The refined Moho depth map in the Carpathian-Pannonian region

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Abstract: We present a new digital Moho depth map of the Carpathian-Pannonian region. The map was produced by compiling Moho discontinuity depth data, which were obtained by interpretation of seismic measurements taking into account the results of 2-D and 3-D integrated geophysical modelling. The resultant map is characterized by significant Moho-depth variations. The trends and features of the Moho in this region were correlated with tectonic units.

Key words: geophysical interpretation, seismics, Moho depth, Carpathian-Pannonian crust

1. Introduction

Research on the morphology of the Moho boundary (the crustal thickness) in the Carpathian-Pannonian region has a long history. It has been a subject of extensive studies since the 1950s, using the two standard geophysical methods for the determination of the depth to the Moho: seismic reflection and refraction measurements (*Szafián and Horváth, 2006*). The first results of the 2-D and 3-D seismic measurements in the states that fall into the area under investigation were published, for example, in works of

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Mayerová et al. (1985, 1994), Bucha and Blížkovský (1994), Guterch et al. (1976, 1983, 1984), Gálfi and Stegena (1960), Szénás (1972), Lazarescu et al. (1983), Dragaševič (1987), Aljinovič (1987), Aric and Gutdeutsch (1987), Sollogub et al. (1973), Sollogub (1988), Chekunov et al. (1988), Kharitonov et al. (1993), Posgay et al. (1996) and *Il'chenko and Buharev (2001).*

To the first works that attempted to compile Moho depth maps belong the publications of *Szénás (1972), Beránek and Zátopek (1981a,b), Guterch et al. (1984, 1986), Šefara et al. (1987), Sollogub (1986), Posgay et al. (1991, 1995), Horváth (1993), Horváth et al. (2006), Dimitrijevič (1995), Lenkey et al. (1998)* and *Lenkey (1999).*

For specific areas of Europe the maps of the depth to Moho were summarized for example in the papers of *Hauser et al., (2001, 2007), Knapp et al. (2005)* and *Martin et al. (2006).*

The results of seismic international projects of the CELEBRATION 2000, ALP 2002 and SUDETES 2003 have contributed exceptional cognition about the crustal thickness in the area of Central Europe. The courses of the Moho interface along the profiles were published in the papers of *Grad et al. (2006, 2009a), Środa et al. (2006), Hrubcová et al. (2005, 2008, 2010), Behm et al. (2007), Brückl et al. (2007, 2010), Hrubcová and Środa (2015), Brückl (2011), Janík et al. (2009, 2011)* and *Malinowski et al. (2009, 2013).*

The digital crustal models of the Moho depth in very small scales were also presented. *Ziegler and Dezes (2006)* produced the Moho depth map for the Western and Central Europe; *Tesauro et al. (2008)* for Europe; *Grad et al. (2009b), Molinari and Morelli (2011)* for European plate; *Artemieva and Thybo (2013)* for Europe, Greenland, and the North Atlantic region.

For completeness, it should be noted that in the past (e.g. *Szafián et al., 1997; Zeyen et al., 2002; Dérerová et al., 2006; Kaban et al., 2010*), as well as in the recent past (e.g. *Alasonati Tašárová et al., 2016; Grinč et al., 2013; Kiss et al., 2015*), the Moho depth calculations have also been made by integrated modelling of the potential fields.

Based on an analysis of the results of the Moho depth determination, we found that in recent years several new Moho depth maps have been published (e.g. *Tesauro et al., 2008; Grad et al., 2009b; Artemieva and Thybo, 2013*), but at too small scales that occupy very large territories. Such maps often miss a more detailed Moho morphology, which has significant impact on the quality and accuracy of potential field modelling. Therefore, the goal of this paper is to present a new digital model of the Moho depth in a larger scale solely for the Carpathian-Pannonian region and its nearest surrounding tectonic units. In addition, we correlate the regional variations in crustal thickness with the main tectonic units.

2. New model of the crustal thickness

Our compilation is based on digitization of original seismic profiles that were produced in the last 15–20 years. In the area of Ukraine, some data were also older, since there were no newer seismic measurements performed, except for the results along the seismic profile PANCAKE (*Starostenko et al., 2013*). For the new Moho depth model (Fig. 1), the results obtained along

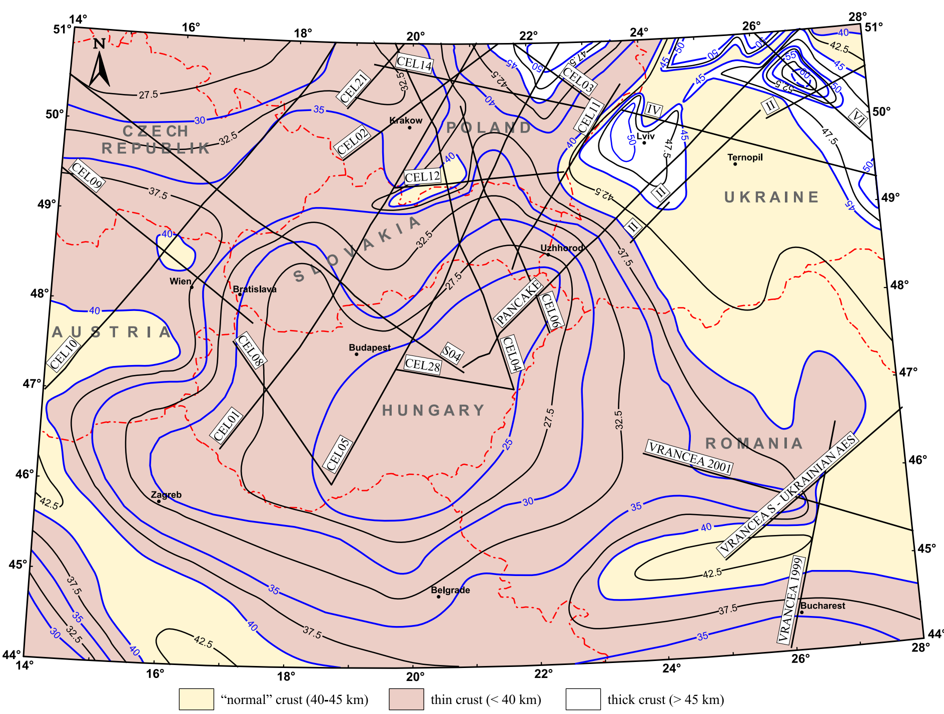

Fig. 1. The Moho depth map in the Carpathian-Pannonian region.

the seismic profiles, which are shown in Table 1, were prominent. There are basically no seismic data for other orogens of the southern Europe (e.g. the Balkanides and the Dinarides, *Artemieva and Thybo, 2013*). From this point of view we used in the Dinarides and Adriatic Sea the results published by *Horváth et al. (2006), Artemieva and Thybo (2013).* For correlation of the Moho depth model with the main tectonic units the tectonic map of the Carpathian-Pannonian region and their surrounding areas is shown in Fig. 2.

Table 1. The profiles that served as key inputs for constructing the Moho depth map.

Profile	**Key references**
CEL01	Środa et al. (2006), Janík et al. (2011)
CEL02	Malinowski et al. (2005), Janík et al. (2009)
CEL03	Janík et al. (2009)
CEL04	Środa et al. (2006), Janík et al. (2011)
CEL05	Grad et al. (2006), Janík et al. (2011)
CEL06	Janík et al. (2011)
CEL08	Malinowski et al. (2003)
CEL09	Hrubcová et al. (2005)
CEL10/Alp04	Hrubcová et al. (2005, 2008), Grad et al. (2009a)
CEL11	Janík et al. (2011)
CEL12	Janík et al. (2011)
CEL14	Janík et al. (2009)
CEL21	Janík et al. (2009)
CEL28	Janík et al. (2011)
VRANCEA99	Hauser et al. (2001)
VRANCEA S - UKRAINIAN AES	Kharitonov et al. (1993)
VRANCEA 2001	Hauser et al. (2007)
PANCAKE	Starostenko et al. 2013
II	Sollogub et al. (1973), Chekunov et al. (1988), Il'chenko and Buharev (2001)
IV	Sollogub (1988)
VI	Sollogub (1988)
SO4	Hrubcová et al. (2010)

3. Correlation of tectonic units with Moho depth

The most interesting feature of the Moho depth map (Fig. 1) is an extraordinarily thin crust, reaching only 24–25 km in its central part of the

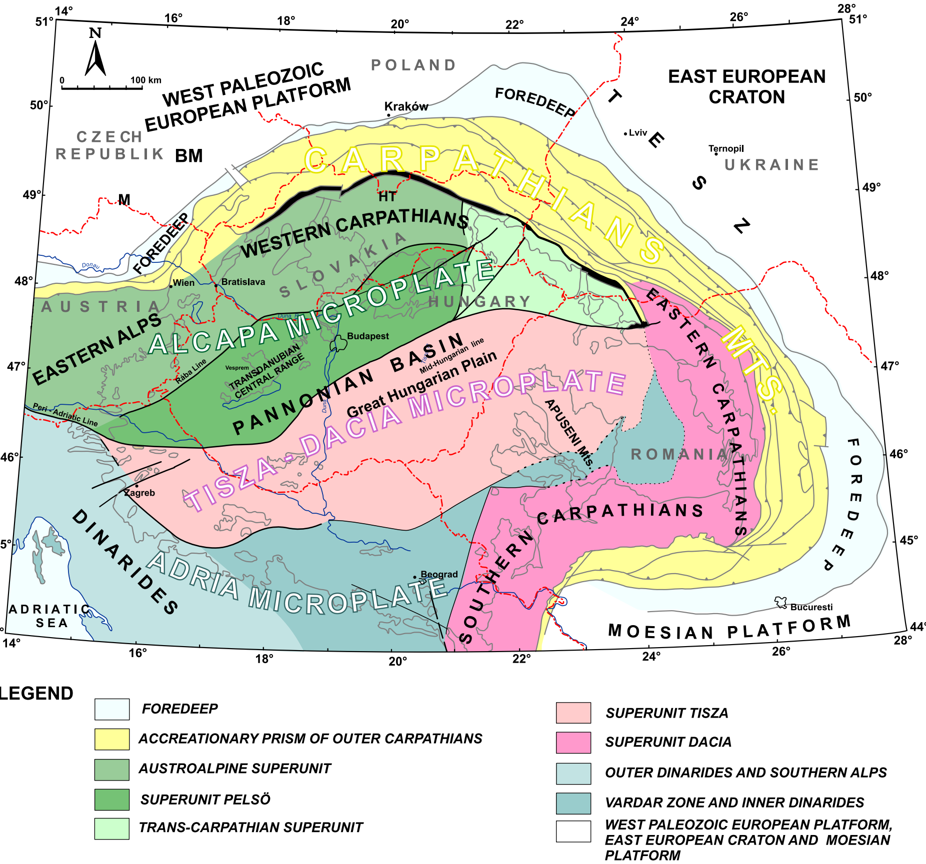

Fig. 2. Tectonic map of the Carpathian-Pannonian basin region (modified after *Bielik 1998 and Kováč, 2000*). BM – Bohemian Massif, M – Moldanubicum, HT – High Tatras, TESZ – Trans European Suture Zone.

Pannonian Basin (the Great Hungarian Plain). From this area, it can be seen that the depth of Moho increases towards all sides. In other words, it grows in the direction to the orogenic regions of the Western, Eastern and Southern Carpathians, Dinarides, Eastern Alps and the Bohemian Massif. The Moho decrease can be observed up to the East European Craton region, where the crust reaches the largest thickness. Here we can see three expressive crustal roots (depressions). The first one is located NE of Krakow and reaches 50 km, while the other (NE of Ternopil') is even larger and is elongated in the NW-SE direction. The crustal thickness reaches ∼60 km, which is the thickest crust in the whole studied area. Both these depressions are split by a third depression, which is characterized by two maximum crustal thicknesses of ∼50 km. Its shape is significantly elongated in the direction of NE–SW. The Trans-European Suture Zone (TESZ) is represented by a linear horizontal gradient of the Moho depth isolines, whose NW–SE direction is identical with the course of this zone. It is interesting to note that the Carpathian Mts. are located over the maximum dip of the Moho in the direction from the Pannonian Basin to the West Paleozoic European platform, the East European Craton and the Moesian Platform. The largest local Moho depression (42 km) in the Western Carpathians is located NE of the High Tatras in Poland. The Bohemian Massif's crust varies from ∼27 km on its NW border to 40 km on its southern one, where it is built by the Moldanubicum. In the Eastern Alps, the thickness of the crust is about 40 km. However, it is well known (*Ziegler and Dezes, 2006*) that this territory is the easiest part of the significant Alpine crustal root (∼55 km). The Dinarides are also characterized by the thicker crust (∼40 km). In the direction to the Adriatic Sea, the crustal thickness thins significantly to only about 30 km.

4. Conclusion

From the resultant Moho depth map the studied area, which is represented by thin (< 40 km), "normal" (40–45 km) and thick (> 45 km) crust, can be divided into the following areas: (a) the Carpathian arc, (b) the Pannonian Basin, (c) the East European Craton, (d) the West Paleozoic European Platform (including the Bohemian Massif), (e) the Trans European Suture Zone, (f) the Eastern Alps, (g) the Dinarides and (h) the Adriatic zone.
Thin crust (< 40 km):

(a) *Carpathian arc*: the crust thickness varies from 30 km in the Internides to 40 km in the Externides. In the Western and Southern Carpathians, two local crustal depressions can be observed. The smaller Western Carpathian one reaches a thickness of 40–42 km and the greater Southern Carpathian one has a maximum thickness of 42.5 km.

(b) *Pannonian Basin*: a very thin crust (24–30 km).

(c) *East European Craton*: a very thick crust (45–60 km). Three crustal roots can be observed with the maximum crustal thicknesses of 50 km and 60 km.

(d) *West-Paleozoic European Platform (including the Bohemian Massif)*: the average crustal thickness varies from 27.5 km to 40 km.

(e) *Trans-European Suture Zone*: typical feature is a sharp drop of Moho from a depth of ∼37.5 km to ∼42.5 km. The drop is in the direction from SW to NE. The depth isolines have NW–SE direction, which correlates with the direction of this significant suture zone.

(f) *Eastern Alps*: thick crust (40 km).

(g) *Dinarides*: thick crust of about 40 km.

(h) *Adriatic zone*: the crustal thickness is ∼30 km.

The results indicate that the Moho depth variations depend mostly on the age of the latest thermal processes, which had been taking place in each of the tectonic units.

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