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High-resolution 3D seismic model of the crustal and uppermost mantle structure in Poland

Marek Grad [a,*], Marcin Polkowski [a], Stanisław R. Ostaficzuk [b]

[a] Institute of Geophysics, Faculty of Physics, University of Warsaw, Pasteura 7, 02-093 Warsaw, Poland
[b] Structural Analyses and Geological Mapping Division, Minerals and Energy Economy Research Institute, Polish Academy of Sciences, Ks. Janusza 64, 01-452 Warsaw, Poland

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ABSTRACT

In the area of Poland a contact between the Precambrian and Phanerozoic Europe and the Carpathians has a complicated structure and a complex P-wave velocity of the sedimentary cover, crystalline crust, Moho depth and the uppermost mantle. The geometry of the uppermost several kilometers of sediments is relatively well recognized from over 100,000 boreholes. The vertical seismic profiling (VSP) from 1188 boreholes provided detailed velocity data for regional tectonic units and for stratigraphic successions from Permian to the Tertiary and Quaternary deposits. These data, however, do not provide information about the velocity and basement depth in the central part of the Trans-European suture zone (TESZ) and in the Carpathians. So, the data set is supplemented by 2D velocity models from 32 deep seismic sounding refraction profiles which also provide information about the crust and uppermost mantle. Together with the results of other methods: vertical seismic profiling, magnetotelluric, allow for the creation of a detailed, high-resolution 3D model for the entire Earth's crust and the uppermost mantle down to a depth of 60 km. The thinnest sedimentary cover in the Mazury–Belarus anteclise is only 0.3 to 1 km thick, which increases to 7 to 8 km along the East European Craton (EEC) margin, and 9 to 12 km in the TESZ. The Variscan domain is characterized by a 1–4 km thick sedimentary cover, while the Carpathians are characterized by very thick sedimentary layers, up to about 20 km. The crystalline crust is differentiated and has a layered structure. The crust beneath the West European Platform (WEP; Variscan domain) is characterized by P-wave velocities of 5.8–6.6 km/s. The upper and middle crusts beneath the EEC are characterized by velocities of 6.1–6.6 km/s, and are underlain by a high velocity lower crust with a velocity of about 7 km/s. A general decrease in velocity is observed from the older to the younger tectonic domains. The TESZ is associated with a steep dip in the Moho depth, from 30–35 km in the Paleozoic Platform to 42–52 km in the Precambrian craton. The new model confirms the Moho depth derived from previous compilations. In the TESZ the lower crust has a very high seismic velocity (>7.0 km/s) which correlates to the high P-wave velocity (about 8.4 km/s) in the uppermost mantle beneath the Polish Basin. The Cratonic area is generally characterized by high P-wave velocities (>8.2 km/s), while the Phanerozoic area is characterized by velocities of ~8.0 km/s. In the TESZ very high velocities of 8.3–8.4 km/s are observed, and the southwestern limitation of this area coincides with a high velocity lower crust, and could be continued to the NW toward the Elbe line. The influence of the structure for teleseismic tomography time residuals of seismic waves traveling through the 3D seismic model was analyzed. Lithological candidates for the crust and uppermost mantle of the EEC and WEP were suggested by comparison to laboratory data. The presented 3D seismic model may make more reliable studies on global dynamics, and geotectonic correlations, particularly for sedimentary basins in the Polish Lowlands, the napped flysch sediment series in the Carpathians, the basement shape, the southwestern edge of the EEC, a high-velocity lower crust and the high-velocity uppermost mantle in the TESZ. Finally, the new 3D velocity model of the crust shows a heterogeneous structure and offers a starting point for the numerical modeling of deeper structures by allowing for a correction of the crustal effects in studies of the mantle heterogeneities.

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1. Introduction

The area of Poland covers a complicated contact between three continental scale tectonic units: the Precambrian East European Craton (EEC) to the northeast, the Variscan West European Platform (WEP) terranes to the southwest, and the younger Carpathian Alpine arc in the south (Fig. 1). The Trans-European suture zone (TESZ) between the EEC and WEP is a major crustal-scale feature, which appears to be a deep-seated discontinuity zone reaching at least down to a depth of about 200 km (e.g., Zielhuis and Nolet, 1994; Schweitzer, 1995; Wilde-Piórko et al., 2010). In Poland the southwestern edge of the EEC

* Corresponding author.
E-mail address: mgrad@mimuw.edu.pl (M. Grad).

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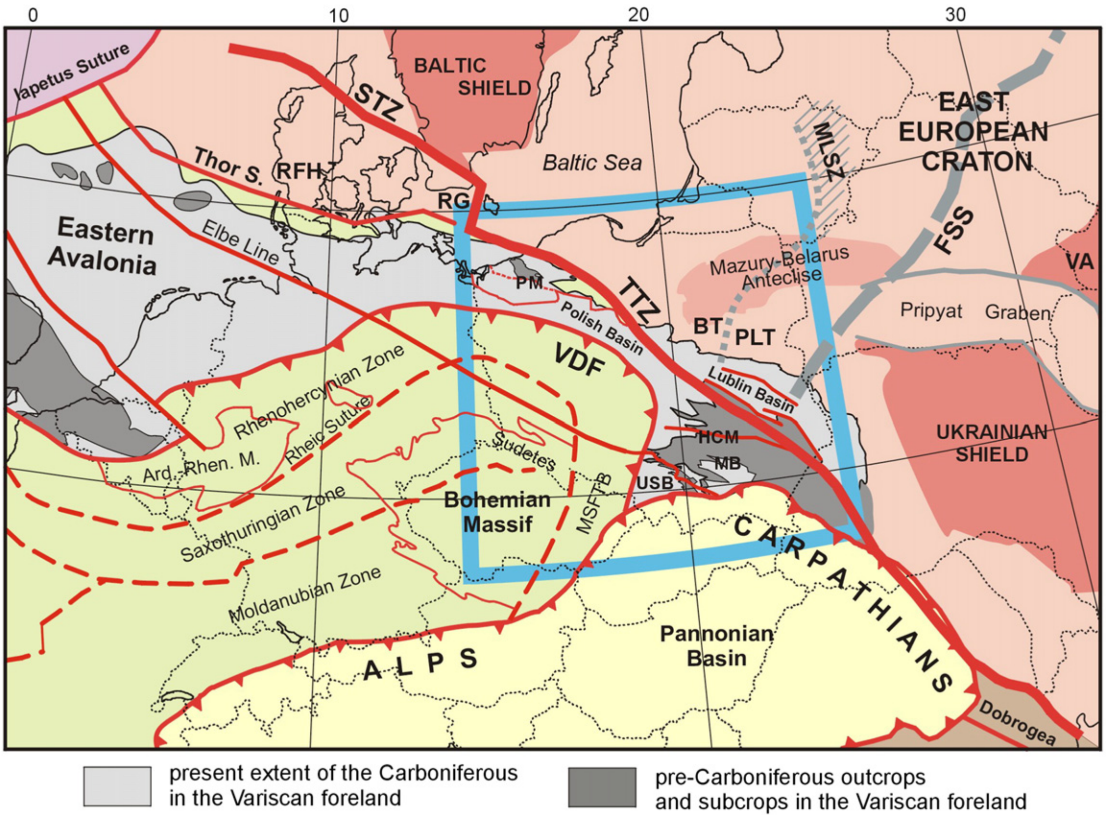

Fig. 1. Tectonic sketch of the pre-Permian Central Europe in the contact of the East European Platform, Variscides and Alpine orogeny. Blue frame shows the location of the study area in Poland. Compiled mainly from: Pożaryski and Dembowski (1983), Ziegler (1990), Winchester and PACE TMR Network Team (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; RO — Rønne Graben; STZ — Sorgenfrei–Tornquist Zone; Thor S. — Thor Suture; TTZ — Teisseyre–Tornquist Zone; USB — Upper Silesian Block; VA — Voronezh Anteclise; VDF — Variscan Deformation Front.

(paleocontinent Baltica) is fault-bounded by the Teisseyre–Tornquist Zone (TTZ) which is continued in Scandinavia along the Sorgenfrei–Tornquist Zone (STZ). Its structure and evolution still remain the important tectonic problems in Europe north of the Alps (e.g., Teisseyre, 1893, 1903; Tornquist, 1908; Znosko, 1970; Dadlez, 1982; Ziegler, 1990; Pożaryski et al., 1992; Berthelsen, 1998; Pharaoh, 1999; Winchester and PACE TMR Network Team, 2002; Teisseyre and Teisseyre, 2002). The Carpathian arc in the south, is an interrelated component of the Mediterranean arc basin, a complex, collisional environment between the North European and Adriatic plates, which involved a variety of micro-continents and oceanic areas (e.g., Golonka et al., 2003a,2003b).

The conjunction of all these continental scale tectonic units in the area of Poland is reflected in the complex tectonic structure in this area. Apart from the complex seismic structure, this area is also associated with significant gravity, magnetic and heat flow anomalies (for compilation see Grad and Polkowski, 2015). These anomalies indicate and mostly correlate with major changes of the tectonic structure.

The Bouguer anomaly values (Królikowski and Petecki, 1995; Wybraniec, 1999; Bielik et al., 2006) display values as low as −60 mGal in the TESZ. The adjacent Paleozoic terranes to the southwest and the EEC to the northeast are characterized by near-zero to positive gravity anomalies of up to +20 and +10 mGal, respectively. In Carpathians Bouguer anomalies reach values of about −80 mGal. The problem of isostatic compensation is widely discussed by Krysiński et al. (2009, 2015).

The magnetic anomalies within the TESZ and in the Carpathians (Wybraniec, 1999; Petecki et al., 2003) are subdued (±100 nT), which may result from the deeply buried magnetic basement. In contrast, the EEC magnetic anomalies vary at a short wavelength from −1500 to +1500 nT and correlate well with tectonic features and intrusions, particularly with the TTZ — the edge of the EEC.

Heat flow variations in the area of Poland (Karwasiecka and Bruszewska, 1997; Majorowicz et al., 2003) indicate a major change in the thermal regime. In general, the TESZ separates the "cold" EEC area with a low heat flow of about 40 mW/m^2 to the northeast from the "hot" area with a higher heat flow of 40–70 mW/m^2 in the Paleozoic terranes and Carpathians to the southwest. According to the map of Szewczyk and Gientka (2009), the heat flow density in Poland varies from less than 40 mW/m^2 in the NE to almost 100 mW/m^2 in the W and SW of Poland.

The aim of this paper is to build a 3D model of the structure for the sedimentary cover with a geometry of layers and their seismic velocities, basement and its geometry, and velocity, as well as interrelationships between the crystalline and consolidated basement, crustal structure with its velocity differentiation, Moho geometry, and the P-wave velocity of the uppermost mantle down to a depth of 60 km.

2. Previous seismic works and their compilations

Seismic velocities in a sedimentary cover are known mostly from an analysis of vertical seismic profiling (VSP) data. Previously, regional compilations for a few regions in Poland were carried out, including the fore-Sudetic monocline (Śliwiński, 1965), selected parts of the marginal synclinorium (Ptak, 1966; Żaruk, 1971; Kamińska and Zagórski, 1978; Świtek, 1983) and the East European and Paleozoic platforms (Grad, 1987, 1991; Grad et al., 1990). The analyzed VSP data were obtained from routine velocity logging during many decades (the oldest profiling was completed in 1952, and the newest in 2003) and velocities were analyzed in terms of succeeding geological periods, from the Tertiary and Quaternary to the Cambrian.

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