

Experiments & data

Before 2000, information on the Moho below the eastern Alps was mainly limited to data obtained from several refraction lines from the 1970's and a seismic reflection profile from the late 1990's. In 2000 and 2002, Central Europe was covered by two very large-scale 3D seismic refraction experiments: CELEBRATION 2000 and ALP 2002. In this study, we concentrate on the data subset from the Eastern Alpine region [fig. 7] and its transition to the surrounding tectonic provinces. Overall 78.000 seismic traces are included in this dataset.



Fig. 7:
Field layout of CELEBRATION 2000 (3rd deployment, grey) and ALP 2002 (black). Triangles show receivers. Total profile length / No. shots / No. receivers: CELEBRATION 2000 (data for this study): 2800 km / 55 / 844 ALP 2002: 4300 km / 39 / 947

Processing

The data from the new experiments have been processed with different 3D inversion algorithms from which images of the P-wave velocity structure of the crust and upper mantle have been obtained. Especially in the Alpine region, the S/N-ratio is sometimes poor. Therefore stacking techniques have been applied. The results provide robust 3D images of delay times [SRF-sorted & stacked Pn-phases; fig. 8a] and two-way travel times [CMP-sorted & stacked PnP-phases; fig. 8d] of the Moho. The delay times have been refined by individual travel time picks where reliable arrivals could be identified. Finally the delay times (fig. 8c) and two-way travel times (fig. 8e) have been merged to yield one image of the Moho, expressed in merged two-way travel times (fig. 8g). With the use of a similarly obtained 3D velocity model of the crust (fig. 8f), the time information has been migrated and converted to depth (fig. 8h). Where the 3D crust model lacks information due to sparse Pg coverage, estimates from NMO-velocities have been substituted. The Pn-velocity has also been estimated by stacking procedures and was checked against individual travel times.

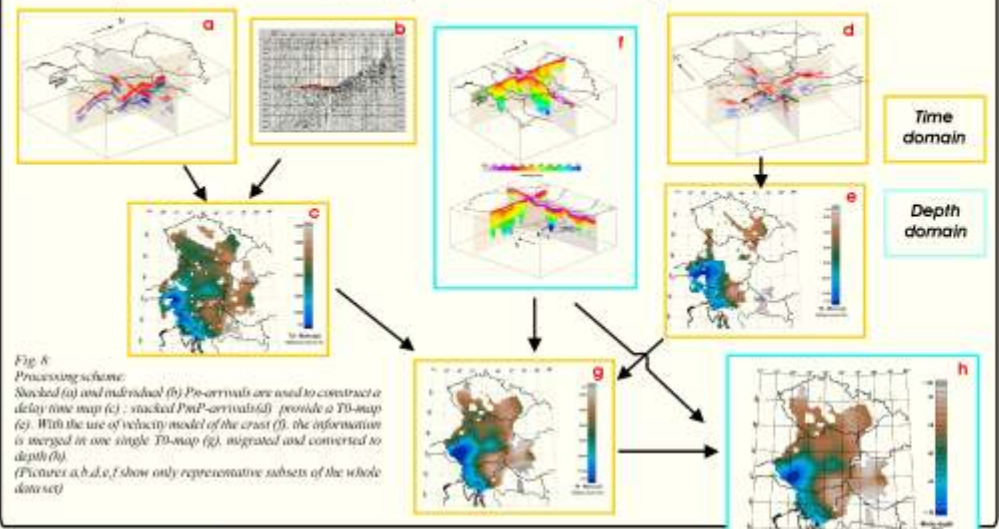


Fig. 8: Processing scheme. Stacked (a) and individual (b) Pn-arrivals are used to construct a delay time map (c); stacked PnP-arrivals (d) provide a TD-map (e). With the use of velocity model of the crust (f), the information is merged in one single TD-map (g), migrated and converted to depth (h). (Pictures a,b,d,f show only representative subsets of the whole dataset)

Accuracy & resolution

In all presented models, the resolution power of the data has been taken into consideration. While in the delay time domain the picked Pn travel times can be reproduced within an accuracy of 0.15 s (std.dev.; fig. 9), the ray tracing in the depth domain yields much higher errors (0.36 s). Since the std.dev. of the crustal arrivals is 0.26 s, approx. 30% of the Pn error may be attributed to errors resulting from the poorly constrained velocity of the lower crust. Fig. 10 gives an idea of the distortion of Moho depths due to lack of velocity information in the lower crust. By a simple tomographic approach, these 30% are attributed to Moho shifts and lower crustal velocity changes. The results indicate where the model needs further improvements and give an estimate of the accuracy. A std.dev. of +/- 0.5 km and maximum values of -1 and +2 km seem reasonable, assuming correct velocities in the crust (fig. 11). A "damped" version of reliable Moho improvements is then used to construct the final Moho depth map (center part of the poster). The std.dev. of the final model is about 0.27 s (fig. 12).

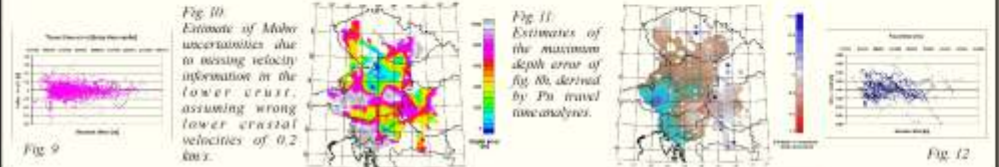


Fig. 9: Estimate of Pn arrival accuracy. **Fig. 10:** Estimate of Moho uncertainties due to missing velocity information in the lower crust, assuming wrong lower crustal velocities of 0.2 km/s. **Fig. 11:** Estimate of Moho uncertainties due to Pn travel time analysis.

The Moho(s) in the Eastern Alps - new insights from recent 3D refraction experiments

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About

We present a new model of the Moho of the Eastern Alps which has been derived by innovative 3D processing of recent WAR/R-data. The results are in good agreement with former models, but reveal also important new features. A new Moho fragment ("Pannonia") is interpreted, and indications for a "Dinaric subduction" could be found.

Tectonic Setting

The Alps are the result of a long and ongoing tectonic evolution, initiated coevally with the opening of the Atlantic Ocean in the early Jurassic. Alpine evolution was very complex, involving several stages, and has been better investigated and understood in the western parts of the orogen compared to the eastern segment. In a regional context, the Eastern Alps are located in between the Bohemian Massif, the Carpathians, the Pannonian domain and the Dinarides. Major geodynamic processes involved in the orogeny of the Eastern Alps include the subduction of the Alpine Tethys and the following head-on collision (Late Cretaceous / Early Tertiary) between the European and Adriatic-Apulian plates. In the Miocene, the Eastern Alps were extruded eastwards into the Pannonian domain along major fault systems (PAL, SEMP-Line, Mur-Muerz-Line).

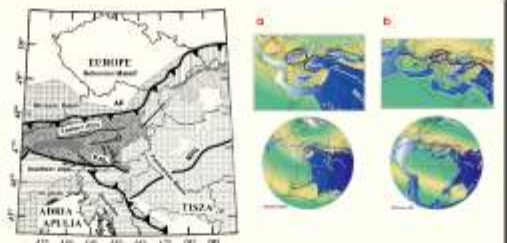


Fig. 1 (left): Major tectonic units of the working area: AF: Alpine Front; MH: Mul-Hungarian Line; PA: Pannonic line. **Fig. 2 (right):** Paleogeographic plate reconstruction for the late Jurassic (a, Alpine Tethys spreading) and Late Cretaceous (b, closure of the Alpine Tethys) after Stampfli et al., 2002. The black ellipse covers approximately the area of the Eastern Alps.

Results - Structure

Structural information was obtained through the 3D images (fig. 4) of the delay times and two way travel times. The Moho is fragmented and overall very variable in depth (fig. 3) and reflectivity. 3 different parts have been identified, with depths ranging between 27 (Western Pannonian Basin) and 52 km (Alpine root).

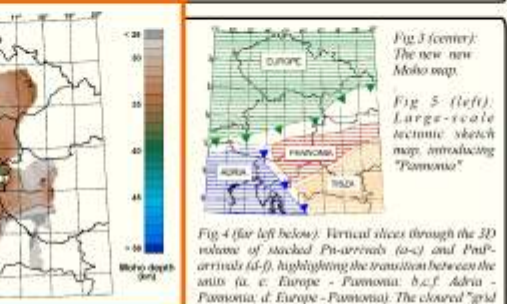
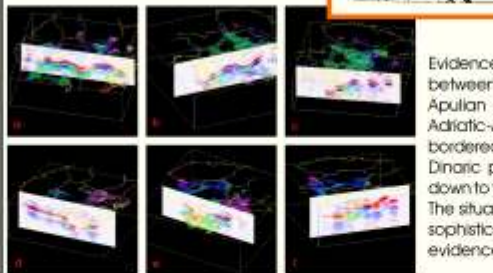


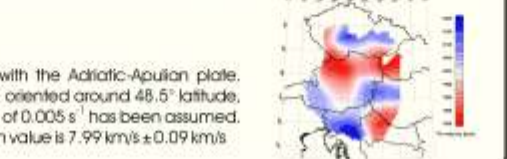
Fig. 3 (center): The new Moho map. **Fig. 4 (left):** Vertical slices through the 3D volume of stacked Pn-arrivals (a-c) and PnP-arrivals (d-f), highlighting the transition between the units a: Europe - Pannonia; b,c: Adria - Pannonia; d: Europe - Pannonia. The closed "grid lines" are picked Pn-delay times resp. TD-times. **Fig. 5 (left):** Large-scale tectonic sketch map, introducing "Pannonia".



Results - Velocity

The velocity pattern shows higher Moho velocities correlating with the Adriatic-Apulian plate. Furthermore, a 100 km broad zone of lower Moho velocities, W-E oriented around 48.5° latitude, has also been interpreted. For the calculation, a uniform gradient of 0.005 s⁻¹ has been assumed. The velocities in the southern part are poorly constrained. The mean value is 7.99 km/s ± 0.09 km/s

Evidence for a downgoing European plate towards the S can be interpreted between 13° and 16° longitude, as well as underthrusting of the Adriatic-Apulian plate towards the ENE. Therefore, both the European and the Adriatic-Apulian plates underthrust a "Pannonian microplate" (fig.5) which is bordered by the Tisza plate further south. "Pannonia" corresponds with the Dinaric part of the formerly known "Alcapan-Unit", but can now be traced down to the Moho. The situation at the "triple junction" is difficult to interpret due to low S/N-ratio, sophisticated crustal structure and the deep Moho(s). However, there is still evidence for a downgoing European plate.



Comparison with other models

We yield a good correlation with the European Moho Map by Dezes & Ziegler. The significant Moho step between Pannonia & Europe is also found in different interpretations from earlier refraction data sets (Yan & Mechie, Sciarascia & Cassinis). The southward subduction of the European Moho is interpreted in Receiver Function Analysis, reflection processing and refraction modelling along the TRANSALP-profile. Models derived by interactive raytracing with the data from ALP 2002 along the profiles ALP01 and ALP02 also show the downgoing European Moho and the step of the junction between Europe, Adria and Pannonia.

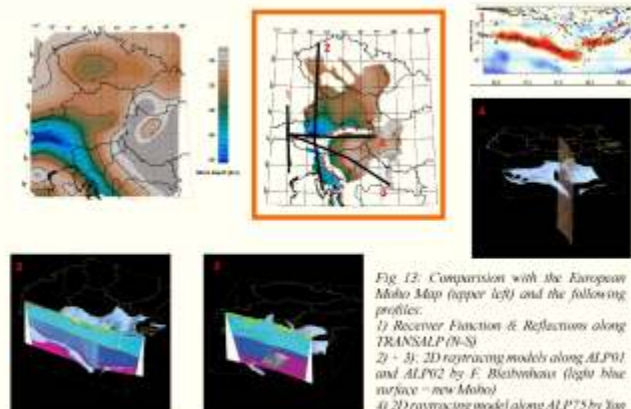


Fig. 12: Comparison with the European Moho Map (upper left) and the following profiles: 1) Receiver Function & Reflections along TRANSALP (9-5) 2) - 3) 2D raytracing models along ALP01 and ALP02 by F. Blahutka (light blue surface = new Moho) 4) 2D raytracing model along ALP75 by Jan & Mechie (dark blue line = Moho by Jan & Mechie)

Tectonic implications

The Dinaric subduction can be seen as the northernmost part of a large subduction system where the Adriatic-Apulian plate underthrusts the Dinaro-Hellenic plate (fig. 14). The Pannonian microplate corresponds with the "Western Dacia" block inferred in oligocene plate reconstructions (fig. 15), while Tisza can be identified as "Eastern Dacia". Superimposing the MHL and the miocene fault lines onto the Moho map supports the concept of lateral extrusion. Given the steps in Moho topography, maybe not only the upper crust, but also the lower crust and uppermost mantle showed rigid behaviour during the extrusion. The different tectonic blocks can also be seen in the crustal velocities (fig. 17), although this picture is distorted due to the different penetration depth of the crustal tomography and local velocity variations.



Fig. 14 (above): Actual tectonic situation. **Fig. 15 (below):** Paleogeographic plate reconstruction for the Oligocene (ED WD: Eastern/Western Dacia). (In both figures, the black rectangle marks the working area of this study).

The transition from Pannonia to Tisza (fig. 18) can be found in the crustal velocities as well as in the delay time stacks, although no Moho depths for the Tisza region have been calculated at this stage.

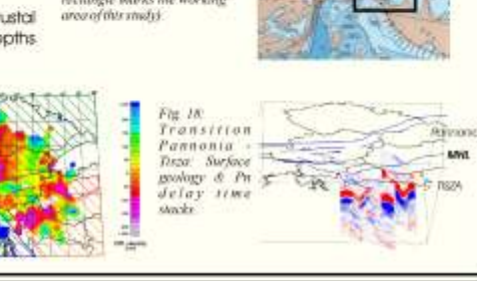


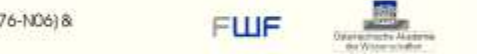
Fig. 16: The new Moho map and the main tectonic lines. **Fig. 17:** The plate tectonic concept and the relative average crustal velocity (blue: fast violet: slow) between 8 km depth and the penetration depth of the diving wave tomography. **Fig. 18:** Transition Pannonia-Tisza Surface geology & Pn delay time stacks.

Outlook & further research

Better constraints on the velocity of the lower crust will be derived from gravimetry (see poster EGU05-A-02610). Together with a more profound analyses of the Pn travel time error, slight modifications of the presented Moho depths can be expected. However, they will not alter the general picture nor the subsequent implications for tectonic and geodynamic interpretations.

Acknowledgment & References

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