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A lower crust shear zone favors delamination and continental subduction in the Apennines

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1 Introduction

Physical properties and structure of the lithosphere are the first step to constrain the evolution of mountain belts, such as the Apennines.
In this work, **detailed 1D Vs models** of the **lithosphere** was computed for the **northern-central Apennines** clarifying a controversial aspect of continental subduction in a peculiar setting:

- **the intricate mechanism of crust delamination from the downgoing plate.**

From the analysis of a complete and dense **teleseismic Receiver Function data set**, we find that the **delamination of the continental lithosphere** is favored by the development of a **low Vs shear weak zone** in the middle-lower crust.
A **double Moho** below the external portions of the present mountain range was observed, suggesting the progressive formation of the shallow interface.
The **delamination edge** is located in the forearc, far eastward than expected, implying that the **re-equilibrationof the thermal unbalance**, generated by the mantle substitution, may last 10-7 Myr.

2 Data & Method

RF analysis to define crustal properties and bulk velocity models of the Adria lithosphere, and extract information on geometric interfaces, was computer from harmonics analysis of the **Q** (i.e., radial) and the **T** (i.e., transversal) components. **Shear-wave velocity profiles** were computed for the entire lithosphere applying a **trans-dimensional non-linear method** (Agostinetti and Maliverno, 2010) for the seismic array deployed in the study area (Fig. 1)

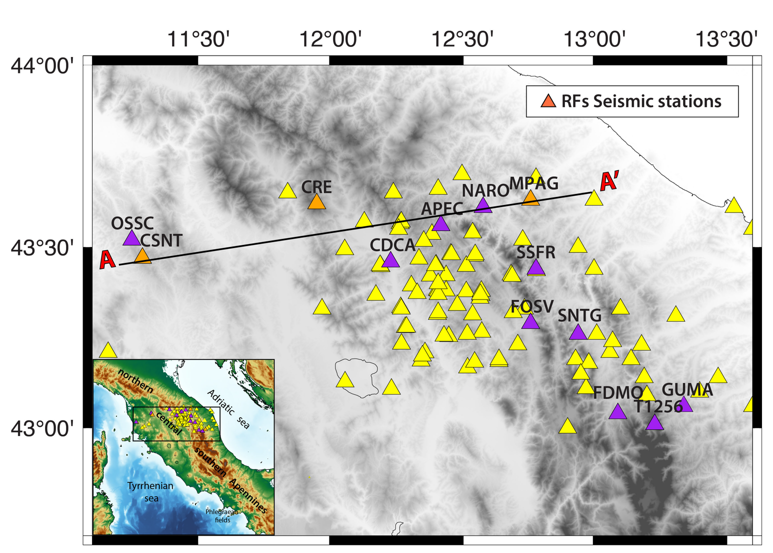

Fig 1. Map of seismic stations anayzed for the computation of RFs | Orange triangles indicate seismic stations whose results are shown in Figures 2, 3. **The 1Vs models for the stations crossed by profile A-A' (purple) are reported in Figure 4 . Yellow triangles are all the other stations analyzed in this work.**

Data

The dataset was made by **15.000 RFs** extracted form **teleseismic events** at epicentral distance of **30°-100°** and **Mw > 5.5** with an **high SNR**. The seismic events were recorded between **2012-2020** by **56 broad-band stations (RSN)** located in the north-central Apennines. Firstly, the seismic records have been rotated to analyze the Ps converted phase in the LQT system.
The teleseismic waves were filtered at 5 - 0.02 Hz. The RFs were obtained by a technique developed by Park & Levin, (2000) from multitaper correlation estimates by frequency domain algorithm.
After, the **radial component (Q-RFs)** was used to compute the **shear-wave velocity profiles** up to **100 km** depth. The back-azimuth harmonics were extracted from the RFs as a function of the incoming P-wavefield direction (Bianchi et al., 2010). All the three components (k= 0, 1 , 2; figure 2) were calculated but only the **isotropic one (k=0)** was discussed in the final interpretation.

Inversion method

To solve the nonlinear problem, the **Reversible-jump Markov chain Monte Carlo (RjMcMc)** scheme was adopted for the computation of the **1D shear wave velocity model** for each seismic station.
The strength of this probabilistic approach is related to the limited depence of the final model on a-priori information.
In particular, a **Posteriori Probability distribution** of the inverted parameters was obtained indicating how many interfaces are located below each station and their most probable depth (see Figure 4).

A distribution of models with acceptable data fit was find through a searching into a **multidimensional parameter space** exploting the **Voronoi cells properties.**
During an initial burn-in phase, 100.000 models were discarded from a total of 200.000 random models calculated for each of the **100 RjMcMc parallel independent Markov chains.**
Hence, **the posteriorprobability density function (PPD)** was obtained using the remaining models (10^7 models). The final results (see Figure 4) are the **PPD of the Vs** and **Vp/Vs**, the **mean model** and the **distribution of the interfaces.**

3 Results

Receiver Functions

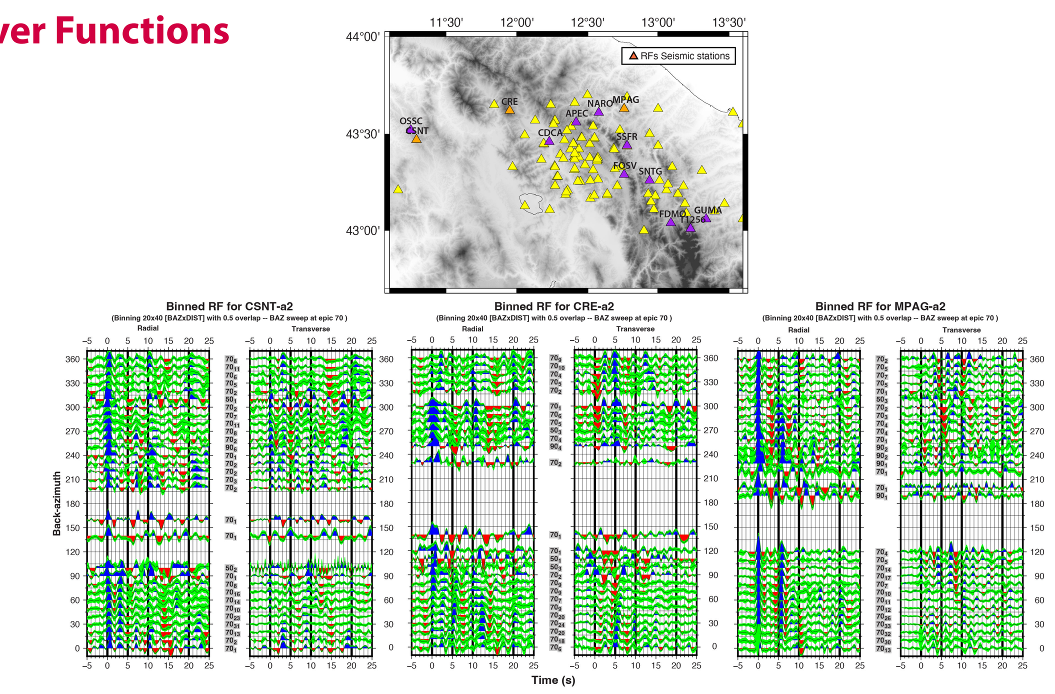

Fig 2. Representative analyzed Receveir Functions | The analyzed Receveir Functions of three representative seismic stations (purple triangles in the map on the top) are plotted for back-azimuth values and epicentral distance (see gray numbers on the right). Blue and red wiggles show positive and negative amplitudes in the RF. Green shading shows variance of the bin-averaged RFs.

Harmonic analysis

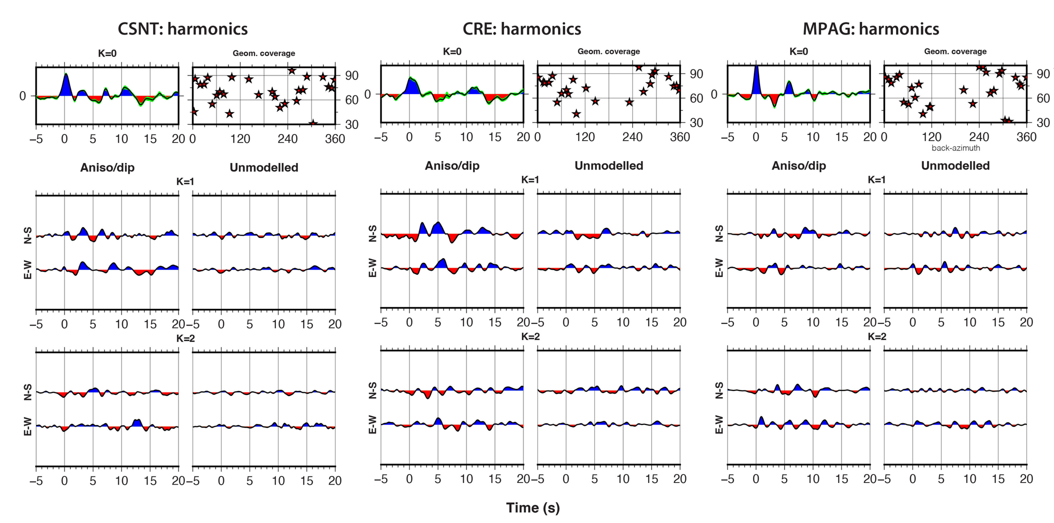

Fig 2. Harmonic decomposition for CSNT, CRE and MPAG stations | On top are reported the isotropic component (k=0; left) and the geometric coverage (right side). On the center and bottom left panels the anisotropic components for k=1 and k=2 harmonics order.
On the right the unmodelled components are reported.

4 Conclusions

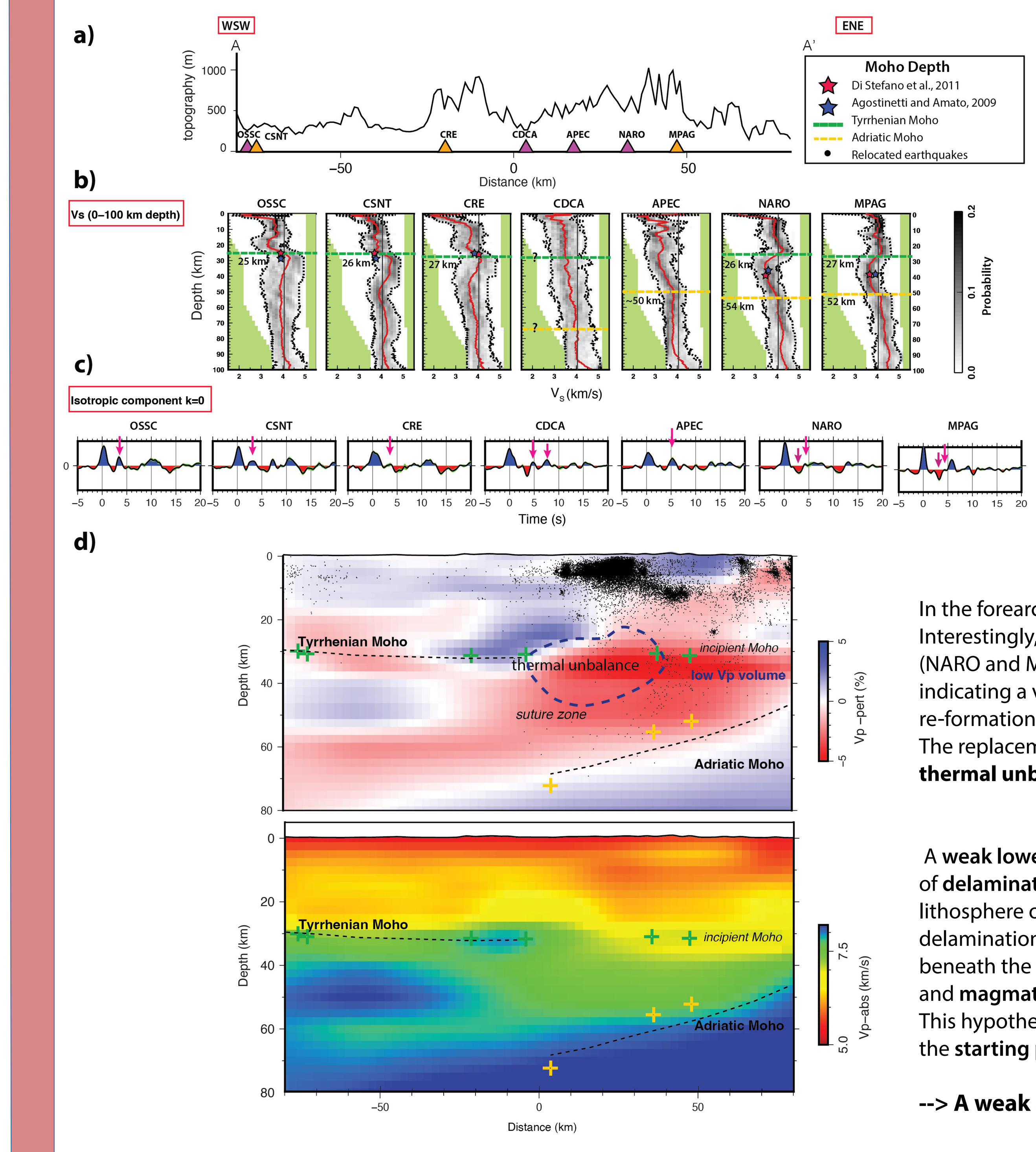

Fig. 4 Comparison of the velocity structure between the western and eastern side of the north-central Apennines | a) Topography of the profile A-A' in the map (see Fig. 1) with the location of the seismic stations reported below. **b)** 1D shear wave velocity model (0-100 km depth) for the seismic stations crossed by the trace. The red line indicates the average S-wave velocity, while the standard deviation interval falls within the black lines. Yellow and green dashed lines define the Adriatic and Tyrrhenian Moho depth, respectively. The red and blue stars are the Moho depth extracted from Di Stefano et al., (2011) and Agostinetti and Amato (2009).
The green color is the background color. **c)** Isotropic composition (k=0) along time (s) extracted by the Rfs analysis at the different seismic stations. Blue and red lobes indicate positive and negative pulses. The light pinkarrows indicate pulses related to mature Moho, the dark ones to non-mature Moho.
d) The corresponding 3D Vp cross-sections from the model of Menichelli et al., (2023).
The black dots are relocated earthquakes (2005–2020) in the 1D velocity models of the Central Mediterranean computed in the work of Menichelli et al., (2022. The green and yellow crosses represent the Tyrrhenian and Adriatic moho depths extracted from the shear wave velocity 1D models for each seismic station, respectively.

In the forearc, the **doubled pulse of positive RF** suggests that the **newly formed Moho** is under development. Interestingly, the **negative pulses at around 3-4 s** detected under the stations in this Apennine sector (NARO and MPAG, Fig. 4c) are related to the **negative jump** in the related shear wave velocity models (Fig. 4b) indicating a velocity reversal within the Adria lower crust, signature of the **ongoing delamination** and immature re-formation of the Moho.
The replacement of sublithospheric mantle after delamination generates a **thermal unbalance beneath** the mountain range.

A **weak lower** crust inhibits the **detachment of the continental slab**, promoting a prolonged process of **delamination, subduction** and **retreat** of part of the lower crust remaining attached to the mantle lithosphere of Adria. **Fluids liberated from the eclogitization** of the lower crust promotes further delamination and retreat of the lithosphere. The **incipient formation of the double Moho** observed beneath the forearc has a **mature-stage** analog in the backarc, where **crustal thinning** and **magmatism** followed the reformation of the **shallow Tyrrhenian Moho**.
This hypothesis leads to the definition of a new scenario for the Apennine subduction where the **starting point of delamination is in the forearc** and a longer thermal rebalancing is required.

--> A weak shear zone facilitates delamination and continental subduction under the Apennines !

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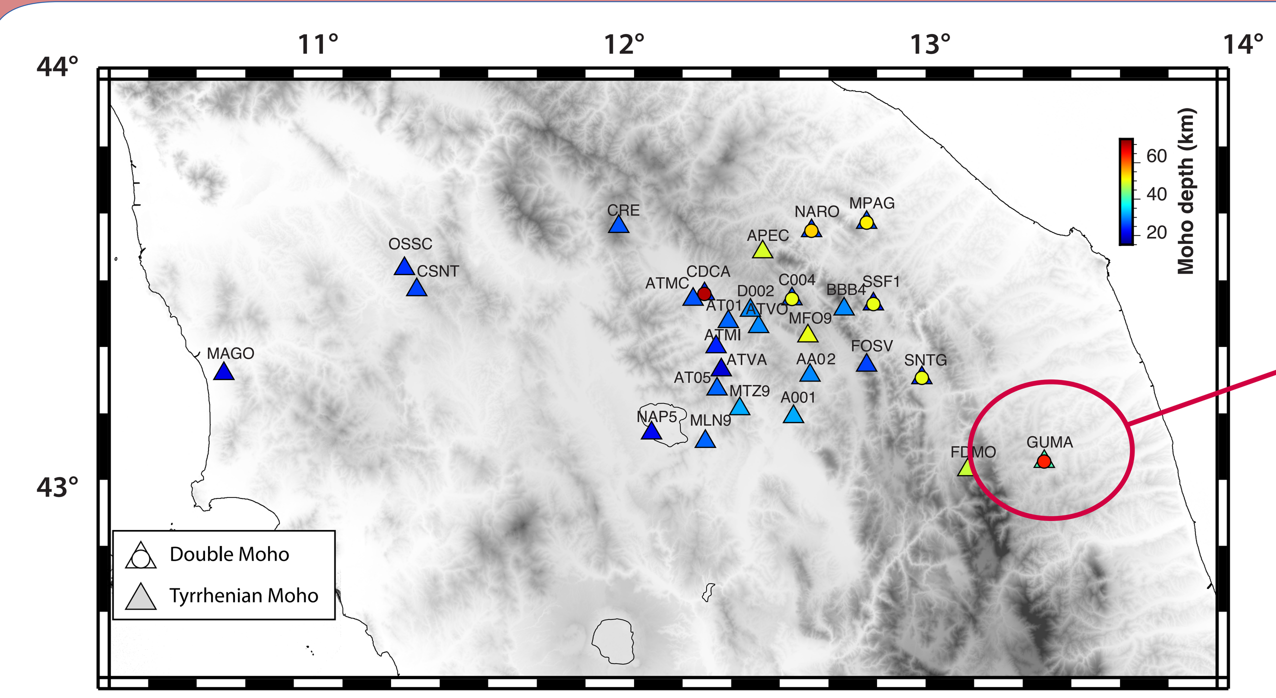
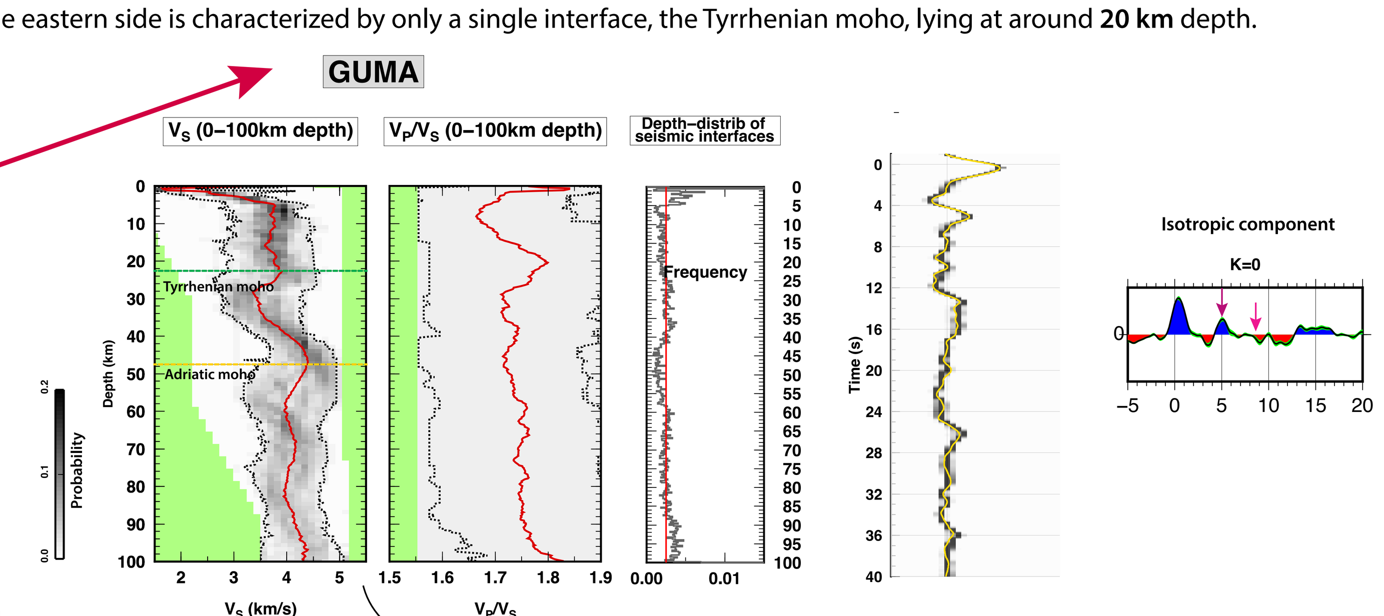


Fig 5. Moho map of the analyzed seismic stations | The Moho depth has been extracted from the Vs profiles (MAGO, OSSC, CSNT, CRE, CDCA, APEC, NARO, MPAG, FOSV, SNTG, FDMO, GUMA). The triangle indicates the Tyrrhenian Moho whereas triangles with circles indicates the presence of a double Moho (i.e., Tyrrhenian and Adriatic ones) depicted below the station.

DOUBLE MOHO??

A **double Moho** (i.e., Thyrrhenian and Adriatic) has been depicted below **NARO, MPAG, C004, SSF1, SNTG** and **GUMA seismic stations** located all along the **eastern side** of the Apenninic chain. In these cases, the **Tyrrhenian moho** depth ranges between **20-25 km**, whereas the **Adriatic one** varies from **50 km** to a maximum of **65 km** below **CDCA** and **GUMA** (red colors).
The eastern side is characterized by only a single interface, the Tyrrhenian moho, lying at around **20 km** depth.



Double Moho example !

CHECK THIS OUT!