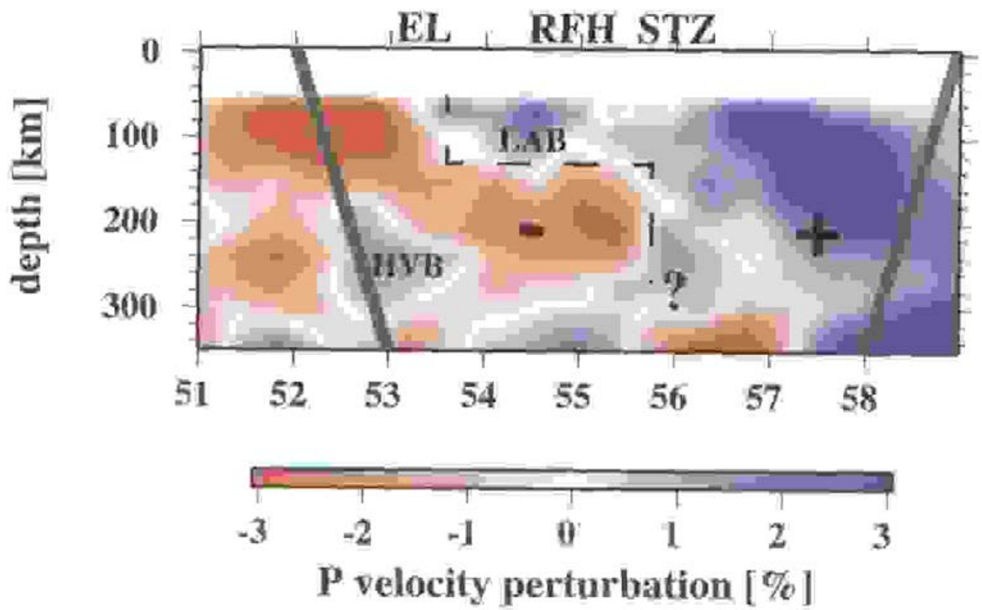
EUROPROBE – TESZ/TOR

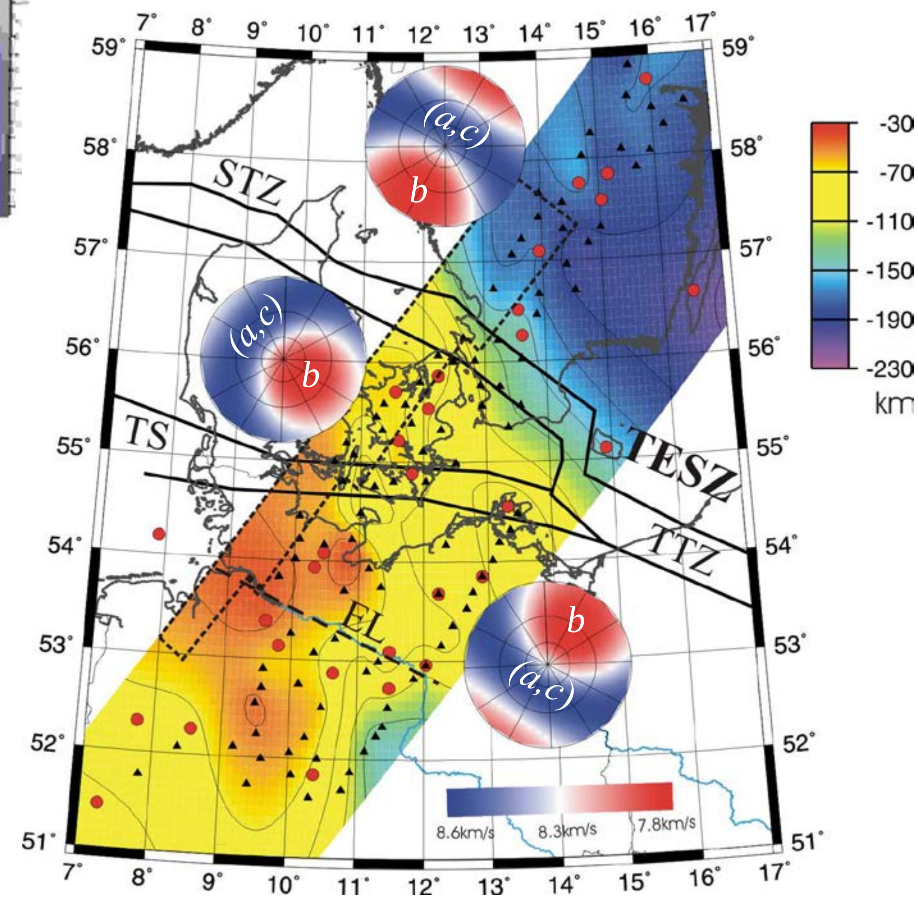
Teleseismic P - velocity Tomography



Shomali, PhD Thesis 2001

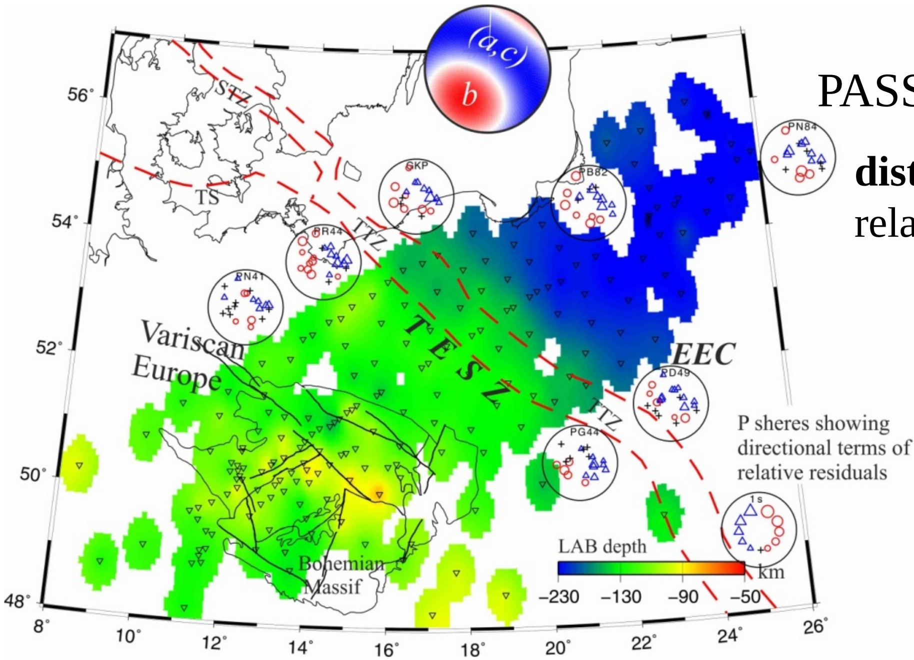
Joint inversion of anisotropic parameters of body waves – anisotropic part of relative travel time delays and shear-wave splitting - three domains of mantle lithosphere of different thickness, but also with different fabrics and sharp boundaries.

Lithosphere thickness and anisotropy along the TOR array crossing the Trans-European Suture Zone in Germany, Denmark and Sweden



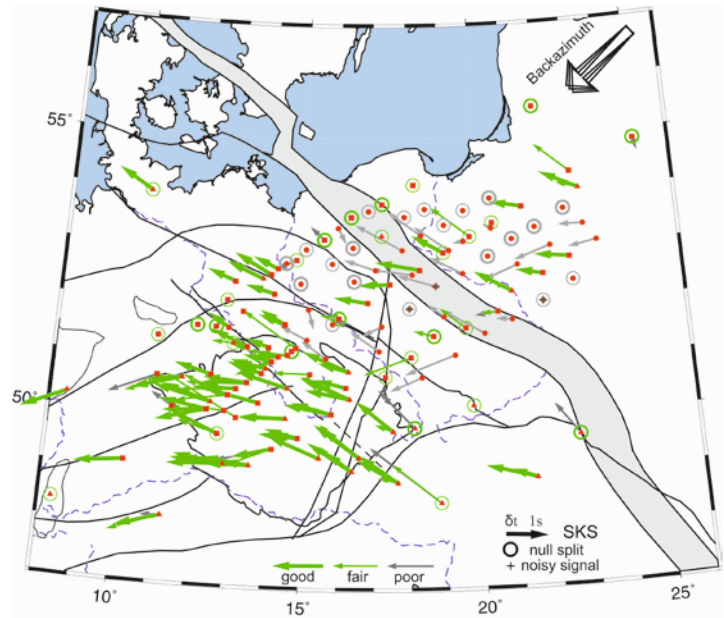
Plomerová et al., Tectonophys., 2001,
Babuška and Plomerová, Terra Nova , 2004

LAB around the central TESZ from P-wave travel times



PASSEQ 2006 - 2008

distinct change in lithosphere **thickness** relates the TTZ – boundary of EEC

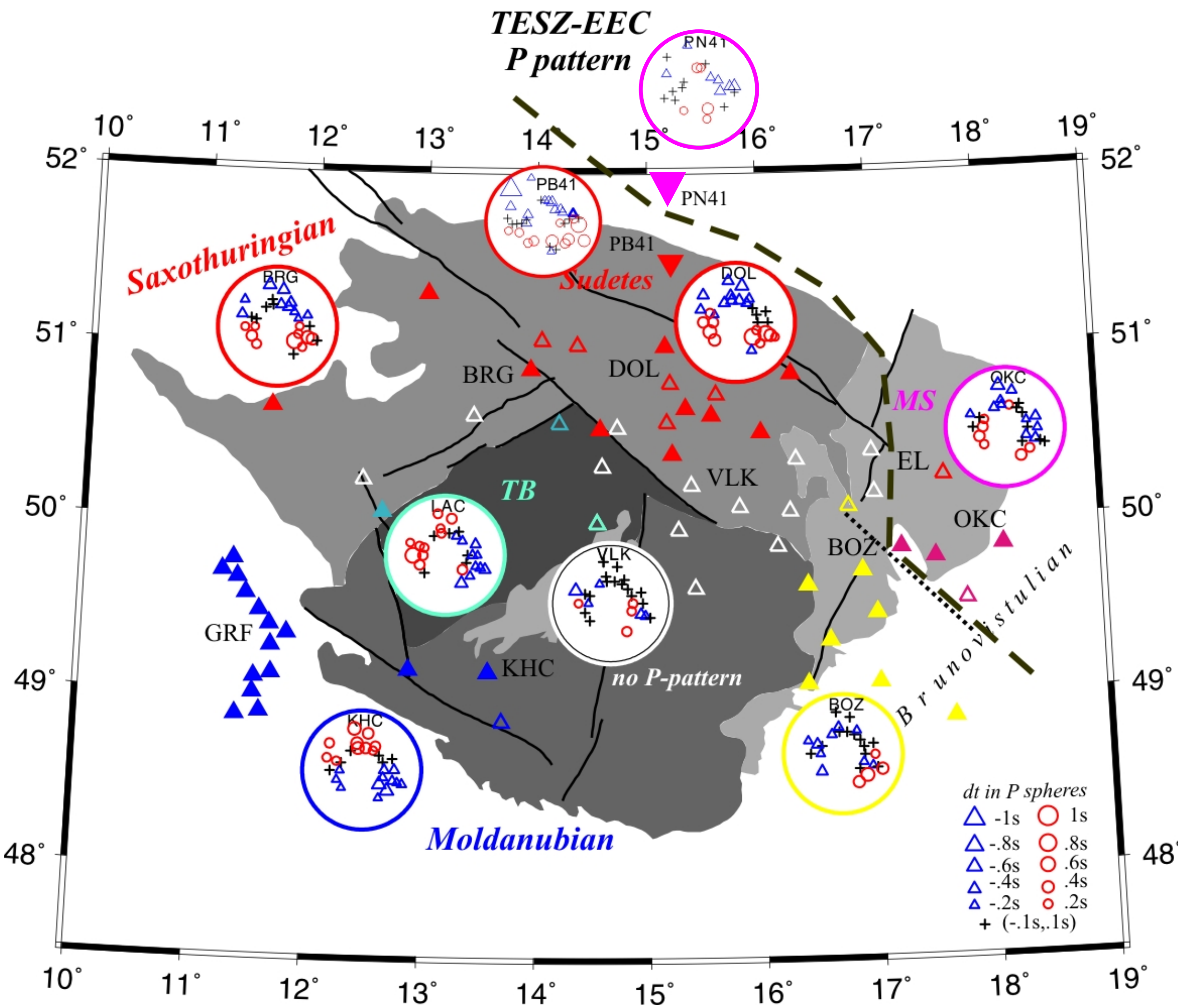


Lateral change of **shear-wave splitting** parameters –the **northern edge of the BM**

- Anisotropic signal **changes north of the BM** both in P spheres and shear-wave (SKS) splitting *(Vecsey et al., Solid Earth 2014)* -
- characterictic P- sphere pattern – similar to that modelled in Fennoscandia *(Eken et al., Tectonophysics 2010)*

- *The Phanerozoic lithosphere East of the TTZ thrusts over the Precambrian lithosphere beneath the EEC; whose mantle lithosphere seems to penetrate SW of the TTZ , probably as far as beneath the BM.*

P- sphere pattern in northern and eastern Bohemian Massif



BOHEMA II (2004-2005)

Stations with similar pattern form **groups**

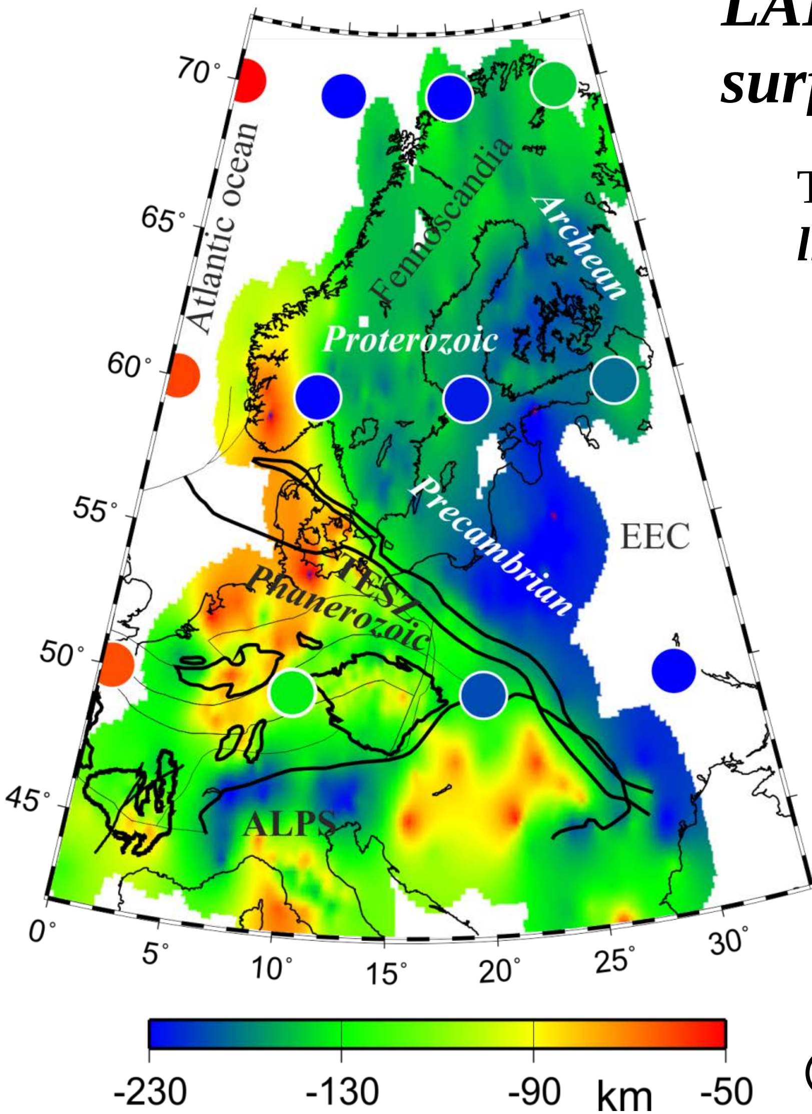
P-sphere pattern remains constant = independent of data set (i.e., array, time interval)

Pattern in **Sudetes = ST**

no pattern - transitional to the MS and BV

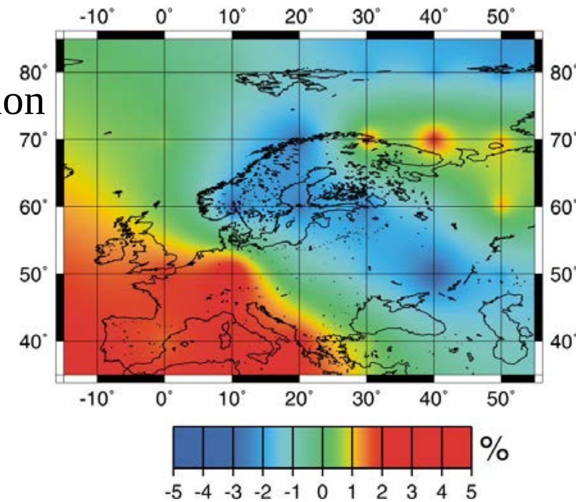
Plomerová et al.,Tectonophysics 2012

LAB from body-wave travel-times and surface-wave anisotropy (ψ_G, ξ) models



TESZ – separates ~***200-250 thick Precambrian lithosphere in both models*** – blue

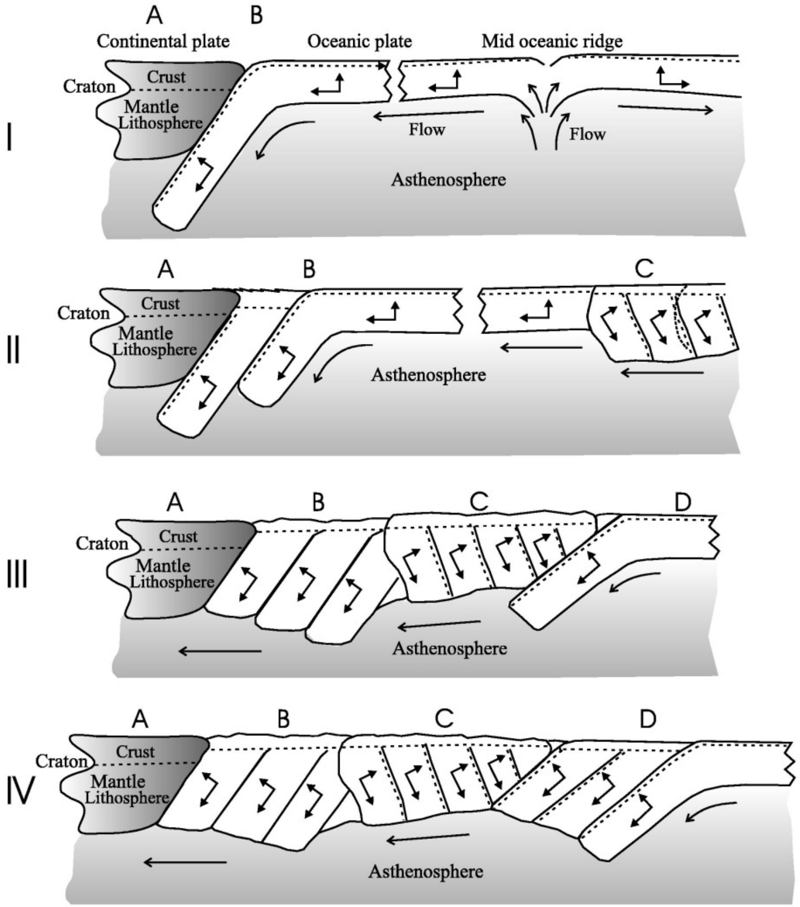
Max deviation
$\xi - \xi_0$



Phanerozoic central Europe - ~120 km green
Shallow beneath basins yellow-red
Lithosphere thinning towards the Atlantic

○ LAB model from azimuthal and radial anisotropy of surface waves, *Plomerová et al., Tectonophysics 2002*

Model of a possible growth of continental mantle lithosphere resulting in inclined fossil fabric - formation by stacking of oceanic plates (successive subductions)

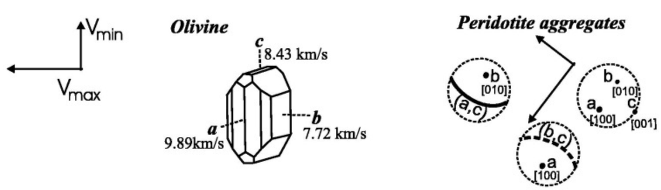


(I) **Oceanic lithosphere** (B) subducting beneath an old continental craton (A) **retains** its preferred olivine orientation (**LPO**) in the mantle part.

(II) **The ongoing subduction ceases and a new one starts** (B) outboard of the enlarged continent.

(III) **Continent-continent collision**, each microplate (B,C) has own **ready-made fabric.** New oceanic subduction (D) starts.

(IV) Deep **parts of the episodically subducting slabs** detach and **the LAB is being gradually smoothed by a mantle flow.**



The **LPO of olivine in peridotite aggregates –** approx. by hexagonal or orthorhombic symmetry **with inclined lineation *a*, or foliation *(a,c)*.**

Babuška and Plomerová, AGU Monogr. 1989; Plomerová and Babuška , Lithos 2010

Conclusions

Evaluating **body-wave velocity anisotropy in 3D** allows us to model **fabrics** of individual regions of continental **mantle lithosphere** and relief of the **LAB**.

The continental lithosphere consists of **mosaic of domains** with their **own fabrics.**

The domains, **amalgamated** during different tectonic processes, retain their original **fossil fabrics**.

Thanks for your attention