Applications of detailed 3D P-wave velocity crustal model in Poland for local, regional and global seismic tomography

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Abstract

The 3D P-wave seismic velocity model was obtained by combining data from multiple studies during past 50 years. Data sources included refraction seismology, reflection seismology, geological boreholes, vertical seismic profiling, magnetotellurics and gravimetry. Use of many data sources allowed creation of detailed 3D P-wave velocity model that reaches to depth of 60 km and includes 6-layers of sediments and 3-layers of the crust. Purpose of this study is to analyze how 3D model influences local (accuracy of location and source time estimation for local events), regional (identification of wide-angle seismic phases) and global (teleseismic tomography) seismic travel times. Additionally we compare results of forward seismic wave propagation with signals observed on short period and broadband stations. National Science Centre Poland provided financial support for this work by NCN grant DEC-2011/02/A/ST10/00284.

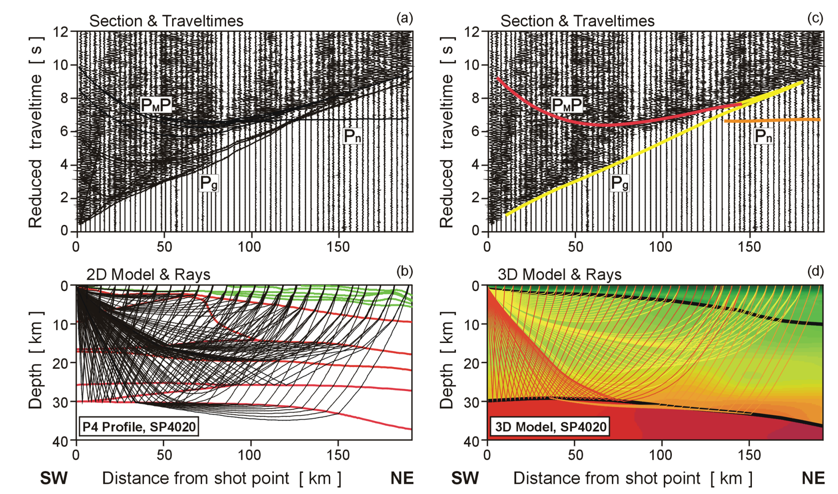

Fig. 14. Comparison of traveltimes for the SW part of profile P4, record section for SP4020. (a) Crustal and uppermost mantle phases for 2D model (Grad et al., 2003). (b) First arrival phases and reflections from the Moho along 2D cross section extracted from the 3D model. Trace-normalized, vertical--component seismic record section is band--pass filtered (2–12 Hz); PMP and Pn - reflected and refracted waves from the Moho; Pg - waves refracted from the basement (upper crust); reduction velocity is 8.0 km/s.

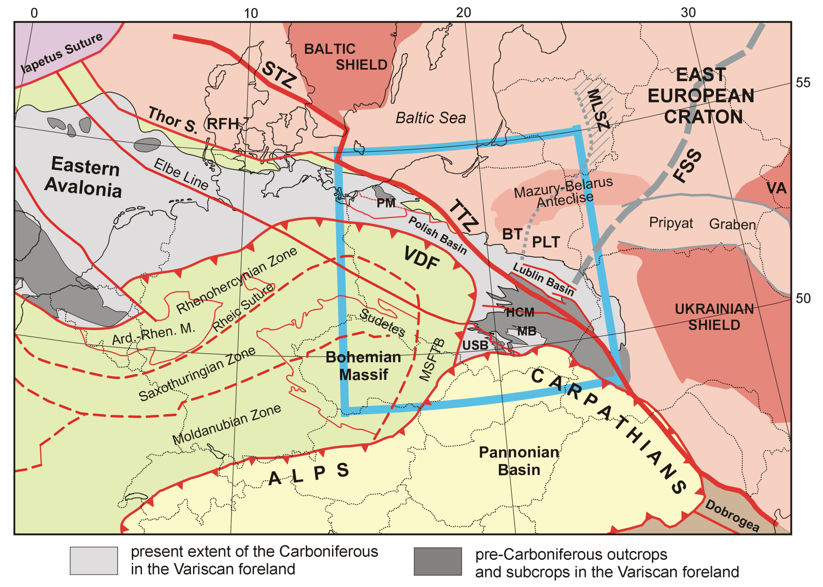

Fig. 1. Tectonic sketch of the pre-Permian Central Europe in the contact of the East European Platform, Variscides and Alpine orogen. Blue frame shows location of the study area in Poland. Compiled mainly from: Pożaryski and Dembowski (1983), Ziegler (1990), Winchester et al. (2002), Narkiewicz et al. (2011, 2015), Cymerman (2007), and Skridlaitė et al. (2006). Ard.--Rhen. M – Ardenno-Rhenish Massif; BT – Baltic Terrane; FSS – Fennoscandia-Sarmatia Suture; HCM – Holy Cross Mountains; MB – Małopolska Block; MLSZ – Mid-Lithuanian Suture Zone; MSFTB – Moravian-Silesian Fold-and-Thrust Belt; PLT – Polish--Latvian Terrane; PM – Pomerania Massif; RFH – Ringkobing--Fyn High; STZ – Sorgenfrei-Tornquist Zone; Thor S. – Thor Suture; TTZ – Teisseyre-Tornquist Zone; USB – Upper Silesian Block; VA – Voronezh Anteclise; VDF – Variscan Deformation Front.

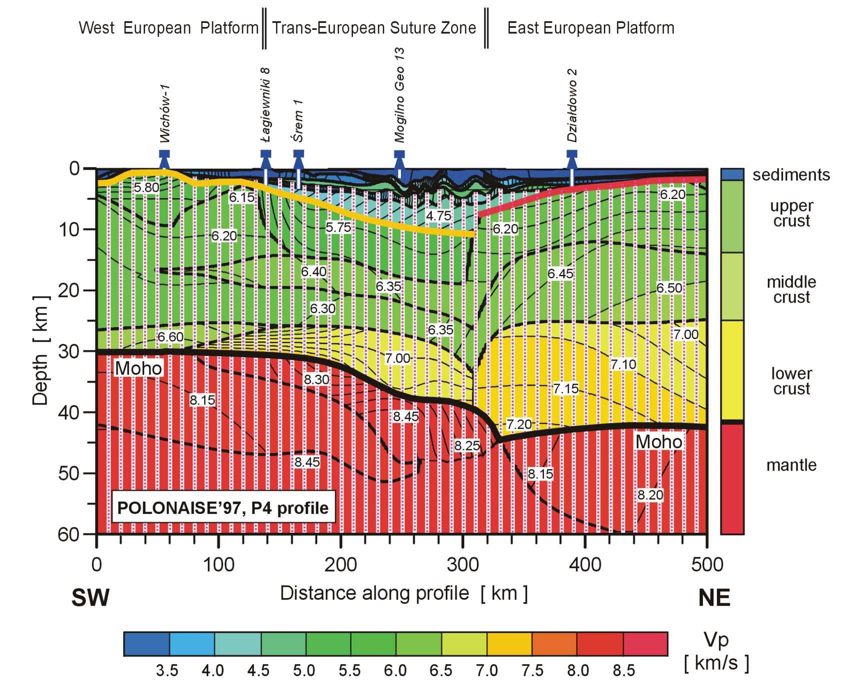

Fig. 3. Seismic model trough the Trans-European Suture Zone (TESZ) in Poland between the East European Craton (EEC) and West European Platform (WEP) alond central part of profile P4 (Grad et al., 2003; see Fig. 2d for location). Precambrian basement is shown by thick red line, Palaeozoic besement by orange line, and Moho by thick black line. Note basement velocity differentiation: c. 6.1 km/s for the EEC and c. 5.8 km/s for the WEP. Basement in the TESZ area is not reached by boreholes (see white lines down to depth of 2-4 km for five boreholes closely to profile line), so velocities of deep sediments and consolidated crust are aviable only from seismic model. Virtual boreholes - seismic logs through the pre-Permian sediments, consolidated crust and uppermost mantle are marked by dashed red lines. Right pannel shows classification of layers.

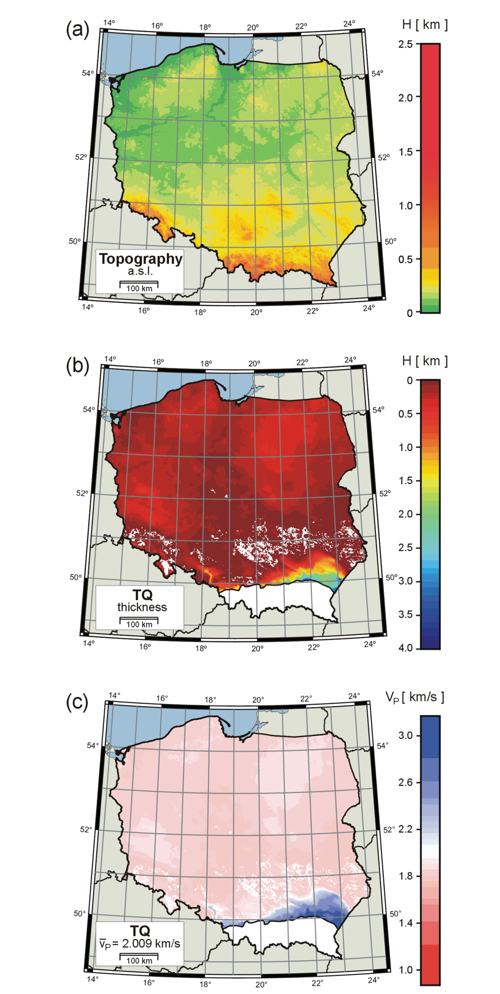

Fig. 4. (a) Topography map of the model area (Michalak, 2004). (b) thickness of the Tertiary and Quatenary sediments. (c) average P-wave velocity in Tertiary–Quaternary sediments.

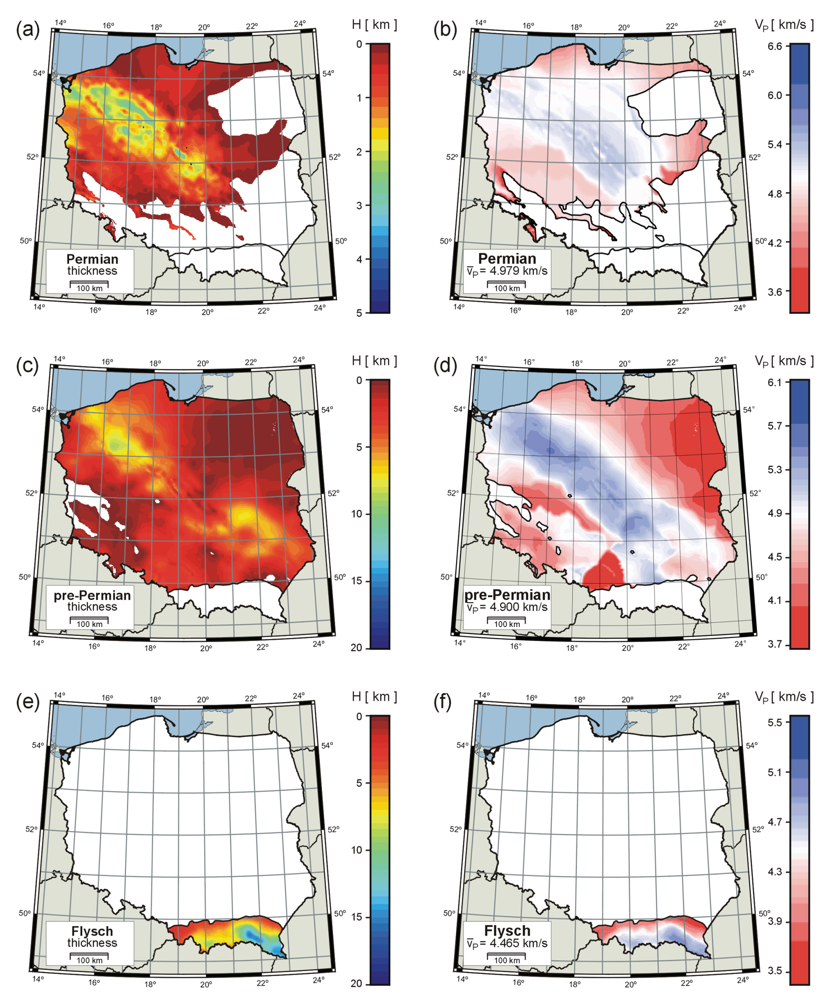

Fig. 6. Thickness maps (a, c, e) and average P-wave velocity maps (b, d, f) of Permian, pre-Permian and Carpathian flinch. White color indicates areas where given layer is not present. Color scale on velocity maps is always symmetric, where white corresponds to average velocity for whole layer.

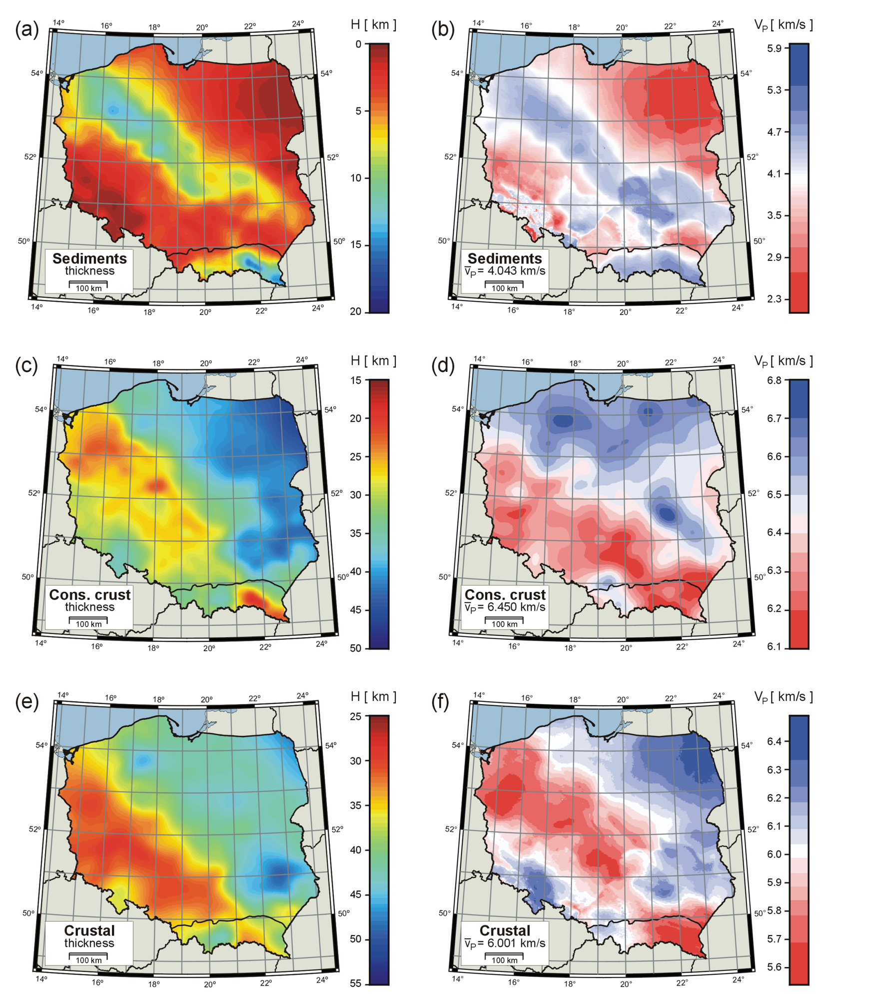

Fig. 8. Summary of 3D model seismic model of the crust in Poland. (a) Cumulative thickness map of the sediments. (c) Cumulative thickness map of the crystalline crust. (e) Whole crust thickness. (b, d, f) – corresponding average P-wave velocity maps. Average velocities are calculated as harmonic mean for all depth ranges.

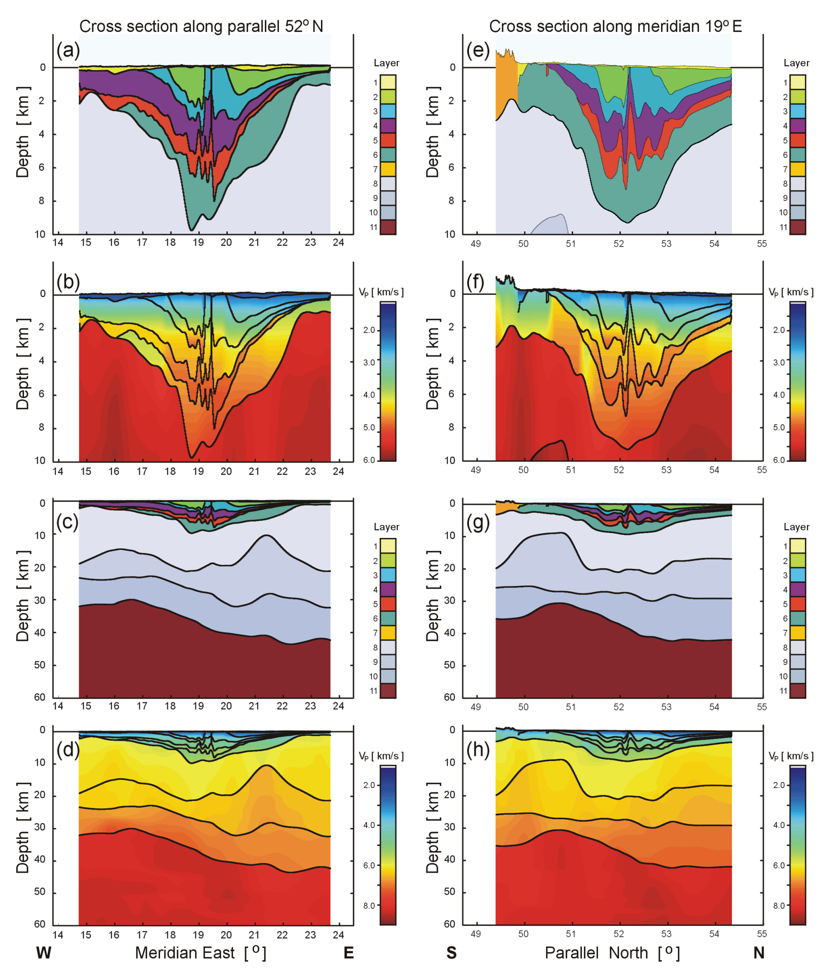

Fig. 10. Geological and seismic vertical cross sections through 3D model: West–East along parallel 52°N (a-d) and South–North along meridian 19°E (e-h); for location see Fig. 2b. Cross sections show in detailes upper 10 km and the whole model range down to 60 km depth. For geological sections right pannel shows classification of layers.

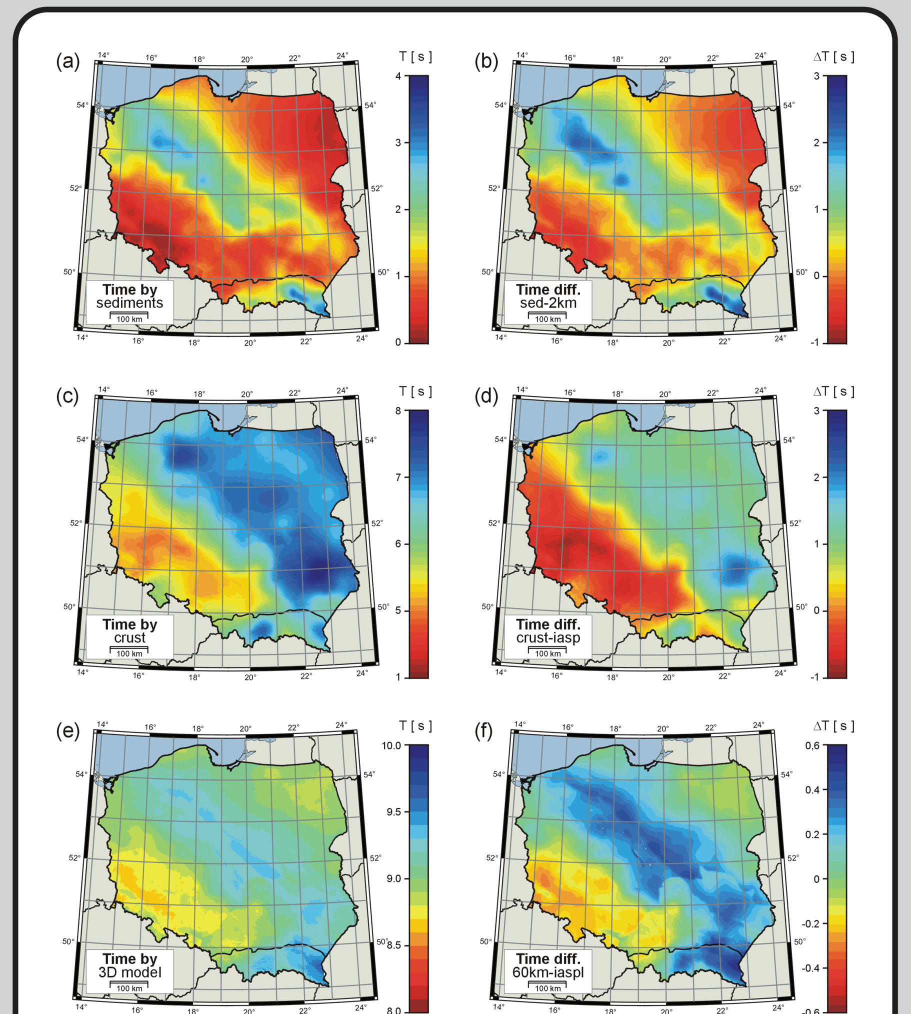

Fig. 16. Comparison of vertical travel times through our 3D model and other models. (a) Vertical pass time through sedimentary cover; (b) time difference in relation to homogeneous 2-km-thick layer with velocity 3 km/s. (c) Vertical pass time through; (d) time difference to iasp91 model. (e) Vertical pass time through whole 3D model and (f) time difference to 60-km-thick of iasp91 model.

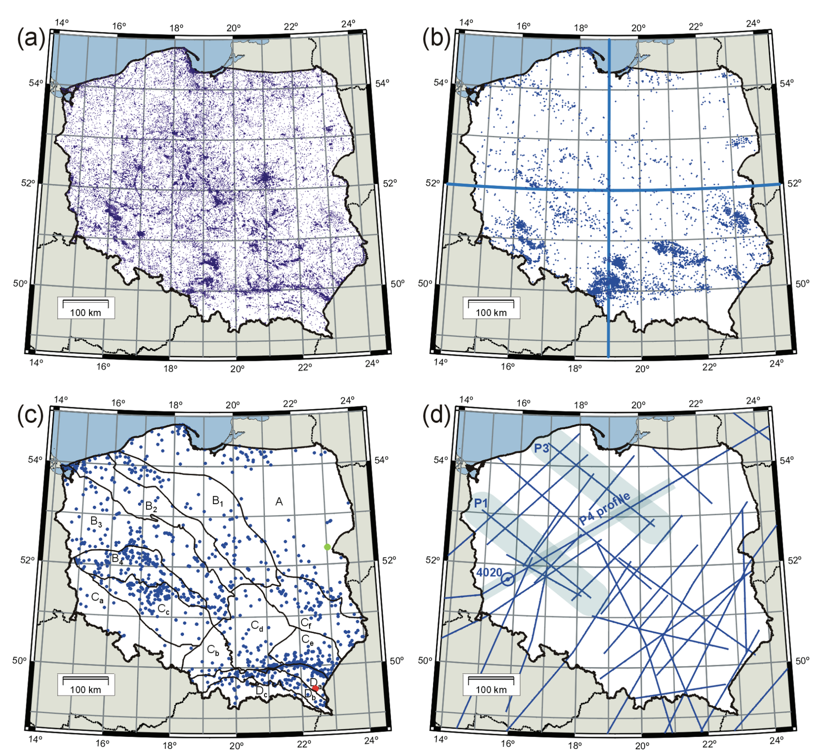

Fig. 2. The location of boreholes and seismic profiles in the area of Poland from which database for the 3D crustal and uppermost mantle model were created. (a) A location over 100,000 boreholes in Poland which were used for determination of geometry stratigraphic layers shown in Figs. 4 nad 5 (Małolepszy 2005; see text for more explanation). (b) Location of 6,028 boreholes which reach pre-Permian sediments; two blue lines show location of representative vertical cross sections through the 3D seismic model shown in Fig. 10. (c) Location map of 1,188 boreholes with VSP used in this study on the background of the geological division of Poland, simplified from Sokołowski (1968). A – East European Craton; B – Lowland: B1 – marginal synclinorium; B2 – Pomorze–Kujawy anticlinorium; B3 – Szczecin–Łódź synclinorium; B4 – northern fore-Sudetic monocline; C – Folded area: Ca – Sudetes and fore-Sudetic block; Cb – Upper Silesian block; Cc – southern fore-Sudetic monocline; Cd – Miechów synclinorium, Goleniów anticlinorium and Holy Cross anticlinorium; Ce – San elevation; Cf – Lublin synclinorium; D – Carpathians: Da – Outer Carpathians; Db – Silesian unit; Dc – Magura unit and Inner Carpathians. The red dot in SE Poland shows the location of the deepest well Kuźmina 1, 7541 m. The green dot in eastern Poland shows the location of the well Mielnik IG 1. (d) Location of modern seismic refraction experiments/profiles: POLONAISE '97: Guterch et al. (1999); profile P1 - Jensen et al. (1999); profile P2 - Janik et al. (2002); profile P3 - Środa et al. (1999); profile P4 - Grad et al. (2003); profile P5 - Czuba et al. (2001); CELEBRATION 2000: Guterch et al. (2003): profiles CEL01 and CEL04 - Środa et al. (2006); profile CEL02 - Malinowski et al. (2005); profile CEL03 - Janik et al. (2005); profile CEL05 - Grad et al. (2006); profile CEL10 - Grad et al. (2009); profiles CEL06, CEL11, CEL12, CEL13, CEL14, CEL21, CEL22, CEL23 - Janik et al. (2009); SUDETES 2003: Grad et al. (2003); profile S01 - Grad et al. (2008); profiles S02, S03, S06 - Majdański et al. (2006); OTHER profiles: LT-2, LT-4, LT-5 - Grad et al. (2005); profile LT-7 - Guterch et al. (1994); profiles M-7, M-9 - Grad et al. (1991); profile TTZ - Grad et al. (1999); profile PANCAKE - Starostenko et al. (2013); profile 1-VI-66 - Grad et al. (1990). Highlighted part of P4 profile shows a location of cross section in Fig. 3 and dot in SW part at P4 profile shows location of shot point SP4020. Highlighted areas around P1 and P3 profiles show areas sampled for comparison crustal and uppermost mantle VP velocity with laboratory measurements of different rock types velocities.

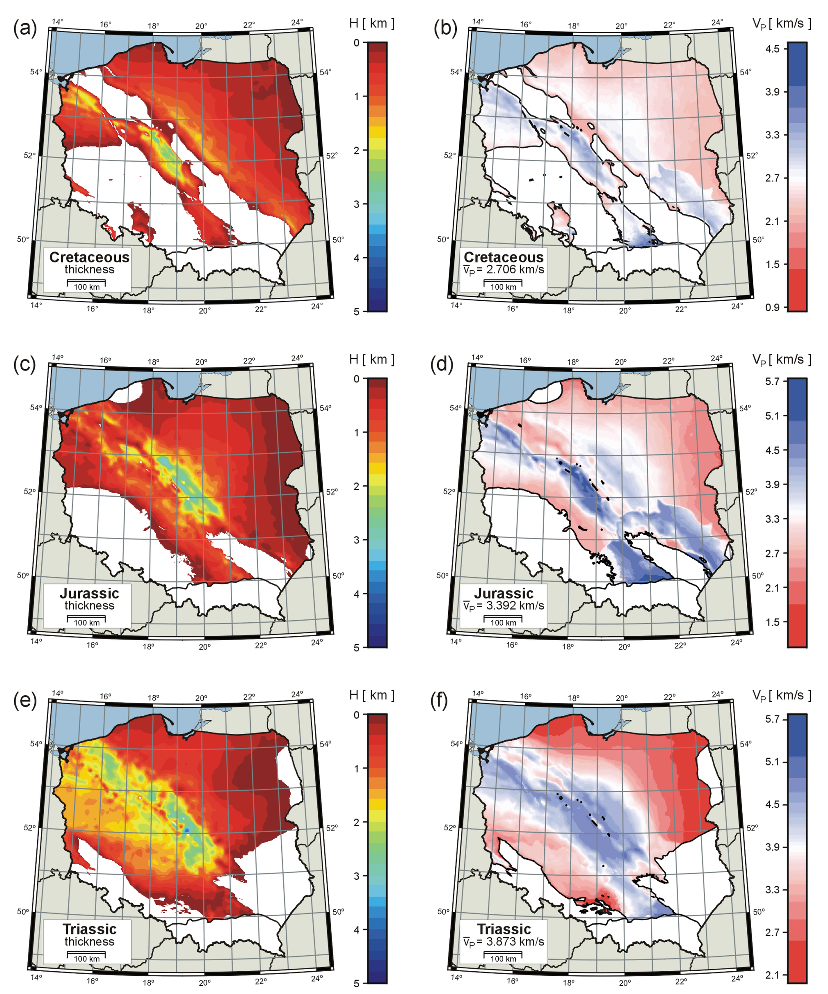

Fig. 5. Thickness maps (a, c, e) and average P-wave velocity maps (b, d, f) of Cretaceous, Jurassic and Triassic.

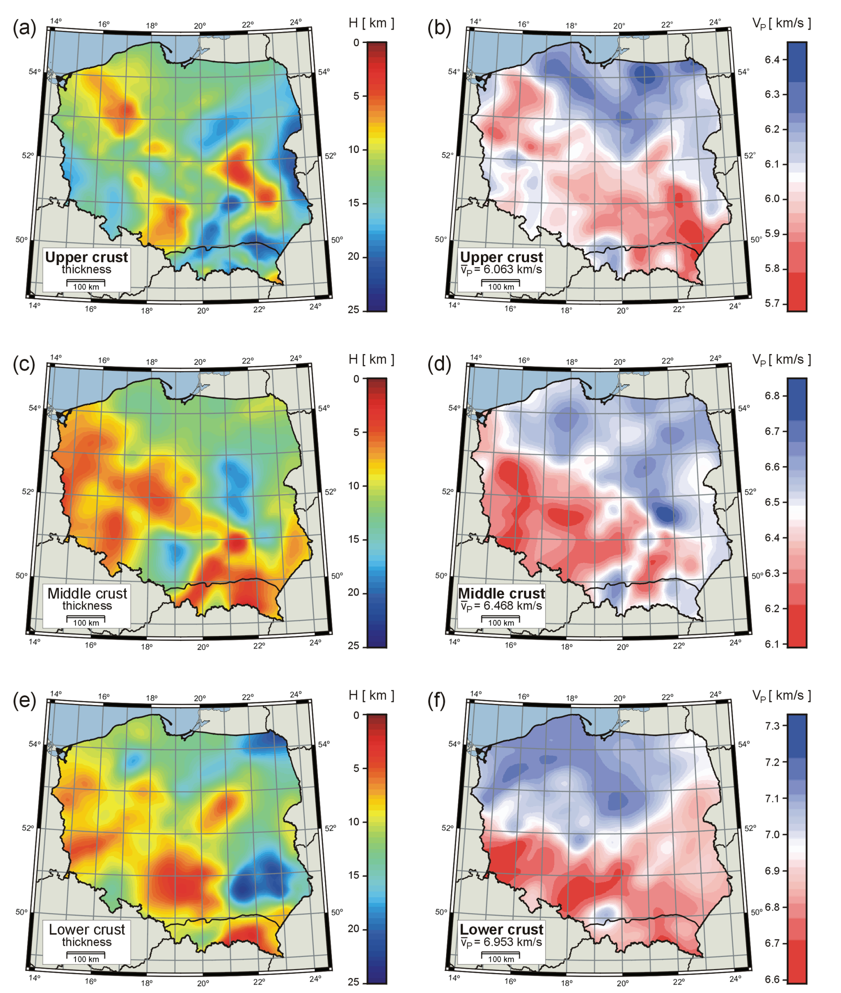

Fig. 7. Thickness maps of the crust: (a, c, e) and corresponding average P-wave velocity maps (b, d, f) for upper crust, middle crust and lower crust.

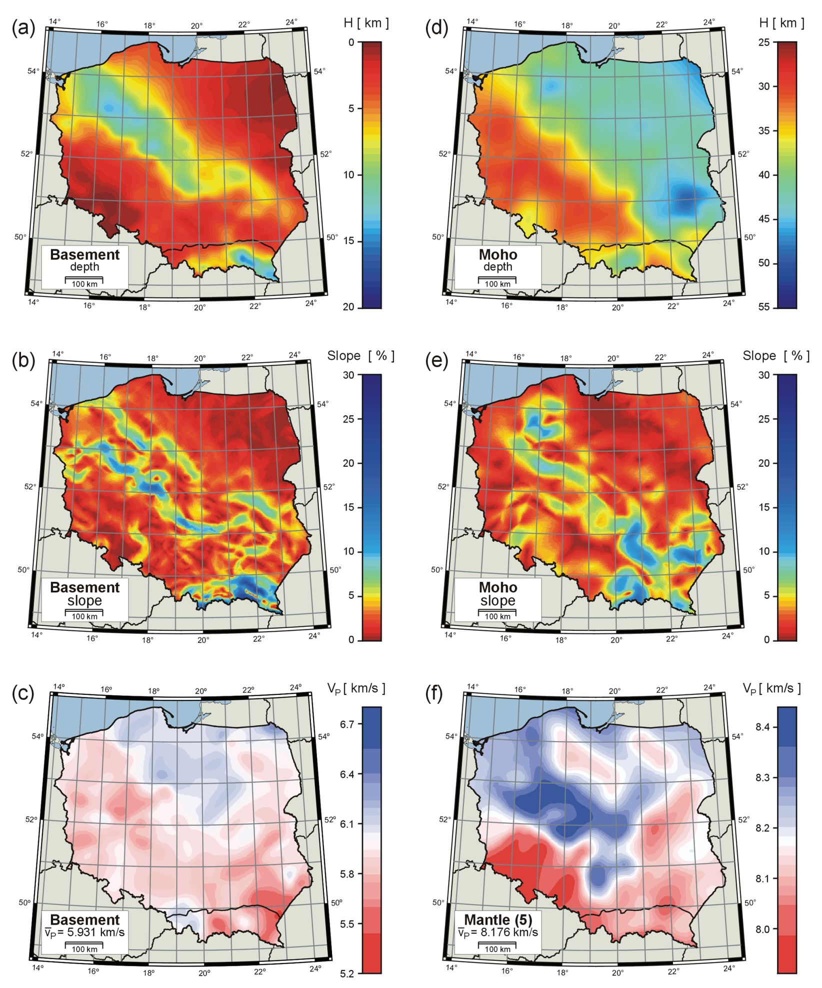

Fig. 9. Maps of depth, slope and P-wave velocity for basement (a, b, c) and Moho (d, e, f).

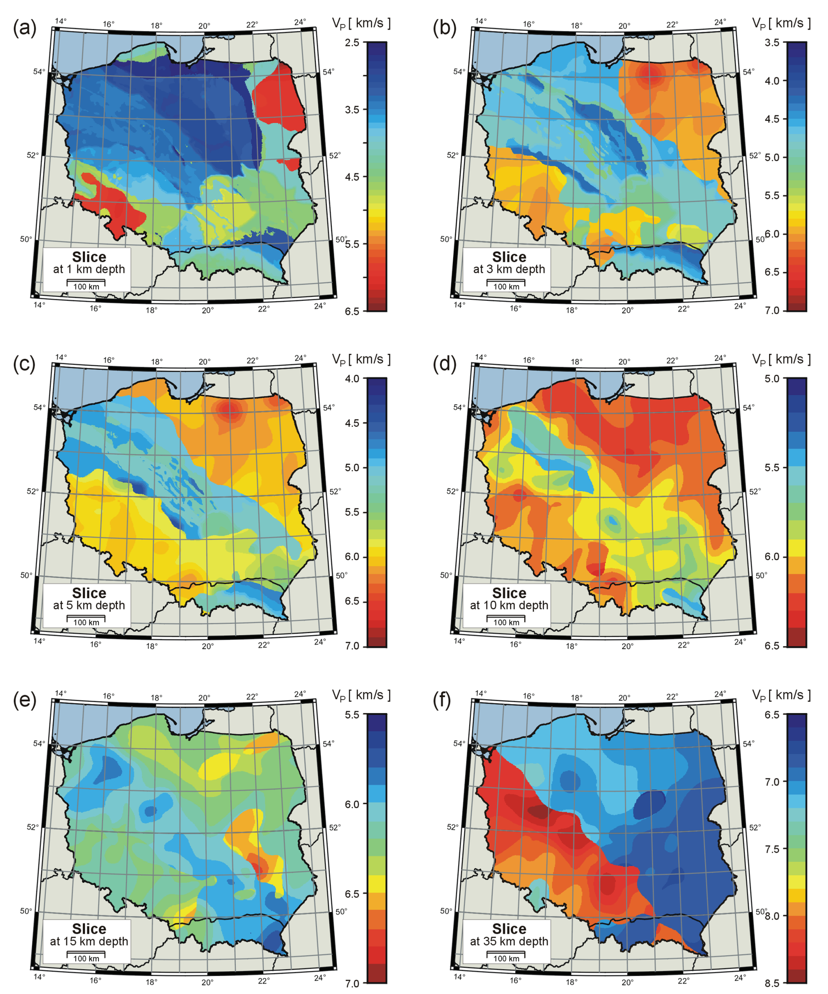

Fig. 11. Horizontal slices through 3D velocity model at depths 1, 3, 5, 10, 15 and 35 km.

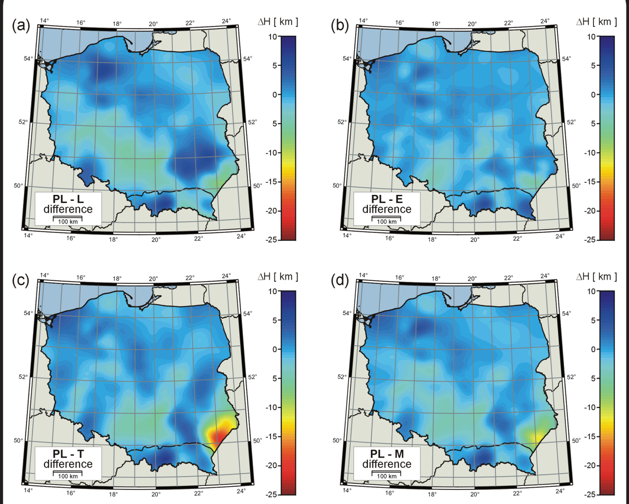

Fig. 15. Comparison of our Moho depth (PL) with previous models for the area of Poland. (a) Difference with global Moho depth by Laske et al. (2002). (b) Difference with ESC Moho depth by Grad et al. (2009). (c) Difference with Moho depth by Tesauro et al. (2008). (d) Difference with Moho depth by Molinari et al. (2011).

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