sciendo

Contributions to Geophysics and Geodesy Vol. 48/2, 2018 (179–190)

The refined Moho depth map in the Carpathian-Pannonian region

Miroslav BIELIK[1,3], Irina MAKARENKO[2], Kristián CSICSAY[3], Olga LEGOSTAEVA[2], Vitaly STAROSTENKO[2], Aleksandra SAVCHENKO[2], Barbora ŠIMONOVÁ[1], Jana DÉREROVÁ[3], Lucia FOJTÍKOVÁ[3], Roman PAŠTEKA[1], Jozef VOZÁR[3]

[1] Department of Applied and Environmental Geophysics, Faculty of Natural Sciences, Comenius University, Mlynská dolina, Ilkovičova 6, 842 48 Bratislava, Slovak Republic; e-mail: bielik@fns.uniba.sk

[2] Institute of Geophysics, National Academy of Sciences of Ukraine, Palladin av. 32, 03680 Kiev, Ukraine

[3] Earth Science Institute, Slovak Academy of Sciences, Dúbravská cesta 9, P. O. Box 106, 840 05 Bratislava, Slovak Republic; e-mail: geofmiro@savba.sk

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

doi: 10.2478/congeo-2018-0007

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

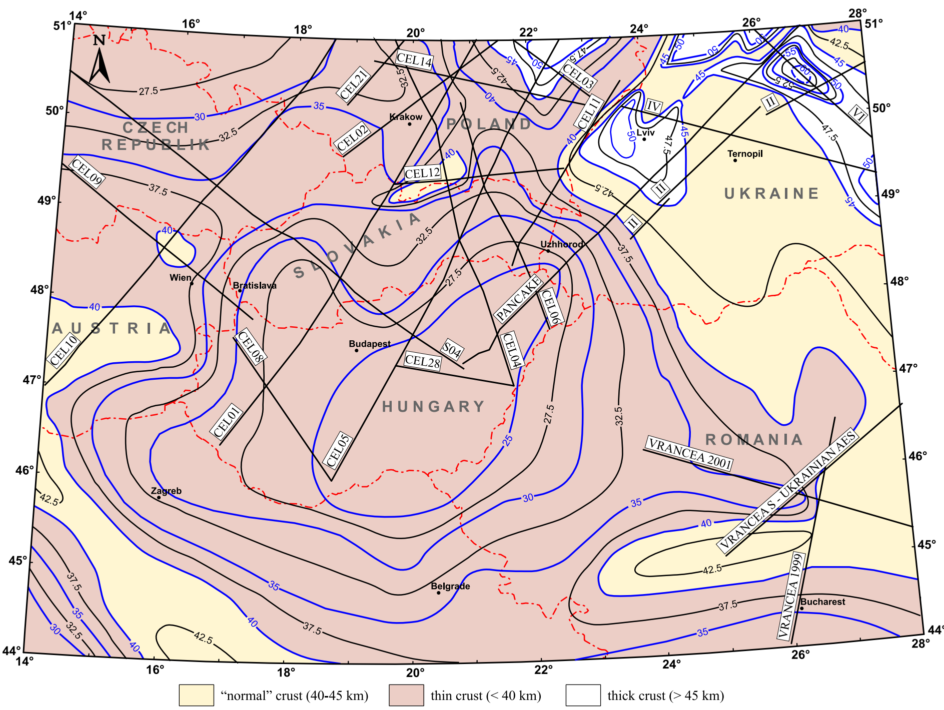

Fig. 1. The Moho depth map in the Carpathian-Pannonian region.

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

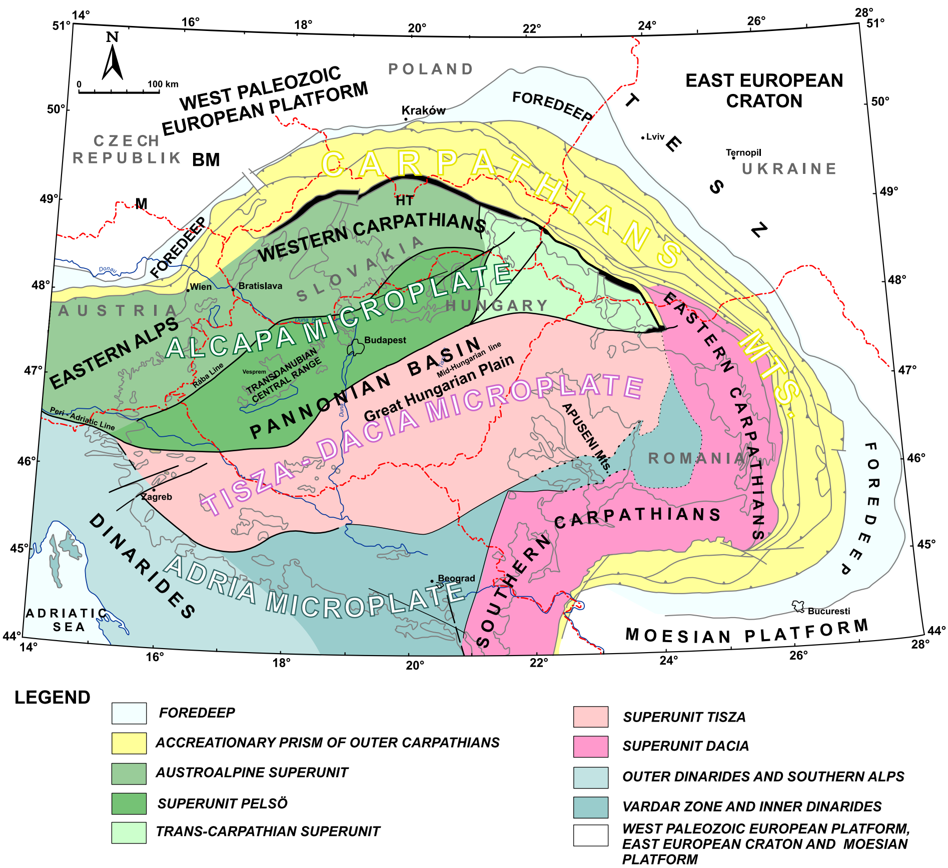

Fig. 2. Tectonic map of the Carpathian-Pannonian basin region (modified after *Bielik 1998 and Kováč, 2000*). BM – Bohemian Massif, M – Moldanubicum, HT – High Tatras, TESZ – Trans European Suture Zone.

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.

Acknowledgements. Special thanks are addressed to all people who participated in the acquisition of gravity data during a long observation history. This work was supported by the Slovak Grant Agency VEGA, grants No. 1/0141/15, 2/0042/15, and APVV grants No. APVV-16-0146, APVV-16-0482.

References

Alasonati Tašárová Z., Fullea J., Bielik M., Środa P., 2016: Lithospheric structure of Central Europe: Puzzle pieces from Pannonian Basin to Trans-European Suture Zone resolved by geophysical-petrological modelling. Tectonics, **35**, 1–32.

Aljinovič B., 1987: On certain characteristics of the Mohorovičič discontinuity in the region of Yugoslavia. Acta Geol. Yugosl. Akad. Znan. Umjet, **17**, 3–20.

Aric K., Gutdeutsch R., 1987: Geophysical aspects of the crustal structures of the Eastern Alps. In: Geodynamics of the Eastern Alps, Eds.: Fluegel H. W., Faupl P., Deuticke F., Verlag, 309–360.

Artemieva I. M., Thybo H., 2013: Moho discontinuity and crustal structure in Europe, Greenland, and the North Atlantic region. Tectonophysics, **609**, 97–153.

Behm M., Brückl E., Mitterbauer U., 2007: A New Seismic Model of the Eastern Alps its Relevance for Geodesy and Geodynamics. VGI Österrreichische Zeitschrift für Vermessung & Geoinformation, **2**, 121–133.

Beránek B., Zátopek A., 1981a: Earth's crust structure in Czechoslovakia and in Central Europe by methods of explosion seismology. In: Geophysical syntheses in Czechoslovakia. Ed.: Zátopek A., VEDA, 243–270.

Beránek B., Zátopek A., 1981b: Preliminary results of geophysical syntheses in Czechoslovakia and Central Europe based on explosion seismology until 1980. In: Geophysical Syntheses in Czechoslovakia, Veda, Bratislava, 469–497.

Brückl E., 2011: Lithospheric Structure and Tectonics of the Eastern Alps – Evidence from New Seismic Data. In: Tectonics, Ed.: Closson D., InTech, Available from: http://www.intechopen.com/books/tectonics/lithospheric-structure-and-tectonics-of-the-eastern-alps-evidence-from-new-seismic-data.

Brückl E., Behm M., Decker K., Grad M., Guterch A., Keller G. R., Thybo H., 2010: Crustal structure and active tectonics in the Eastern Alps. Tectonics, **29**, 1–17.

Brückl E., Bleibinhaus F., Gosar A., Grad M., Guterch A., Hrubcová P., Keller G. R., Majdański M., Šumanovac F. Tiira T., Yliniemi J., Hegedűs E., Thybo H., 2007: Crustal structure due to collisional and escape tectonics in the Eastern Alps region based on profiles Alp01 and Alp02 from the ALP 2002 seismic experiment. J. Geophys. Res., **112**, 1–25.

Bucha V., Blížkovský M. (Eds), 1994: Crustal structure of the Bohemian Massif and the West Carpathians. Springer-Verlag and Academia. Berlin, Heidelberger, New-York and Praha, 177–188.

Chekunov A. V., Ádám A. A., Blížkovský M., Bormann P., Guterch A., Dačev Ch., Kornea I., Kutas R. J., Magnickij V. A., Sollogub V. B., Chain V. E., Sollogub N. V., Starostenko V. J., 1988: Litosphere of Central and Eastern Europe: Geotraverses I, II, V. Naukova dumka, Kiev, 165. (in Russian).

Dérerová J., Zeyen H., Bielik M., Salman K., 2006: Application of integrated geophysical modeling for determination of the continental lithospheric thermal structure in the eastern Carpathians. Tectonics, **25**, TC3009.

Dimitrijevič M. D., 1995: The map of Moho surface and Bouguer gravity map. In: Geological Atlas of Serbia, 1:2000000, Ed.: Dimitrijevič M. D., Republ. Found Geological Investigations and RGF Geophysical Department.

Dragaševič T., 1987: The Mohorovičič discontinuity, structure and classification of the Earth crust in the eastern region of Yugoslavia. Acta Geod. Jugosl. Akad. Znam. Umjet, **17**, 39–45.

Gálfi J., Stegena L., 1960: Deep reflections and crustal structure in the Hungarian Basin. Ann. Univ. Sci. Bp. R. Eötvös nom., **3**, 41–47.

Grad M., Guterch A., Keller G. R., Janik T., Hegedűs E., Vozár J., Slaczka A., Tiira T., Yliniemi J., 2006: Lithospheric structure beneath trans-Carpathian transect from Precambrian platform to Pannonian Basin: CELEBRATION 2000 seismic profile CEL05. J. Geophys. Res., **111**, 1–23.

Grad M., Brückl E., Majdański M., Behm M., Guterch A., CELEBRATION 2000 and ALP 2002 Working Groups, 2009a: Crustal structure of the Eastern Alps and their foreland: seismic model beneath the CEL10/Alp04 profile and tectonic implications. Geophys. J. Int., **177**, 279–295.

Grad M., Tiira, T., ESC Working Group, 2009b: The Moho depth map of the European Plate. Geophys. J. Int., **176**, 279–292.

Grinč M., Zeyen H., Bielik M., Plašienka D., 2013: Lithospheric structure in Central Europe: Integrated geophysical modelling. J. Geodyn., **66**, 13–24.

Guterch A., Grad M., Materzok R., Perchuč E., Toporkiewicz S., 1986: Results of seismic crustal studies in Poland. Publ. Inst. Geophys. Pol. Acad. Sci., **17**, 192, 1–84. (in Polish with English summary).

Guterch A., Kowalski T. J., Materzok R., Toporkiewicz S., 1976: Seismic refraction study of the Earrth's crust in the Teisseyre-Tornquist line zone in Poland along the LT-2 profile. Publ. Inst. Geophys. Pol. Acad. Sci., A-2, **101**, 15–23.

Guterch A., Grad M., Materzok R., Pajchel J., Perchuč E., Toporkiewicz S., 1984: Deep structure of the Earth's crust in the contact zone of the Palaeozoic and Precambrian platforms and the Carpathian Mts in Poland. Acta Geophysica Polonica, **32**, 25–41.

Guterch A., Grad M., Materzok R., Toporkiewicz S., 1983: Structure of the earth's crust of the Permian Basin in Poland. Acta Geophysica Polonica **31**, 121–138.

Hauser F., Raileanu V., Fielitz W., Bala A., Prodehl C., Schulze A., 2001: VRANCEA99 – the crustal structure beneath the southeastern Carpathians and the Moesian Platform from a seismic tefraction profile in Romania. Tectonophysics, **430**, 233–256.

Hauser F., Raileanu V., Fielitz W., Dinu C., Landesa M., Bala A., Prodehl C., 2007: Seismic crustal structure between the Transylvanian Basin and the Black Sea. Tectonophysics, **430**, 1–25.

Horváth F., 1993: Towards a mechanical model for the formation of the Pannonian Basin. Tectonophysics, **226**, 333–357.

Horváth G., Bada F., Szafián P., Tari G.,Ádám A., Cloetingh S., 2006: Formation and deformation of the Pannonian Basin: Constraints from observational data. In: European Lithosphere Dynamics, Geol. Soc. Mem., **32**, Ed.: Gee D., Stephenson R., Geol. Soc., London. 191–206.

Hrubcová P., Środa P., 2015: Complex local Moho topography in the Western Carpathians: Indication of the ALCAPA and the European Plate contact. Tectonophysics, **638**, 63–81.

Hrubcová P., Środa P., CELEBRATION 2000 Working Group, 2008: Crustal structure at the easternmost termination of the Variscan belt based on CELEBRATION 2000 and ALP 2002 data. Tectonophysics, **460**, 55–75.

Hrubcová P., Środa P., Grad M., Geissler W. H., Guterch A., Vozár J., Hegedűs E., Sudetes Working Group, 2010: From the Variscan to the Alpine Orogeny: crustal structure of the Bohemian Massif and the Western Carpathians in the light of the SUDETES 2003 seismic data. Geophys. J. Int., **183**, 611–633.

Hrubcová P., Środa P., Špičák A., Guterch A., Grad M., Keller G. R., Brückl E., Thybo H., 2005: Crustal and uppermost mantle structure of the Bohemian Massif based on CELEBRATION 2000 data. J. Geophys. Res., **110**, 1–21.

Il'chenko T. V., Buharev V. P., 2001: Velocity model of the crust and upper mantle Korostensky Pluto (Ukrainian shield) and its geological interpretation (in profile DSS Shepetovka-Chernihiv). Geofizicheskij zhurnal, **23**, 72–82 (in Russian).

Janik T., Grad M., Guterch A., CELEBRATION 2000 Working Group, 2009: Seismic structure of the lithosphere between the East European Craton and the Carpathians from the net of CELEBRATION 2000 profiles in SE Poland. Geological Quarterly, **53**, 141–158.

Janik T., Grad M., Guterch A., Vozár J., Bielik M., Vozárová A., Hegedűs E., Kovács C. A., Kovács I., CELEBRATION 2000 Working Group, 2011: Crustal structure of the Western Carpathians and Pannonian Basin System: seismic models from CELEBRATION 2000 data and geological implication. J. Geodyn., **52**, 97–113.

Kaban M. K., Tesauro M., Cloetingh S., 2010: An integrated gravity model for Europe's crust and upper mantle, Earth Planet. Sci. Lett., **296**, 195–209.

Kharitonov O. M., Krasovskiy S. S., Kuprienko P. Ya., Kutas V. V., Sologub N. V., Drogitskaya G. M., Timoshenko V. I., Shlyahovskiy V. A., 1993: Lithospheric transect Vrancea-South-Ukrainian AES. Geofizicheskiy zhurnal, **15**, 23–31 (in Russian).

Kiss J., Gúthy T., Zilahi-Sebess L., 2015: Research of the Mohorovičič discontinuity in Hungary – methods, measurements and results. Magyar geofizika, **56**, 152–178 (in Hungarian, summary in English).

Knapp J. H., Knapp C. C., Raileanu V., Matenco L., Mocanu V., Dinu C., 2005: Crustal constraints on the origin of mantle seismicity in the Vrancea zone, Romania: the case for active continental lithospheric delamination. Tectonophysics, **410**, 311–323.

Lazarescu V., Cornea I., Radulescu F., Popescu M., 1983: Moho surface and recent crustal movements in Romania. Geodynamic connections. An. Inst. Geol. Geofiz., **63**, 83–91.

Lenkey L., Horváth F., Dövényi P., Szafián P., 1998: Geophysical features and structural conditions of the Pannonian Basin and its surroundings: a review. Rep. Geod. Warsaw Univ. Techn., **5**, 11–34.

Lenkey I., 1999: Geothermics of the Pannonian Basin and its bearing on the tectonics of Basin evolution. Phd. Thesis. Netherlands Research Scool of Sedimentary Geology publication No. 990112. Amsterdam: Vrije Universiteit Amsterdam, 1–215.

Malinowski M., CELEBRATION 2000 Working Group, 2003: Seismic crustal structure of the Alpine – Pannonian area revealed by the CELEBRATION 2000 experiment. Profiles CEL08 and CEL07. EGS–AGU–EGU Joint Assembly, Abstracts from the meeting held in Nice, France, 6–11 April 2003, abstract#2619.

Malinowski M., Guterch A., Narkiewicz M., Probulski J., Maksym A., Majdański M., Środa P., Czuba W., Gaczyński E., Grad M., Janik T., Jankowski L., Adamczyk A., 2013: Deep seismic reflection profile in Central Europe reveals complex pattern of Paleozoic and Alpine accretion at the East European Craton margin. Geophysical Research Letters, **40**, 1–6.

Malinowski M., Środa P., Grad M., Guterch A., CELEBRATION 2000 Working Group, 2009. Testing robust inversion strategies for three-dimensional Moho topography based on CELEBRATION 2000 data. Geophys. J. Int., **179**, 1093–1104.

Malinowski M., Żelaźniewicz A., Grad M., Guterch A., Janik T., CELEBRATION 2000 Working Group, 2005: Seismic and geological structure of the crust in the transition from Baltica to Palaeozoic Europe in SE Poland – CELEBRATION 2000 experiment, profile CEL02. Tectonophysics, **401** 55–77.

Martin M., Wenzel F., Calixto Working Group, 2006: High-resolution teleseismic body wave tomography beneath SE-Romania – II. Imaging of a slab detachment scenario. Geophys. J. Int., **164**, 579–595.

Mayerová M., Nakládalová Z., Ibrmajer I., Hermann H., 1985: Space distribution of the Moho surface in Czecho-Slovakia based on results of the DSS profile measurements and technical explosions. 8. Celoštátní konference geofyziků. Sekce S1-seizmická. Geofyzika, n.p. Brno, 44–53 (in Czech).

Mayerová, M., Novotný M., Fejfar, M., 1994: Deep seismic sounding in Czechoslovakia. In: Crustal structure of the Bohemian Massif and the West Carpathians. Eds.: Bucha V., Blížkovský M., Academia Press – Springer Verlag, 13–20.

Molinari I., Morelli A., 2011: EPcrust: a reference crustal model for the European Plate. Geophys. J. Int., **185**, 352–364.

Posgay K., Albu I., Mayerova M., Nakládalová Z., Ibrmajer I., Blížkovsky M., Aric K., Gutdeutsch R., 1991: Contour map of the Mohorovičič discontinuity beneath Central Europe. Geophys. Trans., **36**, 7–13.

Posgay K., Bodoky T., Hegedűs E., Kovácsvölgyi S., Lenkey L., Szafián P., Takács E., Tímár Z., Varga G., 1995: Asthenospheric structure beneath a Neogene Basin in SE Hungary. Tectonophysics, **252**, 467–484.

Posgay K., Takács E., Szalay I., Bodoky T., Hegedűs E., Kántor J. I., Timár Z., Varga G., Bérczi I., Szalay Á., Nagy Z., Pápa A., Hajnal Z., Reilkoff B., Mueller St., Ansorge J., De Iaco R., Asudeh I., 1996: International deep reflection survey along the Hungarian Geotraverse. Geophys. Trans., **40**, 1–44.

Šefara J., Bielik M., Bodnár J., Čížek P., Filo M., Gnojek I., Grecula P., Halmešová S., Husák Ľ., Janoštík M., Král M., Kubeš P., Kurkin M., Leško B., Mikuška J., Muška P., Obernauer D., Pospíšil L., Putiš M., Šutora A., Velich R., 1987: Structure-tectonic map of the Inner Western Carpathians for the prognoses of the ore deposits - geophysical interpretations. Explanation to the collection of the maps. Manuscript, 267 (in Slovak).

Sollogub V. B., 1986: Lithosphere of the Ukraine. Naukova dumka, Kiev, 172. (in Russian).

Sollogub V. B. (Ed.), 1988: Lithosphere of the Central and Eastern Europe: Geotraverses IV, VI, VIII. Naukova dumka, Kiev, 172.

Sollogub V. B., Prosen D., Dachev C., Petkov I., Vetchev T., Andonova E., Mihailov S., Mituch E., Posgay K., Militzer H., Knothe C., Uchman I., Constantinescu I., Cornea I., Subbotin S. I., Chekunov A. V., Garkalenko I. A., Khain V. E., Slavin V. I., Beranek B., Weiss J., Hrdlička A., Dudek A., Zounkova M., Suk M., Feifar M., Milovanović B., Roksandić M., 1973: Crustal structure of Central and Southeastern Europe by data of explosion seismology. Tectonophysics, **20**, 1–33.

Środa P., Czuba W., Grad M., Guterch A., Tokarski A. K., Janik T., Rauch M., Keller G. R., Hegedűs E., Vozár J., Celebration 2000 Working Group, 2006: Crustal and upper mantle structure of the Western Carpathians from CELEBRATION 2000 profiles CEL01 and CEL04: seismic models and geological implications. Geophys. J. Int., **167**, 737–760.

Starostenko V., Janik T., Kolomiyets K., Czuba W., Środa P., Grad M., Kovacs I., Stephenson R., Lysynchuk D., Thybo H., Artemieva I., Omelchenko V., Gintov O., Kutas R., Gryn D., Guterch A., Hegedűs E., Komminaho K., Legostaeva O., Tiira T., Tolkunov A., 2013: Seismic velocity model of the crust and upper mantle along profile PANCAKE across the Carpathians between the Pannonian Basin and the East European Craton. Tectonophysics, **608**, 1049–1072.

Szafián P., Horváth F., Cloetingh S., 1997: Gravity constrains on the crustal structure and slab evolution along a trans-Carpathian transect. Tectonophysics, **272**, 233–247.

Szafián P., Horváth F., 2006: Crustal structure in the Carpatho-Pannonian region: insights from three-dimensional gravity modelling and their geodynamic significance. Int. J. Earth Sci. (Geol. Rundsch.), **95**, 50–67.

Szénás Gy. (Ed), 1972: The crustal structure of Central and Southeastern Europe based on the results of explosion seismology. Spec. Edit. Geophys. Transact., 1–172.

Tesauro M., Kaban M. K., Cloetingh S., 2008: EuCRUST-07: A new reference model for the European crust. Geophys. Res. Lett., **35**, L05313.

Zeyen H., Dérerová J., Bielik M., 2002: Determination of the continental lithosphere thermal structure in the Western Carpathians: integrated modelling of surface heat flow, gravity anomalies and topography. Physics of the Earth and Planetary Interiors, **134**, 89–104.

Ziegler P. A., Dezes P., 2006: Crustal evolution of Western and Central Europe. In: European Lithosphere Dynamics. Eds.: Gee D., Stephenson R., Geol. Soc. London Sp. Publ., **32**, 43–56.