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Magnetotelluric data across Ciomadul volcano and the Perşani Volcanic Field — constraints on the nature and structure of the magma storage system

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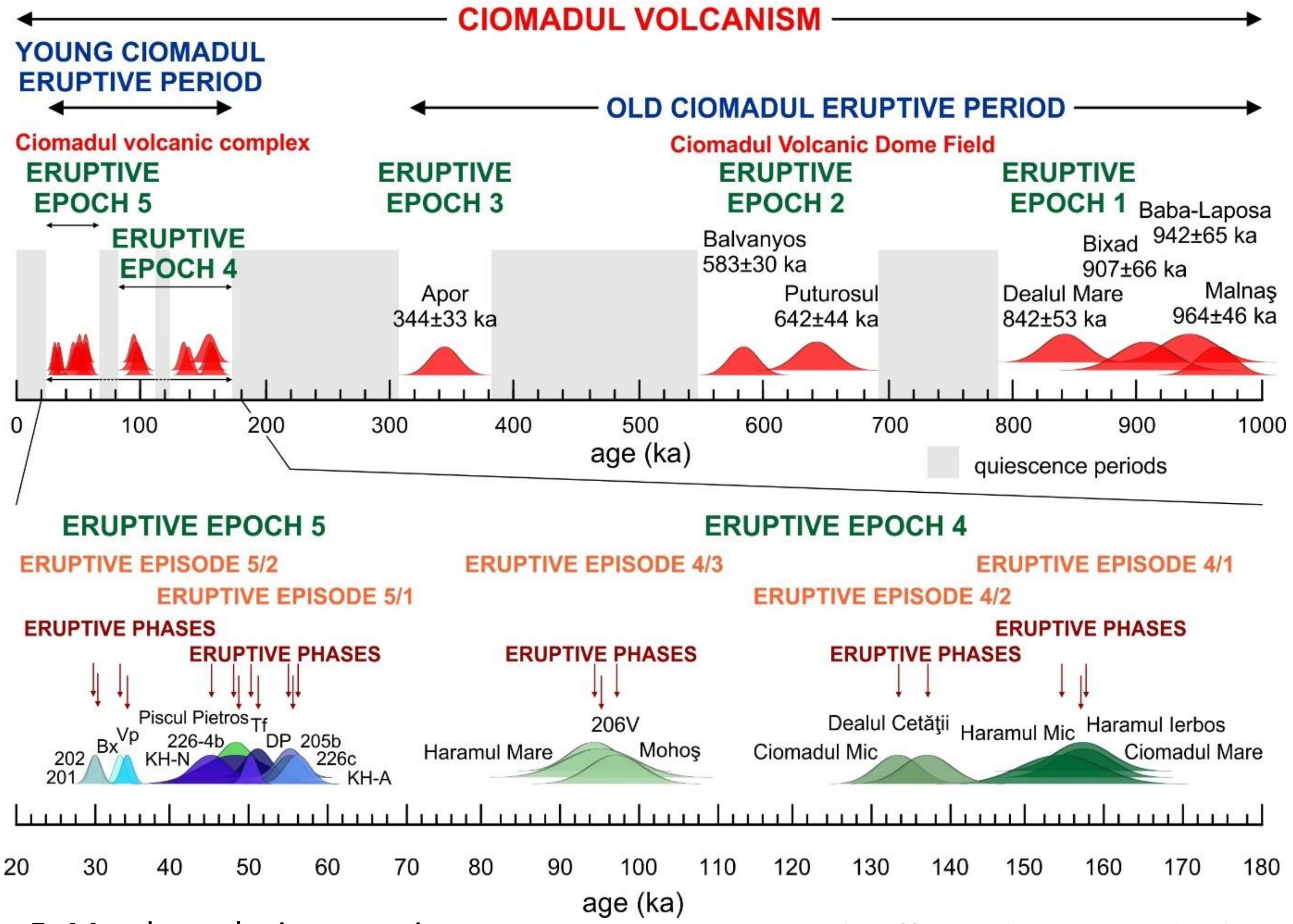
VOLCANOES WITH POTENTIALLY ACTIVE MAGMA STORAGE

- How do decide if a volcano is "inactive"?
- Length of time since last eruption? (some definitions 10+ ka)
- At seemingly inactive ("sleeping", dormant) volcanic activity could be renewed, in the right conditions.
- To gain insights, one must examine the nature and structure of the magma storage system beneath the volcano, as well as its eruptive histoy.
- What is the depth and geometry of magma storage and what is the amount of magma or crystal mush present?

VOLCANOES WITH POTENTIALLY ACTIVE MAGMA STORAGE

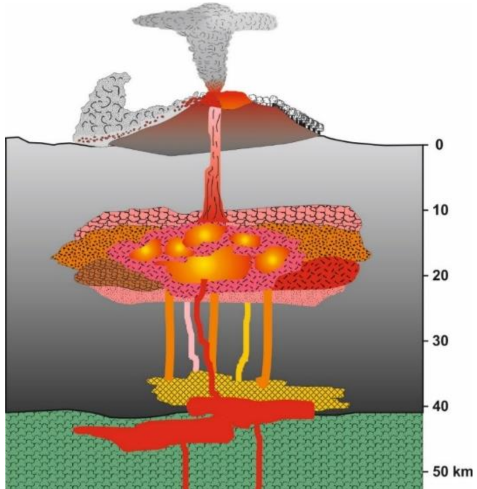


5: Mostly explosive eruption stage (ca. 56-30 ka)

4: Mostly effusive lava dome-building stage (ca. 160-100 ka)

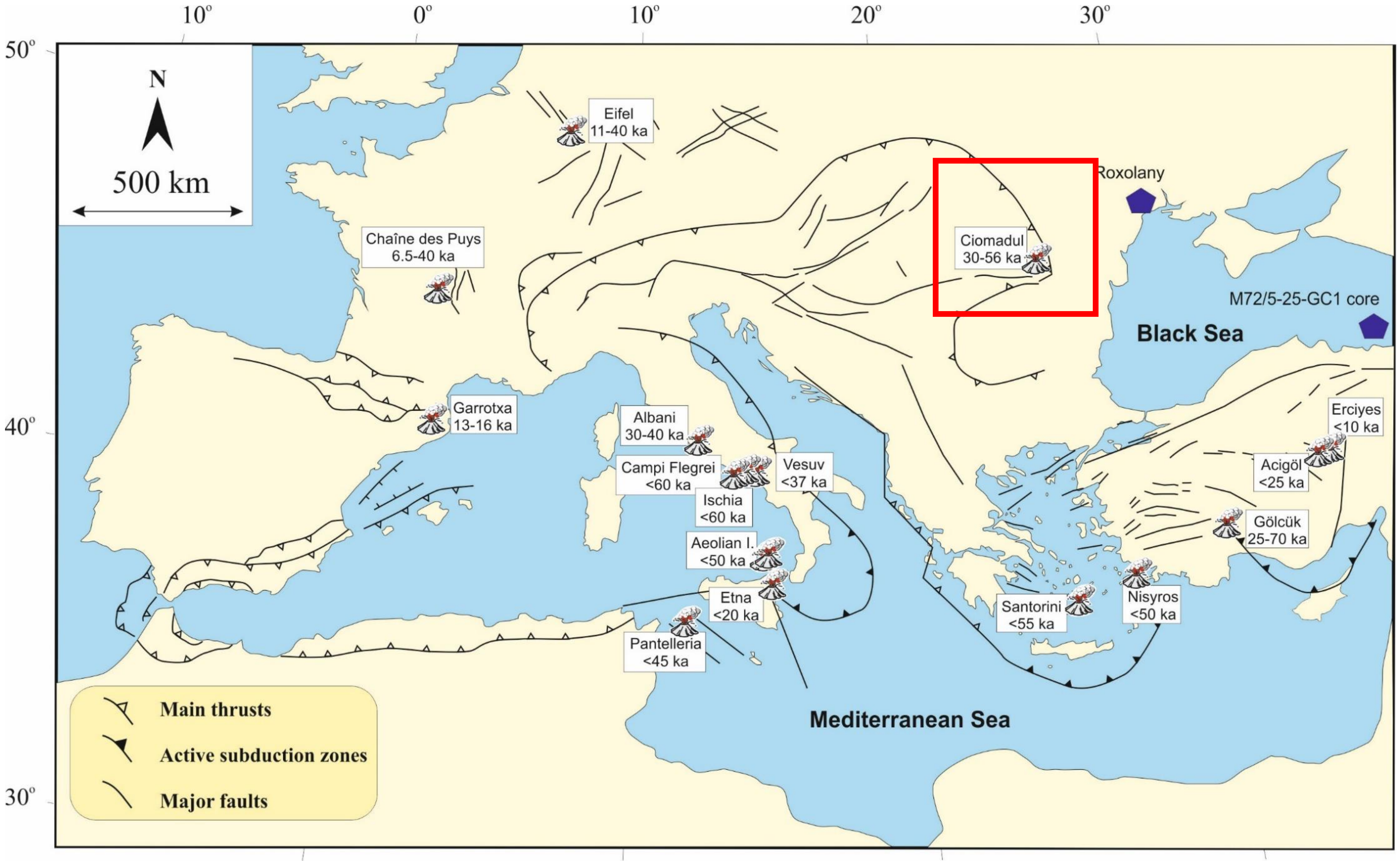
Harangi et al., 2010; Harangi et al., 2015, 2020; Molnár et al. 2018; 2019

- Volcanoes with Potentially Active Magmatic Storage
- Target: Ciomadul Volcano
- Detailed eruption history (revealed by (U-Th)/He and U-Th zircon dating) shows long repose time, 10,000-100,000 years, between phases
- Volcanism can be rejuvenated after long quiescence.
- Last eruption at Ciomadul occurred at 30,000 years ago
- Long lifetime of the magma storage - near-solidus "cold" crystal-mush state over 10,000s years.
- Remobilization due to injection of hot mafic magma
- Very fast reactivation possible - within weeks/months!
- Ciomadul: Potential for future reactivation and volcanic eruption even after 30,000 year lull in volcanic activity, an underrated risk.
- PAMS volcanoes (Volcanoes with Potentially Active Magmatic Storage) need more attention.



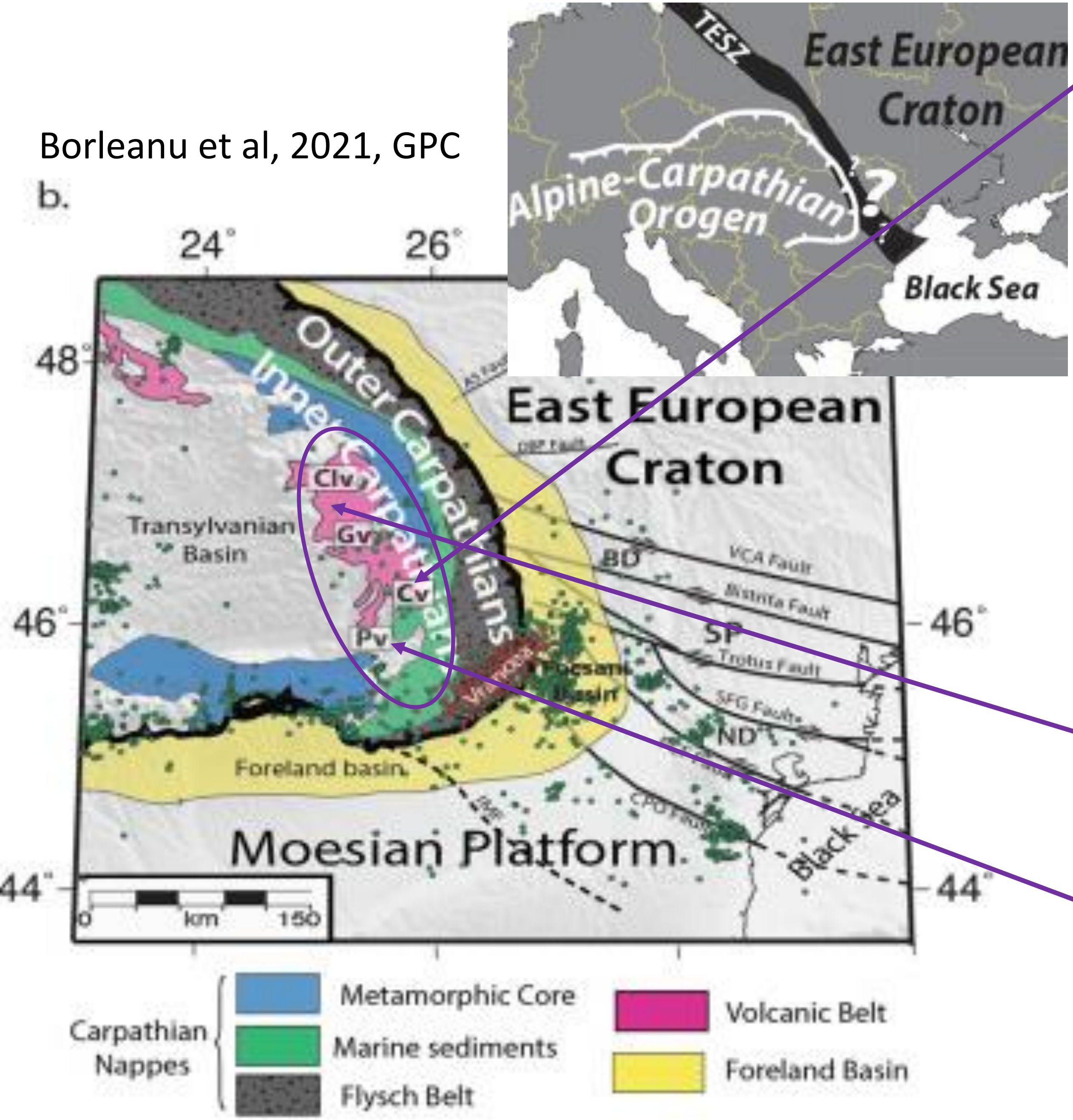
CIOMADUL (ROMANIA)

- Ciomadul volcano is located at the south-eastern terminus of the Carpathian volcanic arc (Romania).



CIOMADUL (ROMANIA)

Borleanu et al, 2021, GPC



- Ciomadul volcano is located at the south-eastern terminus of the Carpathian volcanic arc (Romania).
- It is the youngest volcano in eastern-central Europe, with the last eruption occurring at 32 ka.
- Petrological constraints indicate a melt-bearing silicic crystal mush body approximately 5-20 km below surface.
- The geometry and size of the magma storage region and quantity of melt is unknown.
- Understanding the nature and structure of the volcanic plumbing system is crucial to understanding the evolution of the system, as well as to assess the hazard potential.
- To the north and north-west lies a chain of older volcanic complexes, the Călimani–Gurghiu-Harghita volcanic complex.
- To the west lies an enigmatic basaltic volcanic region, the Perşani volcanic field, with monogenetic cones.

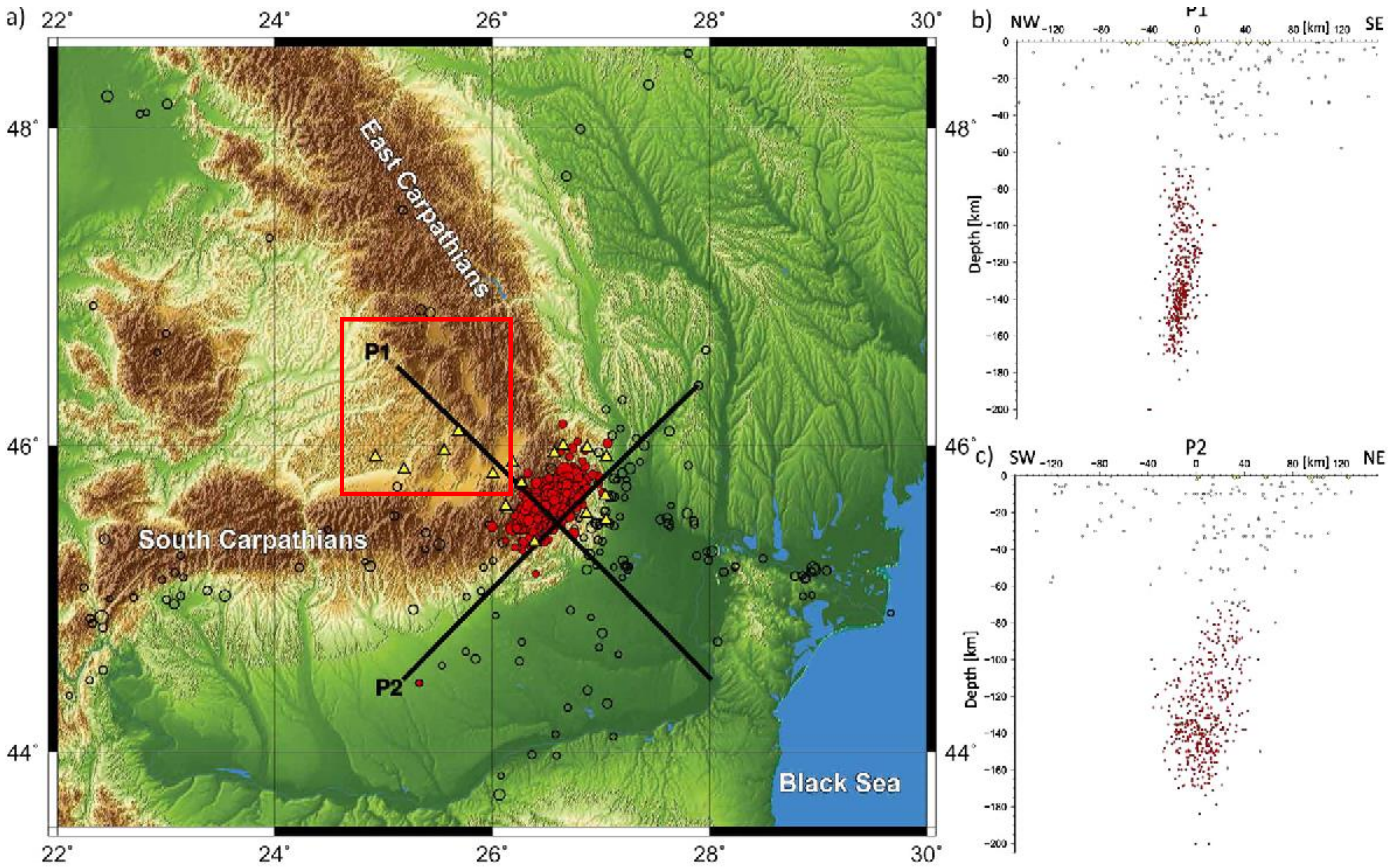
CIOMADUL (ROMANIA) VIEW OF DOME AND CRATER

Szakacs et al, 2015, BV

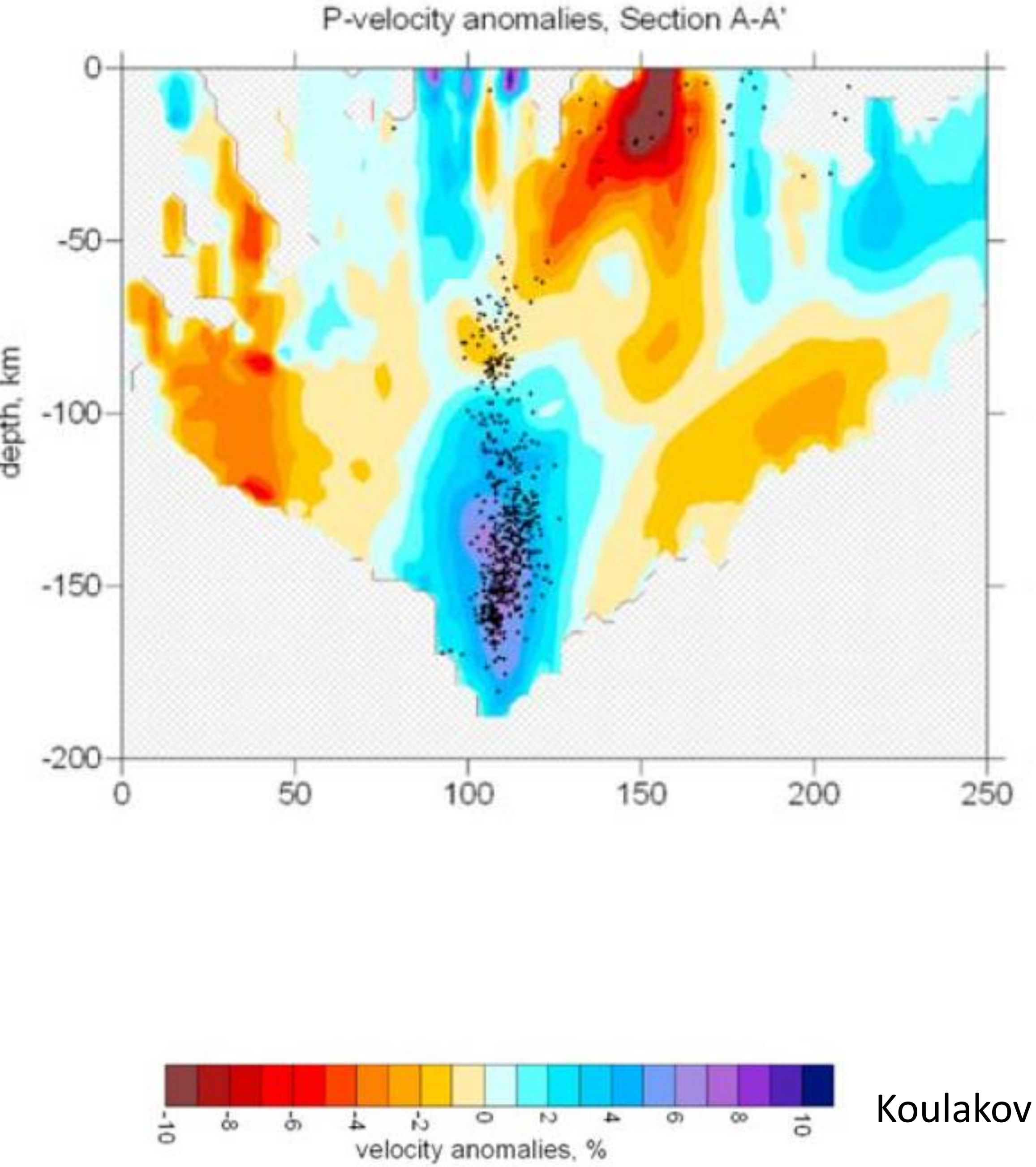
VRANCEA SEISMIC ZONE

- Vrancea region of the southeastern Carpathians is one of the most active seismic zones in Europe.
- It has many strong intermediate depth (70-180 km) earthquakes.
- A high-velocity body, associated with strong earthquakes, extends to at least 350 km depth. Possibly a descending slab?

Bokelmann et al, 2014, EPSL

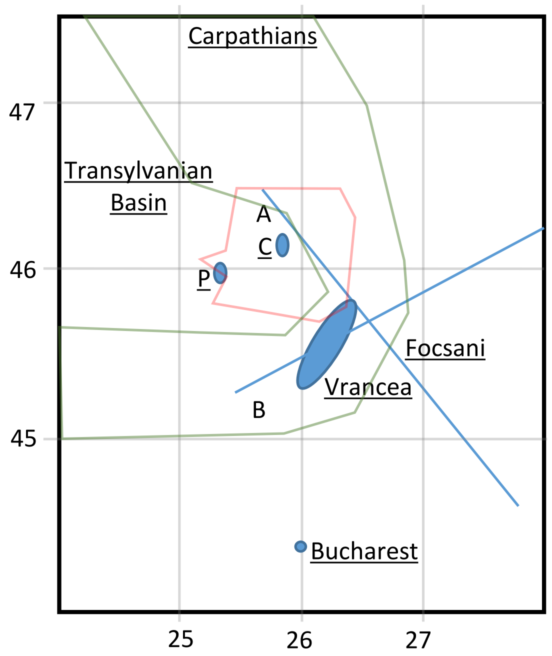


SEISMIC TOMOGRAPHY MODEL (Vp) - VRANCEA



Koulakov et al, 2010, G3

- Tomography results indicate the presence of high-velocity material beneath Vrancea at 60-200 km depth.
- Coincides with distribution of seismicity.
- High-velocity anomaly might represent the delamination and descent of dense eclogitized lower crust, which underwent a transformation due to thickening from continent-continent collision.
- Delamination can lead to high topography.
- Return flow leads to upwelling at the edges of (asthenospheric) mantle material



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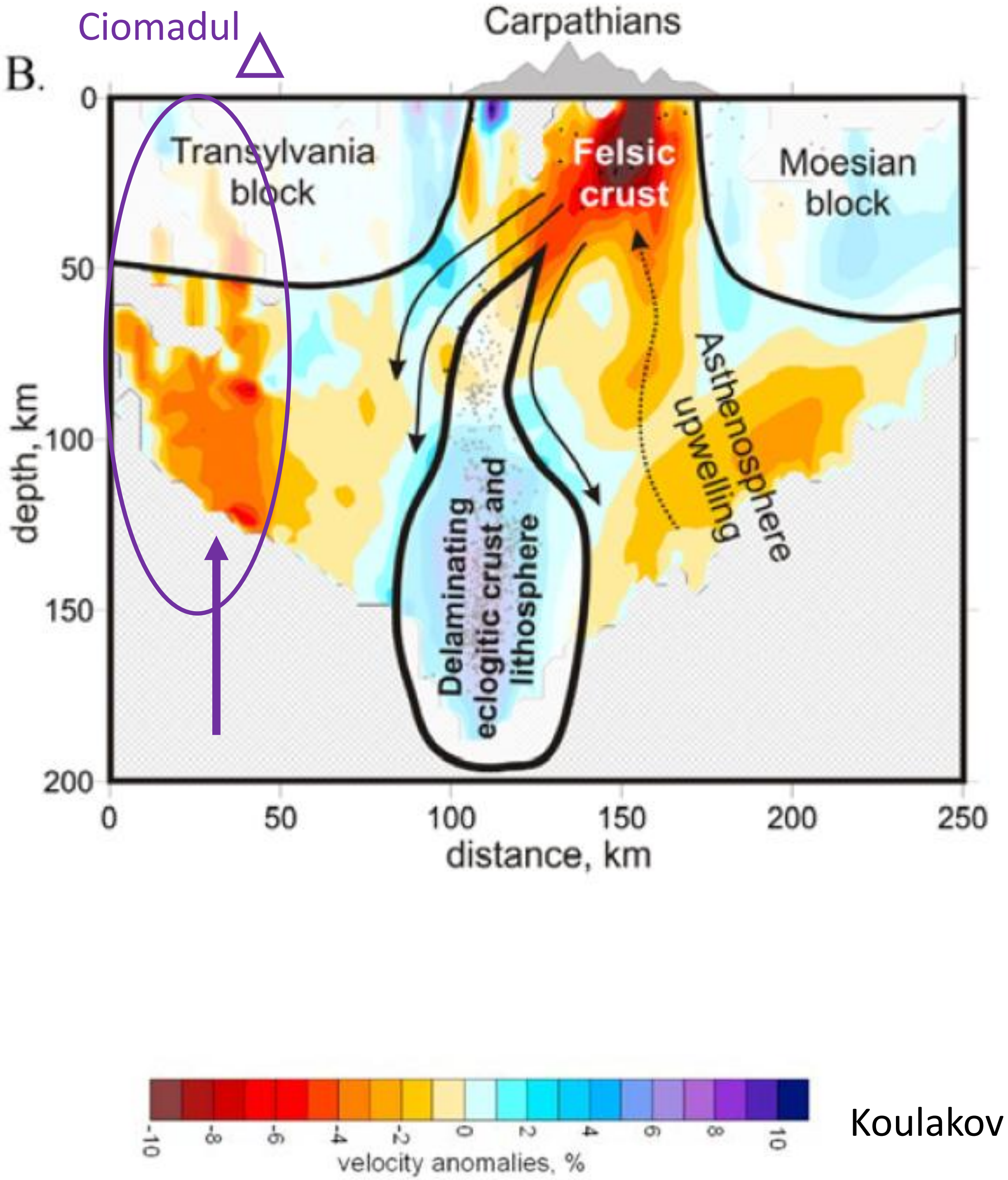

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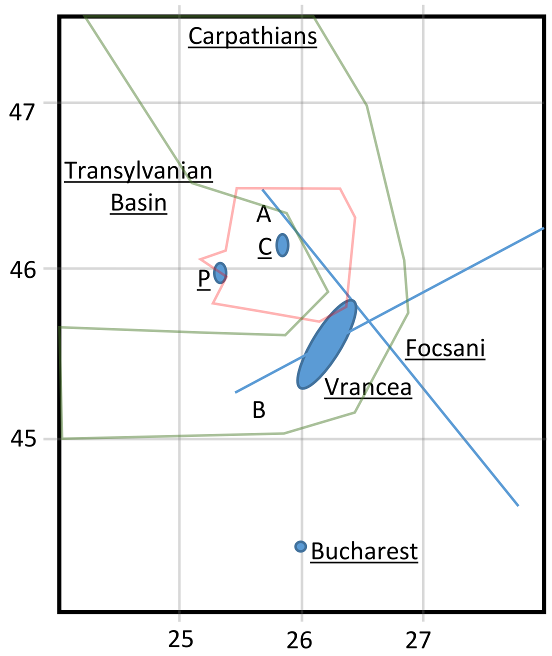

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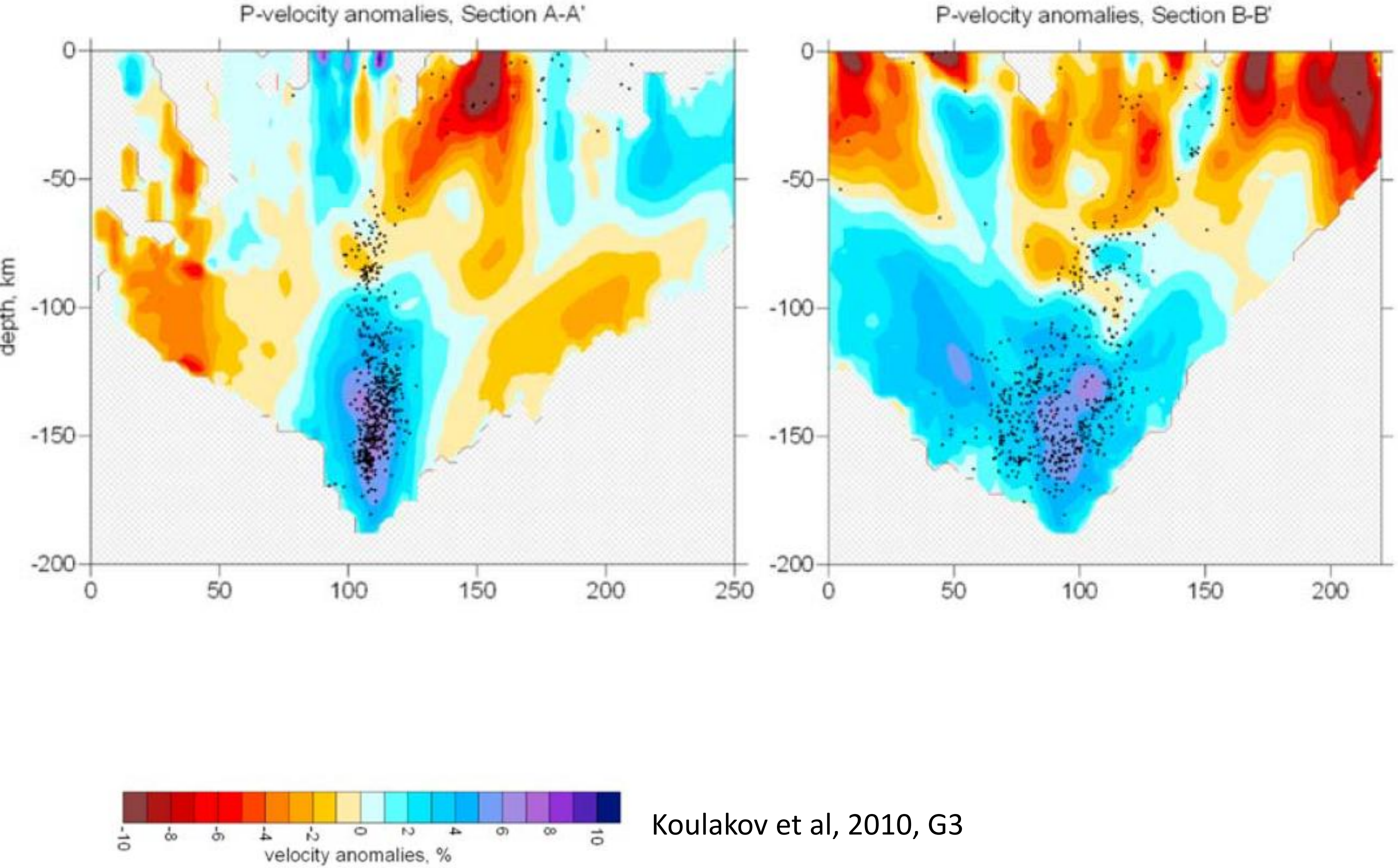
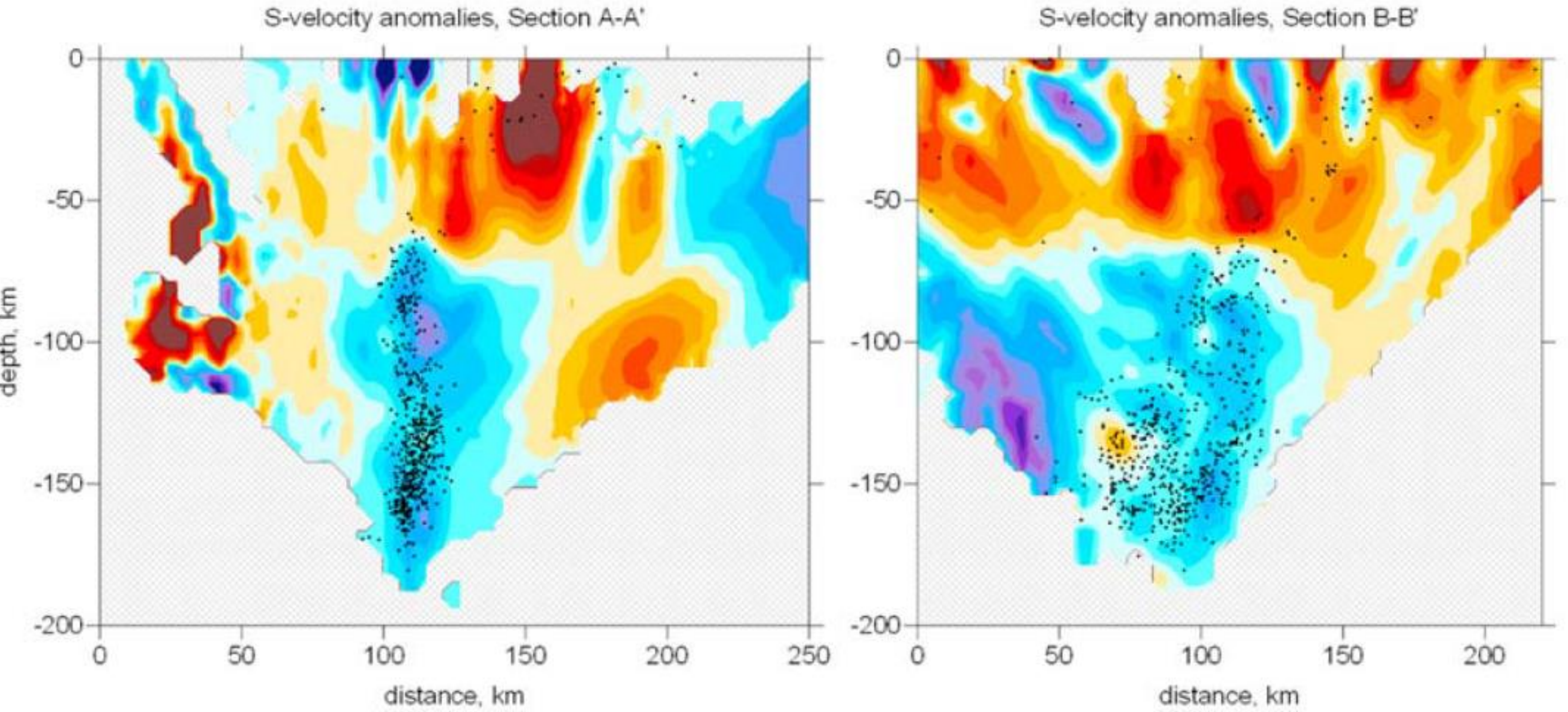


Koulakov et al, 2010, G3

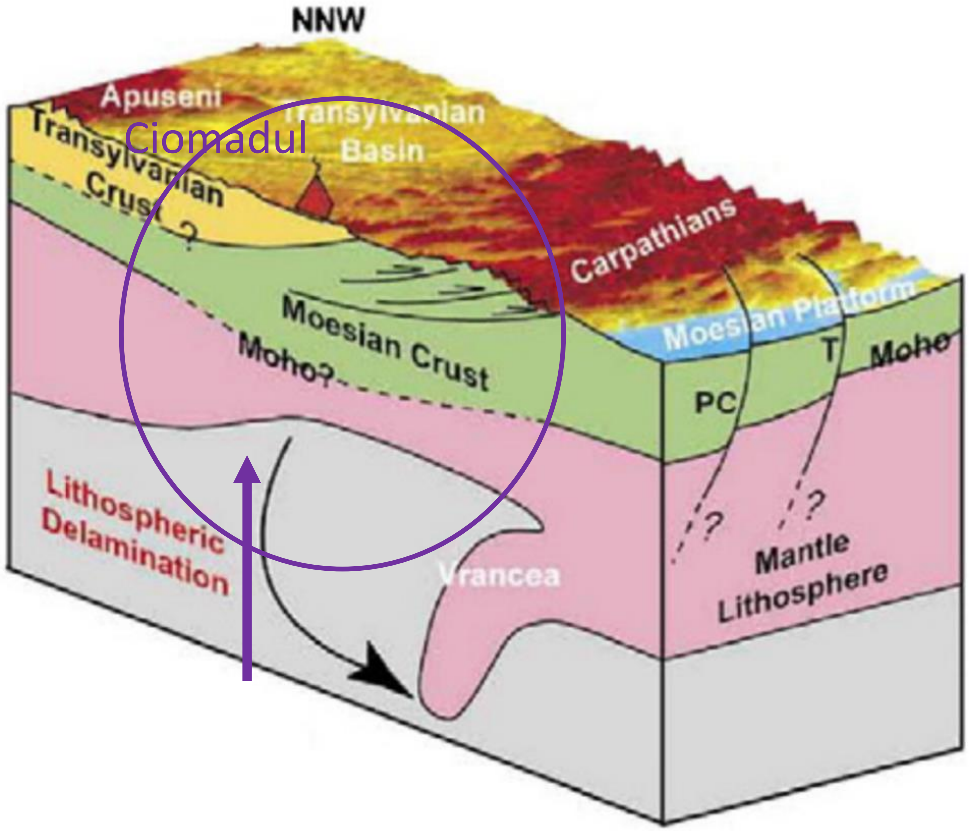
SEISMIC TOMOGRAPHY MODEL (Vs) - VRANCEA



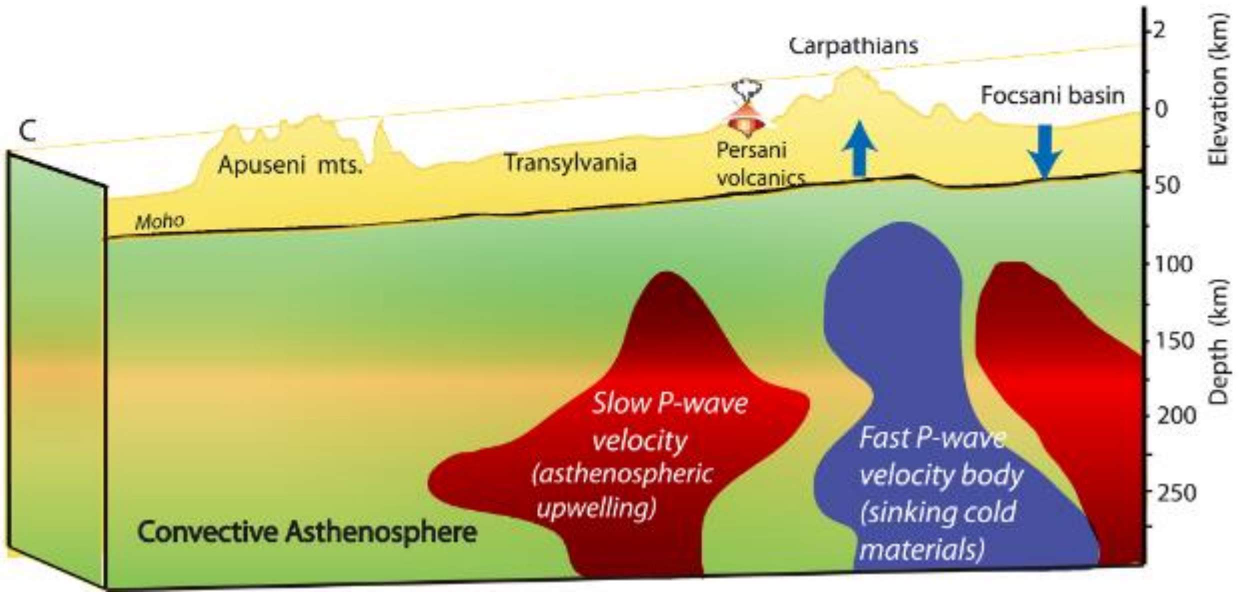
Koulakov et al, 2010, G3

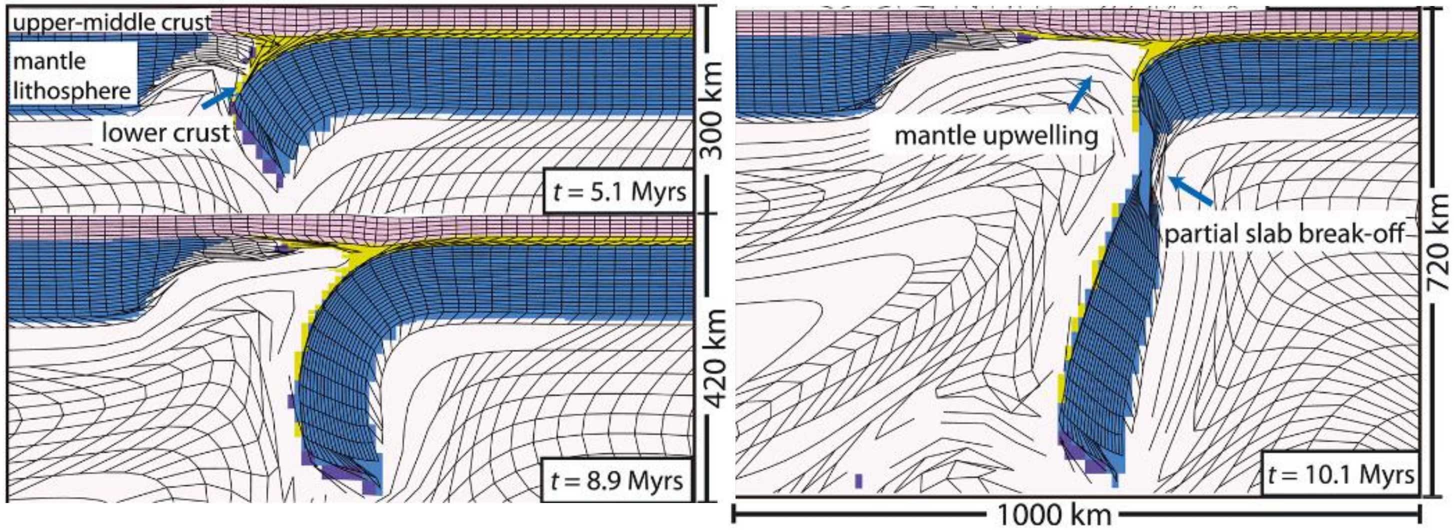
GEODYNAMIC MODEL - VRANCEA

- Numerical geodynamic models of lithospheric delamiantion can satisfy the observations: high topography and volcanic activity



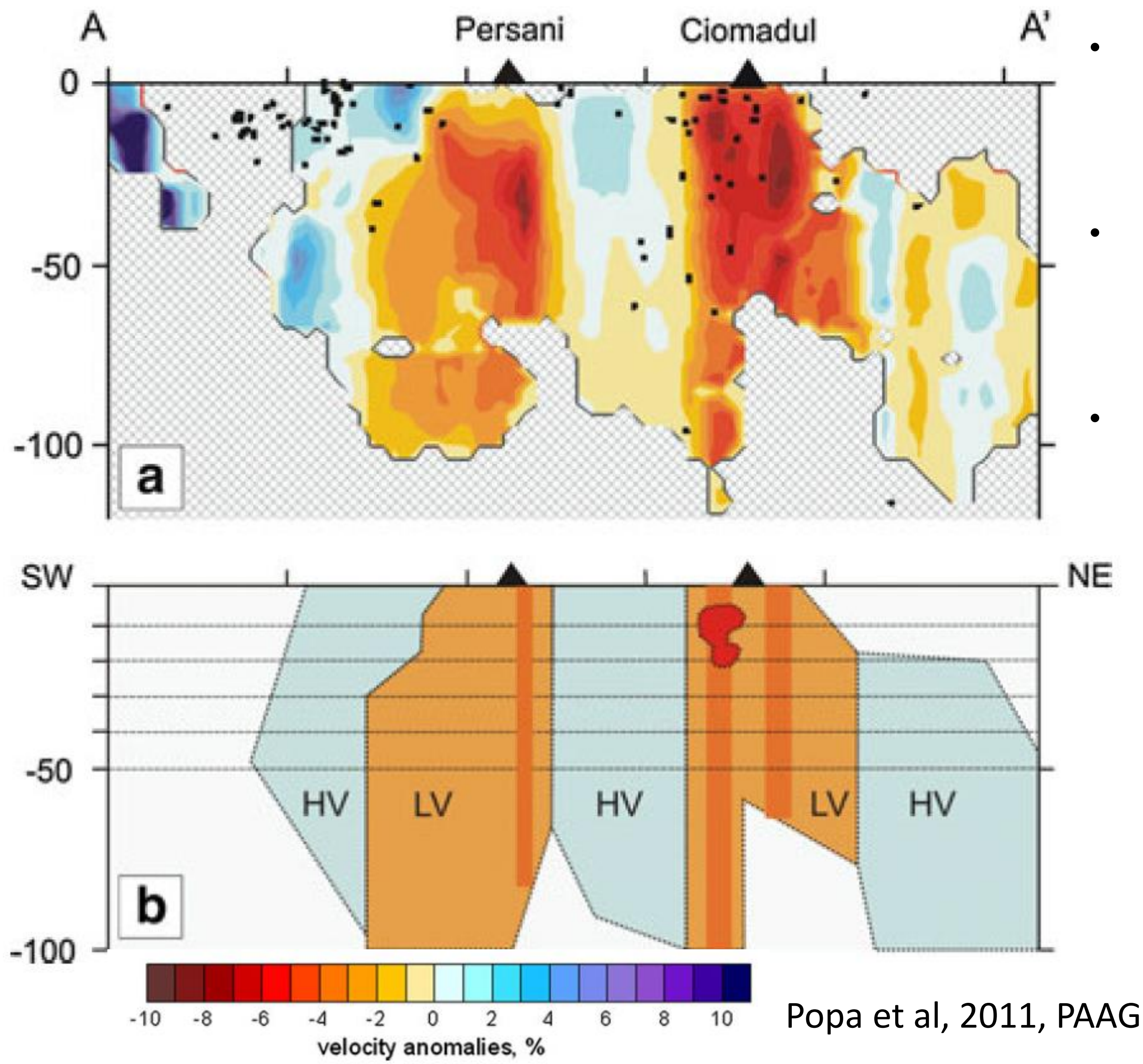
Knapp et al, 2005, Tectonophysics





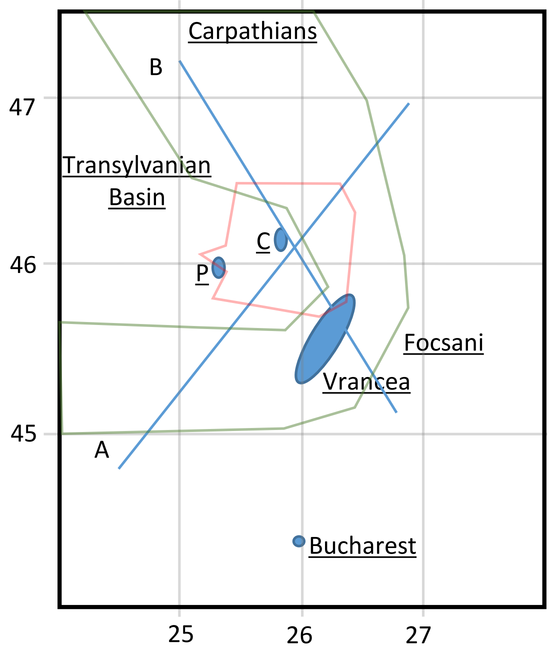
Göğüş et al, 2016, Tectonics

SEISMIC TOMOGRAPHY MODEL (Vs) – VOLCANIC ZONE

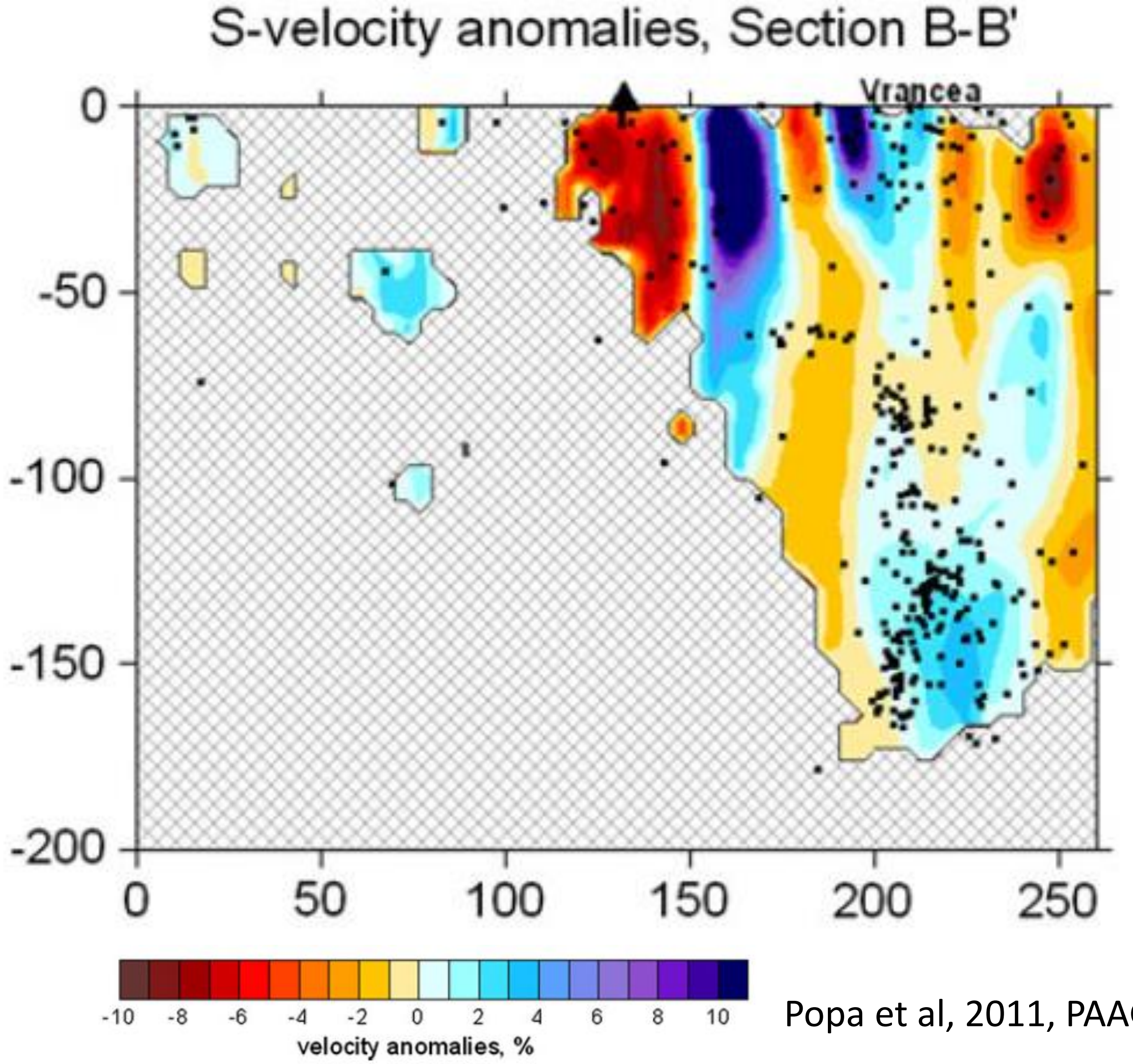


Popa et al, 2011, PAAG

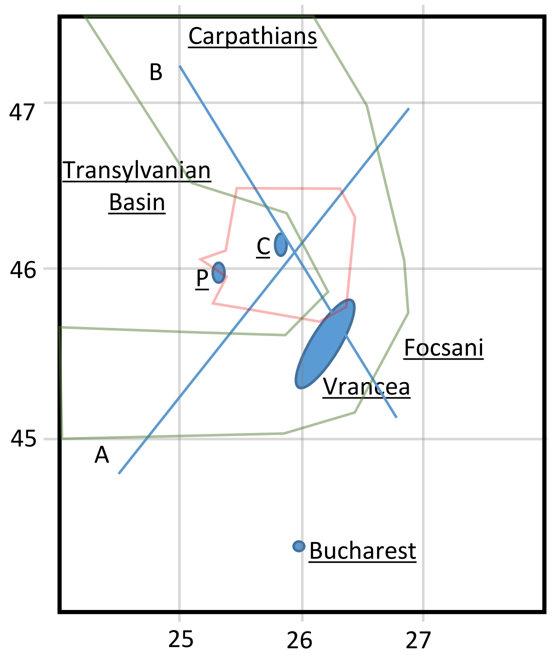
- Low-velocity lithosphere column beneath the Ciomadul area and the Persani area.
- Anomalies are possibly related to a thermal anomaly generated by migrating fluids or magma ascent and magma chamber processes,
  likely related to recent magmatic activity of Ciomadul volcano.
- The anomalies are interpreted to represent a crustal magma chamber (8-20 km depth) connected to a magma-generation area in the asthenosphere (85-105 km depth), consistent with geochemical evidence.
- Ciomadul, in this view, is part of a larger and more complex magmatic system:
  transcrustal magmatic system? intraplate volcanism? source?



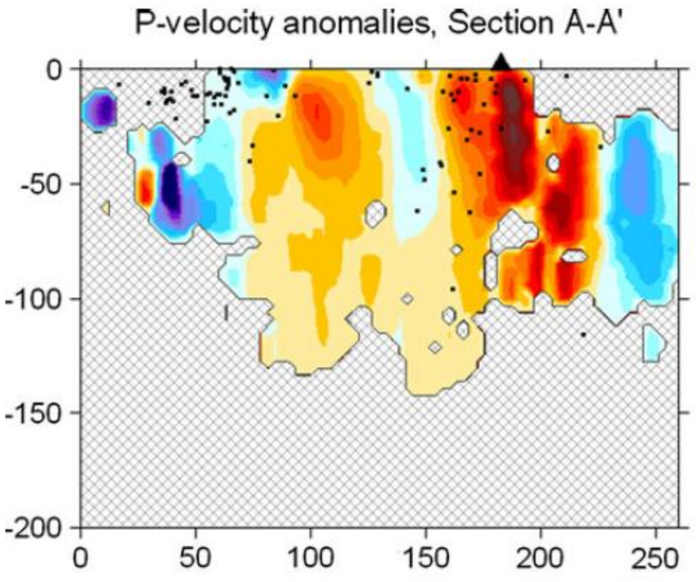
SEISMIC TOMOGRAPHY MODEL (Vs) – VOLCANIC ZONE

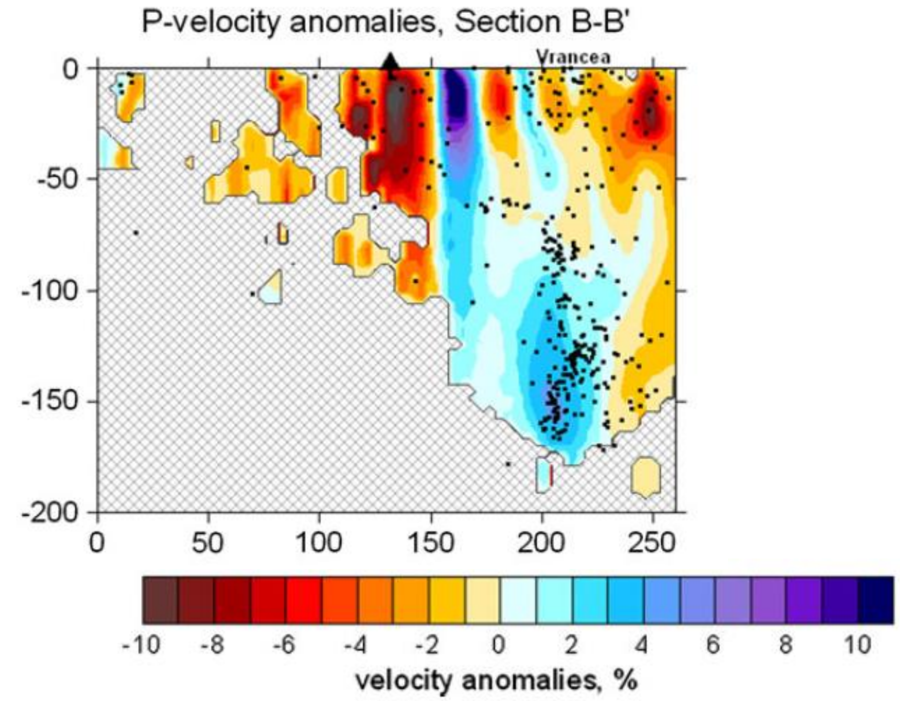


Popa et al, 2011, PAAG

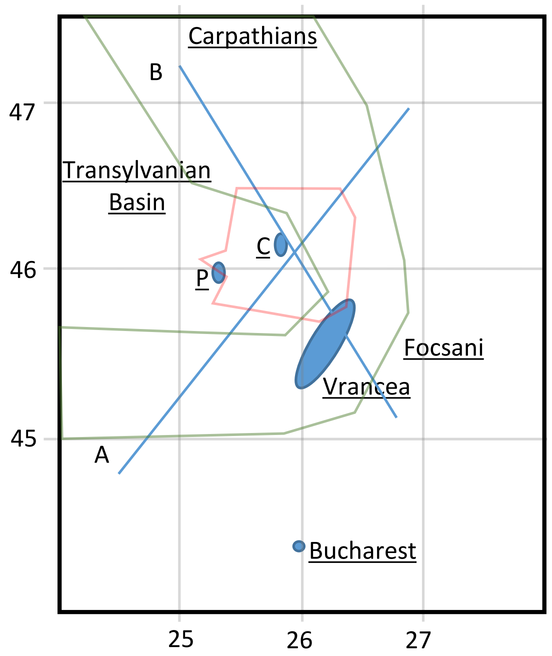


SEISMIC TOMOGRAPHY MODEL (Vp) – VOLCANIC ZONE

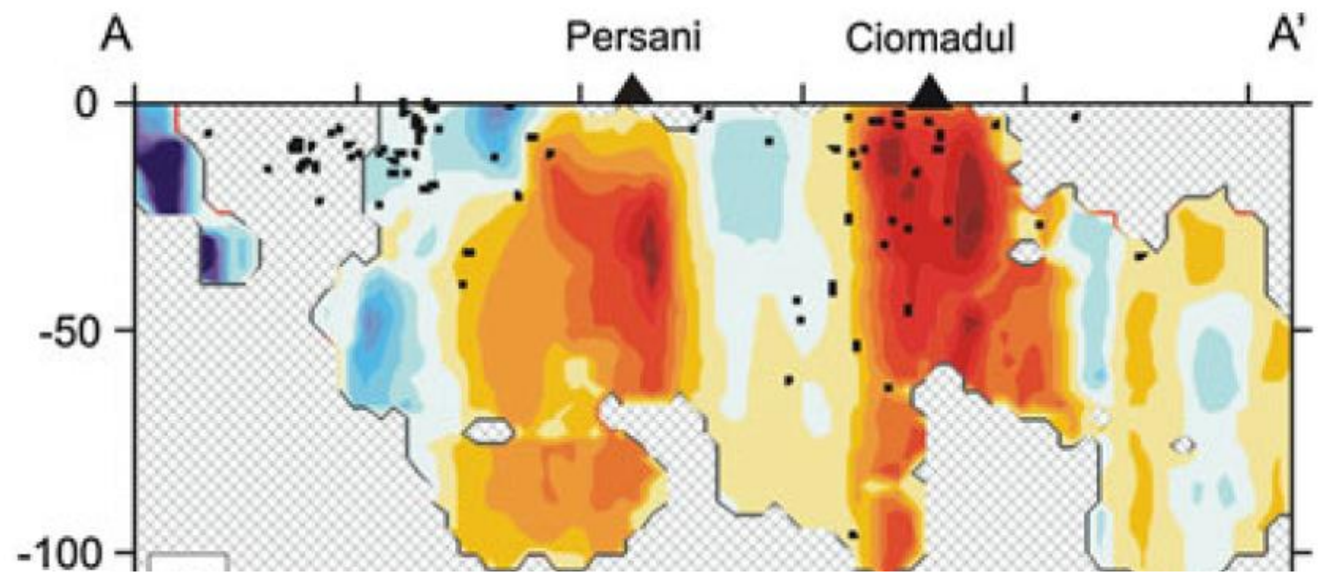


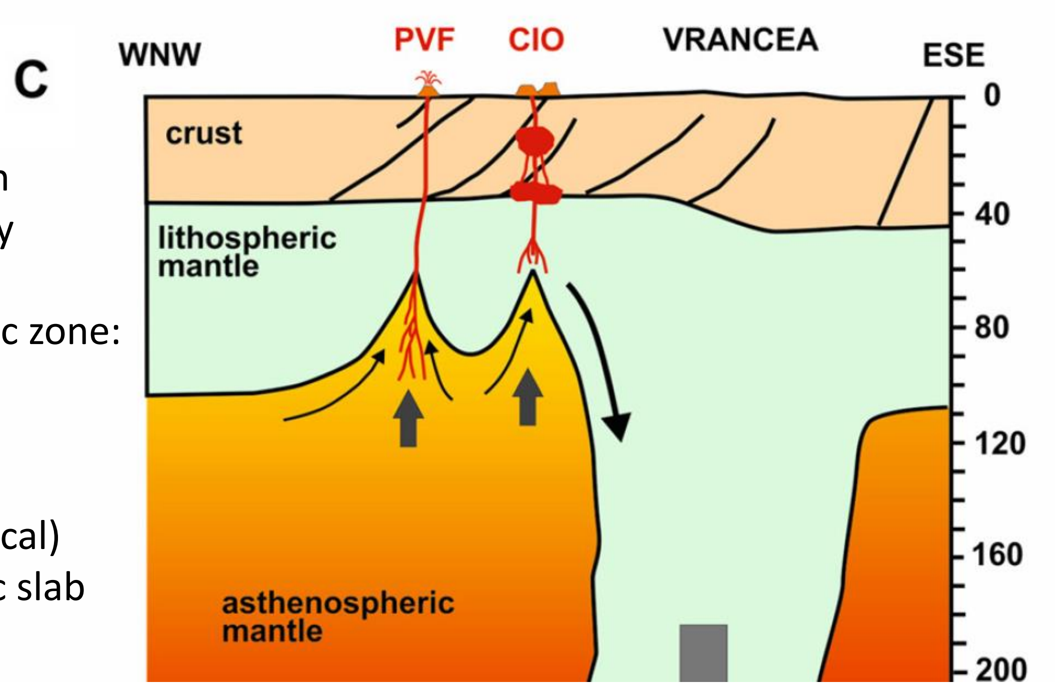


Popa et al, 2011, PAAG

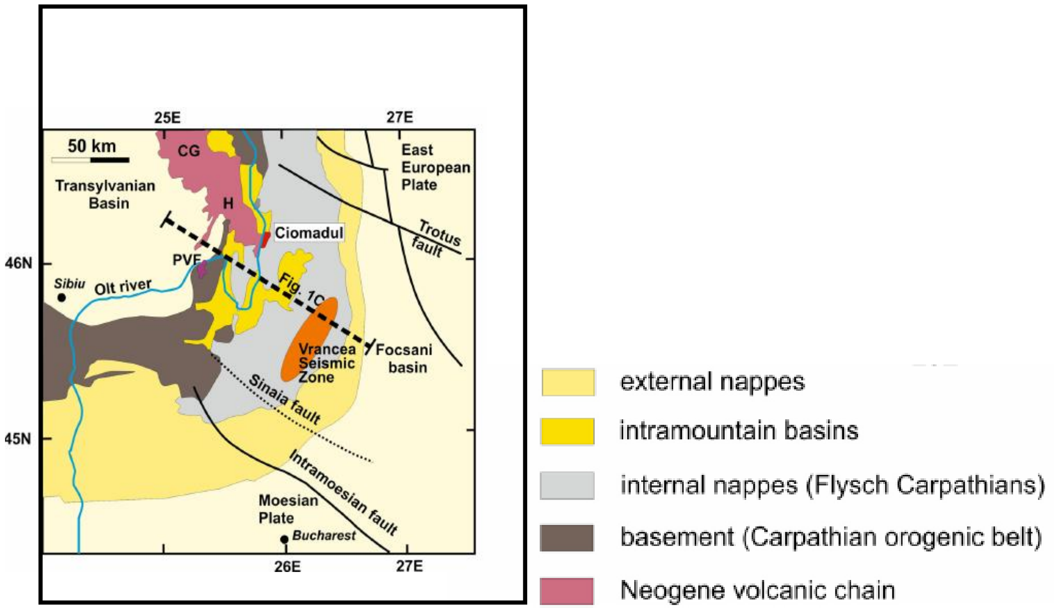


CIOMADUL AND PERSANI PART OF LARGER AND MORE COMPLEX SYSTEM





Schematic cross section through the Quaternary volcanic areas
and the Vrancea seismic zone: conceptual model for asthenospheric mantle upwelling
due to the (nearly vertical) downgoing lithospheric slab in the Vrancea zone



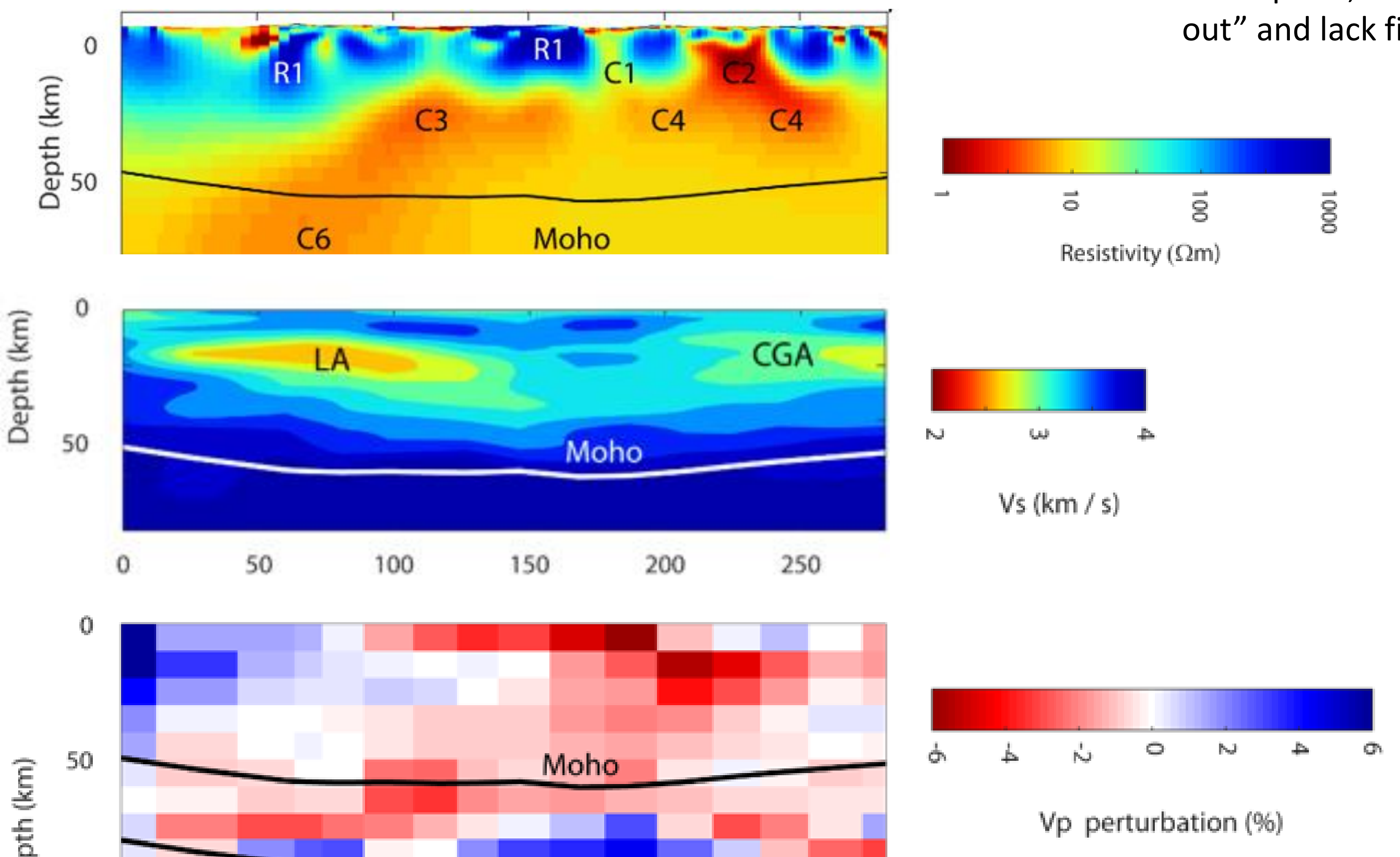
Laumonier et al, 2019, EPSL

A NOTE ON TYPICAL RESOLUTION DIFFERENCES BETWEEN SEISMIC AND ELECTRICAL MEASUREMENTS

- Seismic tomography models and electrical resitivity models across a volcanic zone on the Puna plateau in the Andes illustrates typical differences in resolution between the methods.

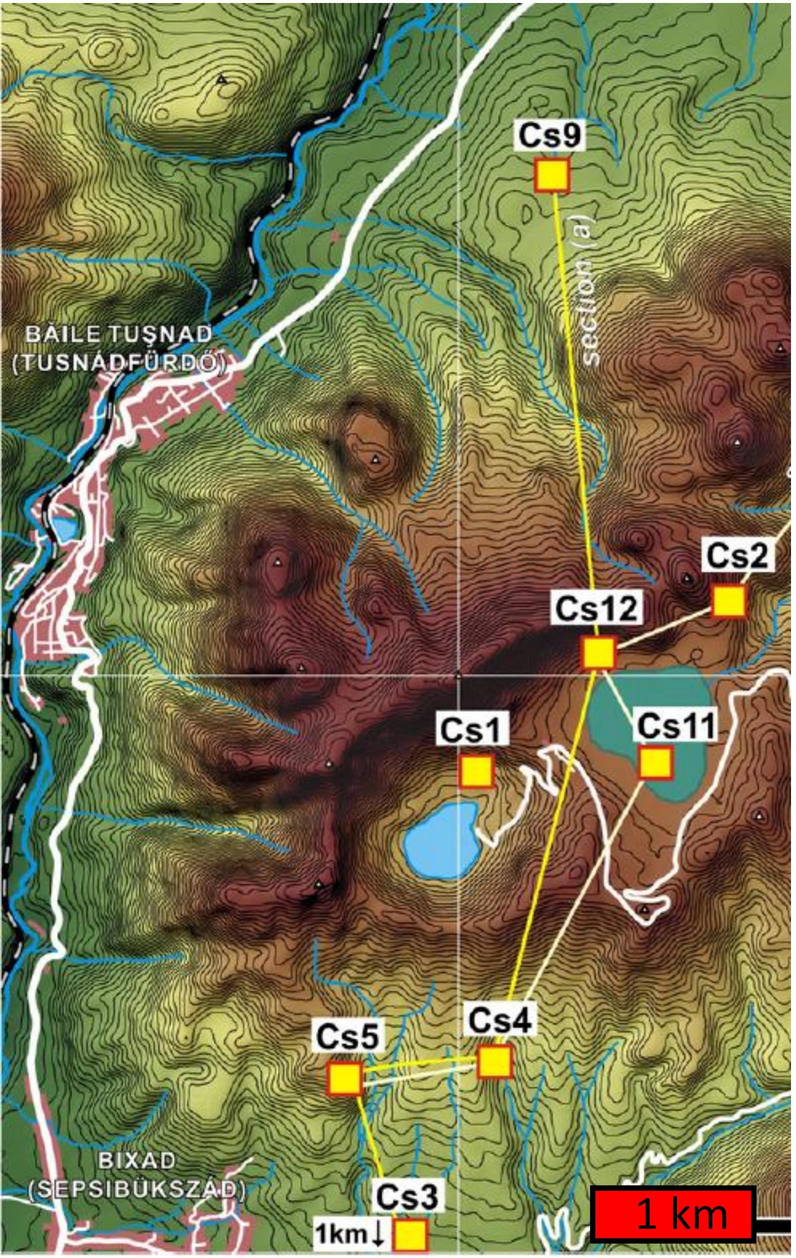
- The low-velocity anomalies and low-resistivity anomalies roughly correspond; However, the sesimic models tend to be “smeared-out” and lack fine crustal details.

Unsworth, Comeau, et al, GEOSPHERE, 2023



PREVIOUS ELECTRICAL RESISTIVITY MODEL

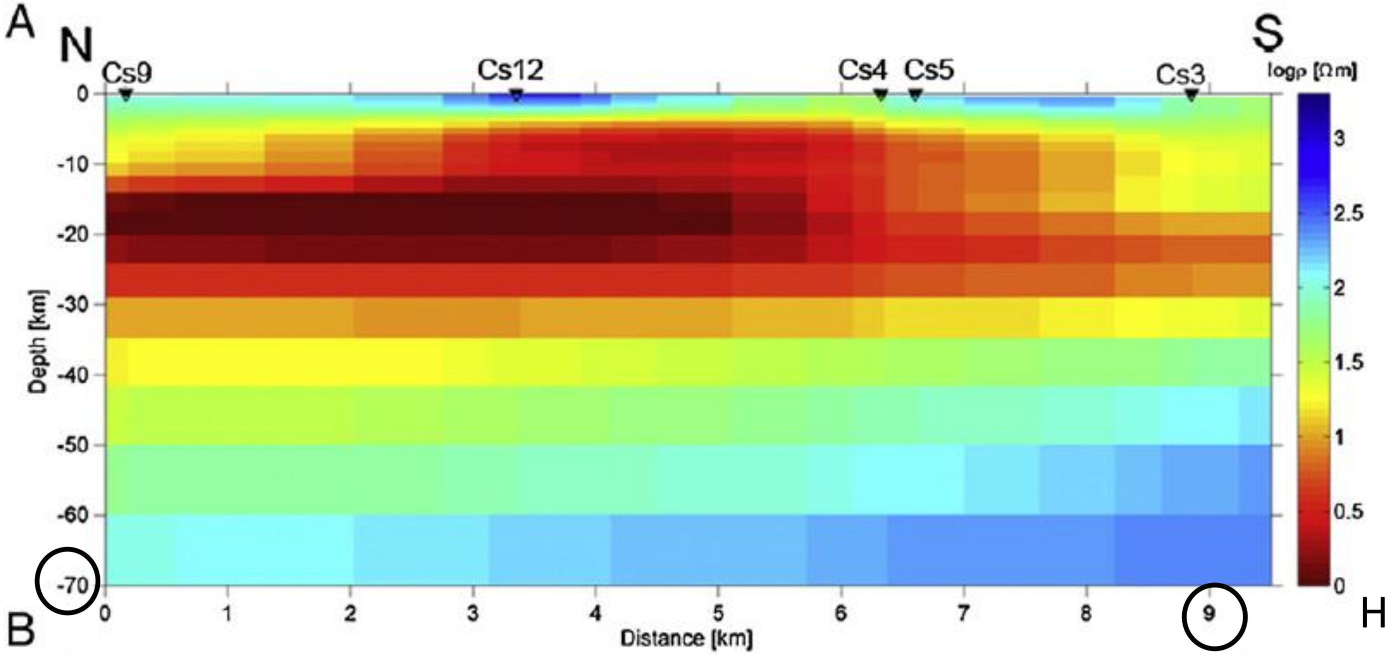
Harangi et al, 2015, JVGR



- In 2010, MT measurements in 12 locations across cone.
- 2-D inversion results (2015) along North-South profile from a selection of sites across the volcanic cone (with algorithm of algorithm by Rodi and Mackie, 2001).

- Low electric resistivity values at depth of 5–30 km beneath volcanic center.

- Interpreted as implying a partially melted zone - a crystal mush body containing 5–15% melt fraction.
- Consistent with petrologic constraints.
- Thermal modelling implies up to 45% fraction.

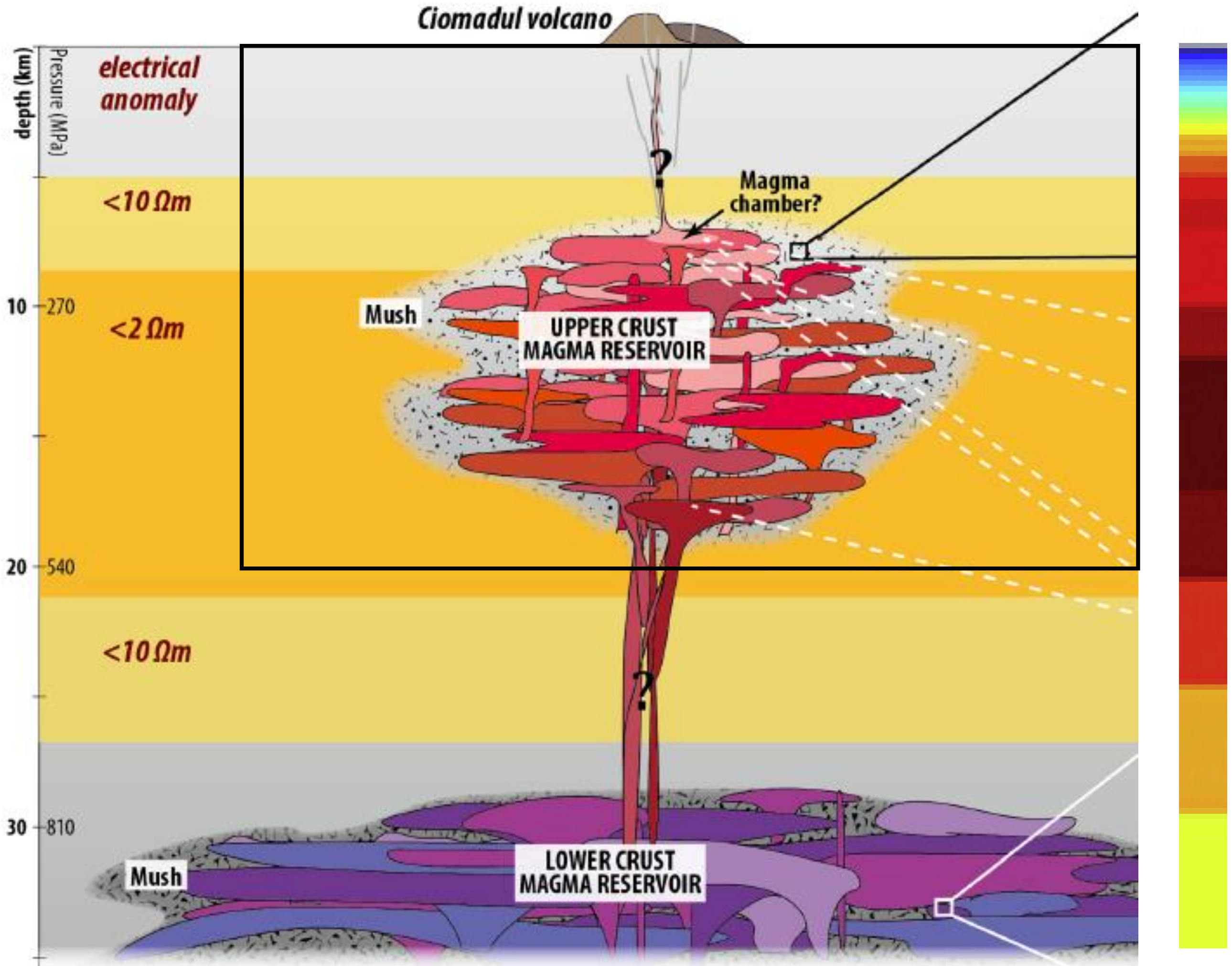


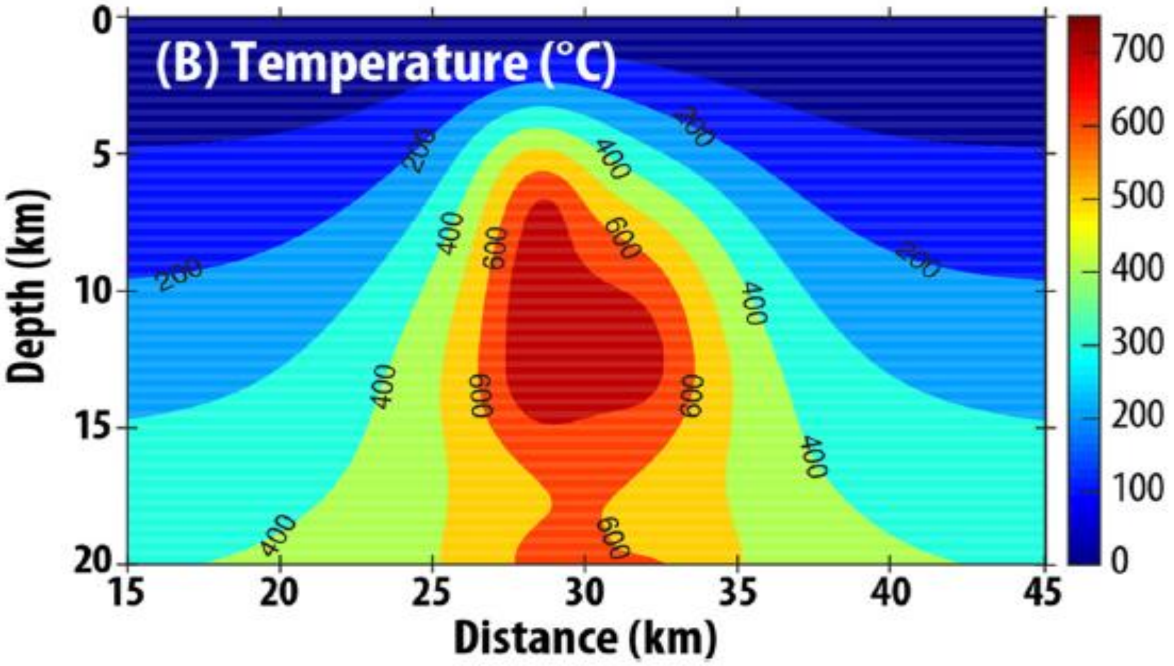
Harangi et al., 2015

MODEL DERIVED FROM INTEGRATING PETROLOGY AND GEOPHYSICS

- Magma reservoir in the upper crust likely has more complex geometry than a “chamber”, e.g., stacked sills and dykes.
- Can we refine the electrical models?

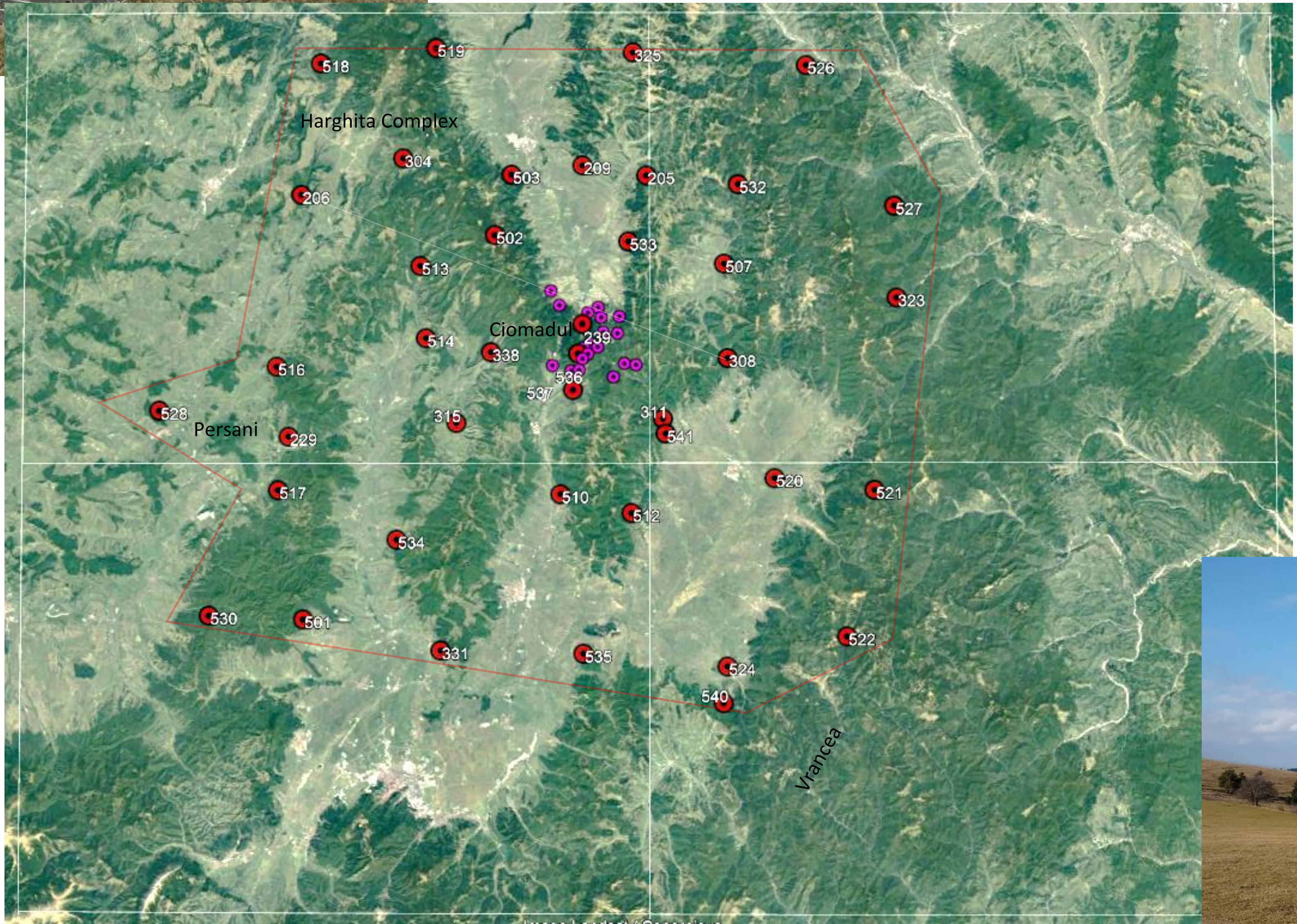
- A lower crustal magma reservoir likely exsits.
- Can we resolve structure of deep features (lower crustal reservoir)?





Laumonier et al, 2019, EPSL

MAGNETOTELLURIC MEASUREMENT SITE DISTRIBUTION



- In Autumn 2022, 41 new MT measurements were acquired.
- The region covered reaches from the Persani volcanic field (Racoș, Homorod; about 40 km west of Ciomadul), across Ciomadul, and to the edge of the Vrancea (50 km south-east of Ciomadul).
- Approximately 75 x 75 km. A 100 km long transect NW-SE across the array has a measurement spacing of less than 15 km.
- In 2010, 12 sites near Ciomadul cone, within an area of approx. 5 x 10 km.

IMPRESSIONS





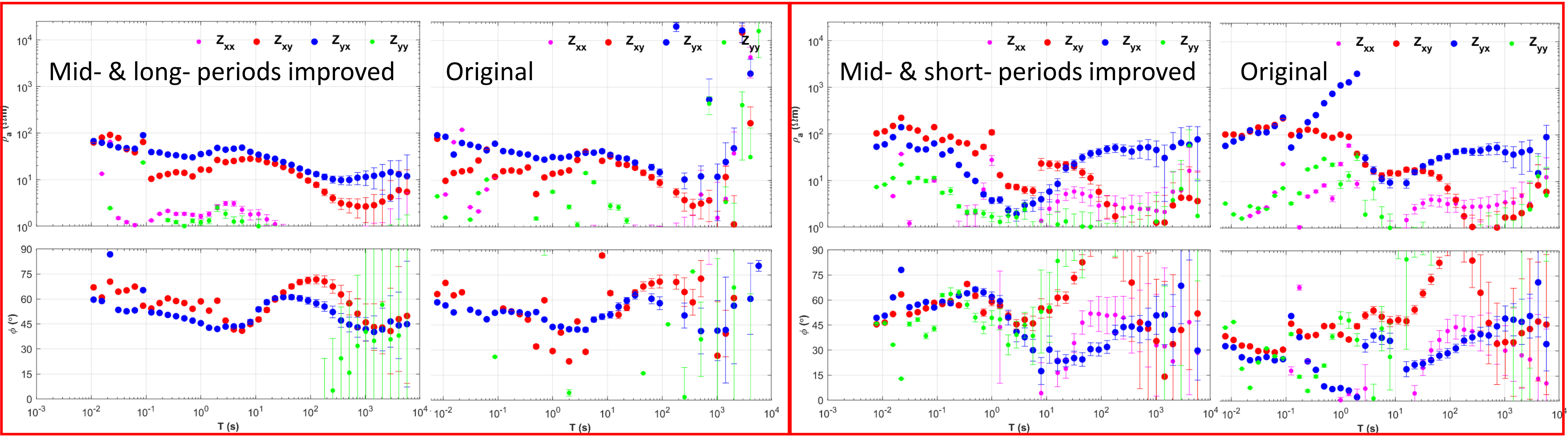




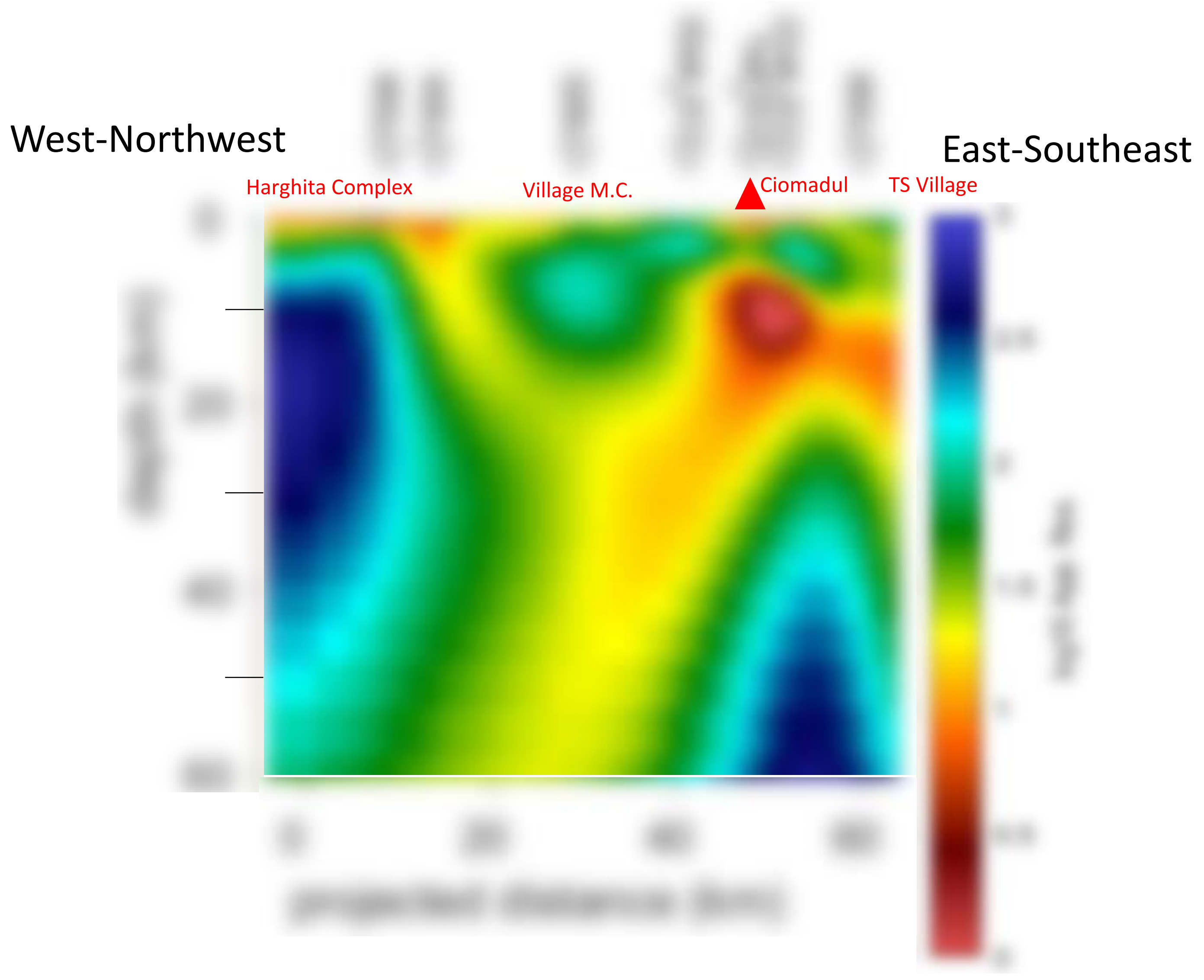

MAGNETOTELLURIC DATA

- <u>Good quality could be achieved</u>. Recordings were 1-5 days.
- Noise at some locations was an issue.

- At some locations, cultural electromagnetic noise contaminated the signals and degraded the data
- <u>Choosing appropriate locations</u> for measurement was critical.
- <u>Estimating transfer functions required special care</u>
- -Manual time window selection
- -Applying data pre-selection schemes:
  coherency threshold (keep only coherent fields, e.g. 90%),
  power order statistics (remove strong signals, e.g., top 30%),
  different estimators (including multi-taper method),
  leverage control (remove data outside diagonal tensor), etc
  -For inter-station TF choose best base site

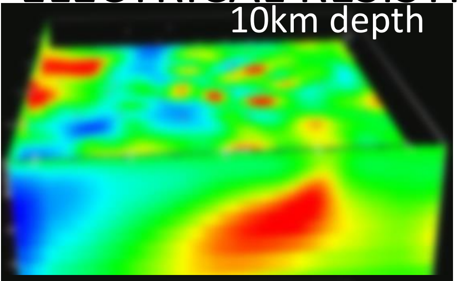


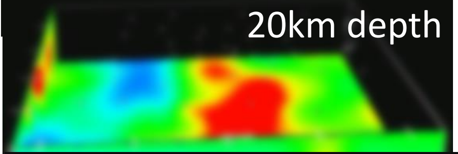
ELECTRICAL RESISTIVITY MODEL (PRELIMINARY)



- 2-D model (2022) gives a quick look.
- Preliminary inversion in 2D from 7 selected sites across profile NW to SE.
- RMS error reduced from 14 to 2.86, error floors of 10% on app. res. and 5% on phase (starting model of 100 ohm).
- Algorithm used was Emilia from T. Kalscheuer.
- Can recover crustal structure. Consistent anomaly depth with that expected. Features below each volcanic zone.
- Detailed analysis require 3-D models.

ELECTRICAL RESISTIVITY MODEL 3D (PRELIMINARY)





- 3-D model (2022) gives a quick look.
- Preliminary inversion with MODEM
- 125 iterations, final RMS of 1.88
- Error floor 5% sqrt(abs(ZxyZyx))