Acta Geodyn. Geomater., Vol. 6, No. 2 (154), 143–154, 2009

SHALLOW CRUSTAL STRUCTURE OF THE CENTRAL BOHEMIAN PLUTON, CZECH REPUBLIC, INFERRED FROM REFRACTION MEASUREMENTS

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(*Received* November 2008, *accepted* February 2009)

ABSTRACT
Since 1998, a seismic network has been monitoring the underground gas storage located near the town of Příbram in the Central Bohemian Pluton, Czech Republic. Hundreds of weak induced seismic events have been recorded there. Moreover, several weak earthquakes have also been recorded from the vicinity of the nearby Orlík water reservoir. To improve location of both types of seismic events, shallow crustal structure of the region is studied in the present paper. Refraction measurements to distances of about 20 km were carried out using quarry blasts as seismic sources. Smoothed *P*-wave travel times were interpreted using the Wiechert-Herglotz method, which yielded a 1-D velocity model of shallow crustal structure down to a depth of about 1.7 km. The *P*-wave velocity of the model increases from about 5.0 km/s at the surface to about 6.15 km/s at the 1.7 km depth.

KEYWORDS: Central Bohemian Pluton, shallow structure, refraction method, Wiechert-Herglotz method

1. INTRODUCTION

The town of Příbram, located about 60 km southwest of Prague, has been known for mining of silver and polymetals since the Middle Ages. In the 1950s and 1960s the mining was oriented to uranium ore and finally stopped in the 1980s. For an exceptional strength and compactness of the local rocks, an underground gas storage of cavern type was then constructed at the locality of Příbram-Háje. The storage is formed by a system of corridors at a depth of about 950 m (Brož et al., 2001). Its contour is shown on the map in Figure 1.

Since 1998, the gas storage has been monitored with a local seismic network. At present, the stations are equipped with broadband three-component Guralp CMG-40T sensors, yielding the records with a sampling frequency of 100 Hz. Several hundreds of weak induced seismic events have been recorded since 1998. To extend the capacity of the storage, it is now intended to increase the gas pressure. This calls for further monitoring and accurate location of the induced seismic events.

At a distance of about 10 km from the Příbram-Háje seismic network, there is the Orlík reservoir, constructed on the Vltava River in the 1960s. No earthquakes from the Orlík region were reported in historical catalogues. However, since 1992, more than 20 microearthquakes in this region have been recorded with the Temelín local seismic network in southern Bohemia (Nehybka et al., 2006). The strongest earthquake occurred there on January 13, 2007 (Hanžlová et al., 2007). Despite its relatively low magnitude of about 2.4, the earthquake was macroseismically felt at the village of Klučenice with a striking maximum intensity of 5° of the European Macroseismic Scale 1998 (EMS-98). The earthquake was recorded up to a distance of about 290 km at the most Czech seismological stations and at numerous stations abroad (Austria, Germany, Poland and Slovakia). Using the onsets of longitudinal and shear waves at these stations, and the IASPEI travel-time curves, Hanžlová et al. (2007) obtained the epicentral coordinates of 49.55°N and 14.19°E. According to this localisation, the depth of hypocentre is 2 km. This small depth corresponds well to the relatively strong macroseismic intensity of the earthquake. The error of epicentre determination is estimated up to the first kilometres. The most questionable parameter is the depth, as its reliable determination requires a station in a close vicinity of the epicentre. Note that another preliminary localisation yielded a focal depth of about 8 km. We shall return to this problem briefly in Section 5.

To increase the accuracy of locating seismic events in the regions of the gas storage and Orlík reservoir, a suitable local model of the uppermost crustal structure is needed. Its derivation, based on refraction measurements, is the subject of the present paper.

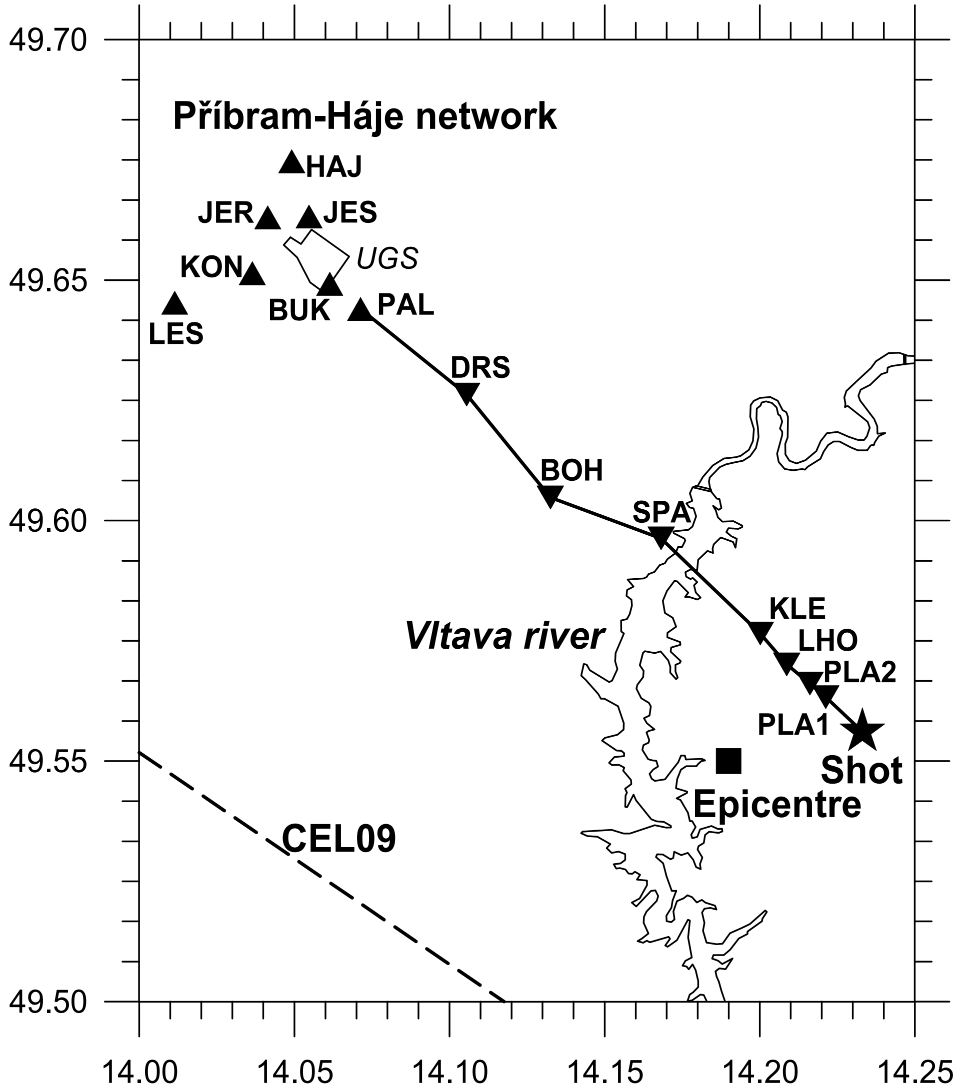

Fig. 1 Sketch map of the region under study: solid line - profile Lašovice-Palivo; *UGS* – contour of the underground gas storage; dashed line – part of profile CEL09; ▲ - permanent stations of the Příbram-Háje network; ▼ - temporary stations; ★ - shot points at the Lašovice quarry; ■ - epicentre of the earthquake of January 13, 2007. The geographical coordinates are given in degrees.

2. PREVIOUS STRUCTURAL MODELS

Geologically, the region under study (Fig. 1) belongs to the Central Bohemian Pluton, which forms one of the prominent geological units of the Bohemian Massif. The first systematic studies of the crustal structure of the pluton were carried out as part of deep seismic soundings (DSS) along International Profiles VI and VII within 1964-1972 using borehole shots (Beránek, 1971; Beránek et al., 1973, 1975). Various details of this research have also been described in several review articles (Beránek and Zátopek, 1981; Mayerová et al., 1994; Novotný, 1997). Profile VI traversed the pluton approximately from NW to SE, and Profile VII from SW to NE. The profiles crossed in the northeastern part of the Central Bohemian Pluton close to the town of Benešov. The profiles are not shown in Figure 1 as Profile VI lay north, and Profile VII east of the displayed area. The crustal structure of the pluton was originally presented in a graphical form as a 1-D model of *P*-wave velocities. Its piecewise linear approximation is given in Table 1 and shown in Figure 2 (Novotný and Urban, 1988). We shall refer to this model here as model BP1. Note that the superficial *P*-wave velocity is 5.6 km/s in this model.

A new period of DSS in the Bohemian Massif was opened in the year 2000 in the framework of the CELEBRATION 2000 experiment (Central European Lithospheric Experiment Based on Refraction); see Guterch et al. (2003 a,b). One profile, designated CEL09, again traversed the Central Bohemian Pluton. This profile was approximately parallel to Profile VI, but shifted towards the southwest (Fig. 1). The measurements were performed with an offset of about

Table 1 Crustal models of the Central Bohemian Pluton: BP1 – model along DSS Profiles VI and VII (Beránek et al., 1975); BP2 – model along Profile CEL09 (Hrubcová et al., 2005); BP3 – another model along Profile CEL09, composed of homogeneous layers (Růžek et al., 2007). Symbol *H* is the depth in kilometres, and v_P is the *P*-wave velocity in km/s. Velocity v_P varies linearly between the given depths for models BP1 and BP2, but it is constant in the given depth intervals for model BP3.

BP1		BP2		BP3	
H	v_P	***H***	v_P	***H***	v_P
0	5.6	0.0	5.33	0.0- 3.1	6.100
1	5.8	0.2	5.35	3.1- 6.2	6.168
3	6.0	0.2	5.67	6.2- 9.3	6.265
8	6.2	1.5	5.90	9.3-12.4	6.314
16	6.2	2.2	6.00	12.4-15.5	6.365
17	6.4	2.7	6.05	15.5-18.6	6.362
20	6.6	3.5	6.07	18.6-21.7	6.312
30	6.6	7.8	5.97	21.7-24.8	6.318
32	6.8	11.7	6.04	24.8-27.9	6.410
33	7.0	11.7	6.12	27.9-31.0	6.591
34	7.2	18.6	6.25	31.0-34.1	6.884
35	7.4	19.1	6.28	34.1-37.2	7.201
36.5	7.6	19.1	6.53		8.303
38	7.8	21.2	6.55		
38	8.2	33.2	6.85		
		37.5	6.91		
		37.5	8.05		
		40.0	8.10		

Table 2 Models of the shallow crustal structure for the gas storage region (Málek and Brokešová, 2003): GS1 – homogeneous model; GS2 – model with a linear velocity distribution. Symbol *H* denotes the depth in kilometres, v_P is the *P*-wave velocity at this depth in km/s, and v_S is the *S*-wave velocity.

GS1				GS2			
H	v_P	v_S	v_P / v_S	***H***	v_P	v_S	v_P / v_S
0	5.32	3.20	1.66	0	4.99	2.74	1.82
1	5.32	3.20	1.66	2	6.42	4.53	1.42

3 km, the distances between shot points being about 30 km. Hrubcová et al. (2005) derived a 2-D velocity model of the crust and uppermost mantle along the CEL09 profile. For our purposes we have selected the point in this profile with coordinates 49.539 N, 14.029 E, which is close to the Příbram-Háje seismic network (its distance from the nearest seismic station Lešetice is about 11.9 km). The vertical velocity cross-section at this point is denoted as model BP2 (Table 1 and Fig. 2). Recently, the same refraction data along the CEL09 profile were reinterpreted using a new inverse method (Růžek et al., 2007). In this case, the final structural model consists of homogeneous rectangles. A cross-section in this model, which is again close to the Příbram-Háje network, is denoted as model BP3. Note that the latter model is less detailed at shallow depths than models BP1 and BP2. It is also worth mentioning that the velocity of 6.1 km/s in the first layer of model BP3 seems to be very high.

Two simple models of shallow structure are routinely used in locating induced events in the Příbram-Háje region, i.e. in the gas storage region (Málek and Brokešová, 2003). Their parameters are given in Table 2, and we shall refer to them as models GS1 and GS2, respectively. Model GS1 is a homogeneous half-space, and model GS2 is characterised by a linear velocity increase with depth.

Recently, Gaždová et al. (2008) studied the dispersion of short-period Rayleigh waves generated by quarry blasts in a broader vicinity of the Příbram-Háje network. They derived models of *S*-wave velocities down to a depth of 1.8 km for the gas storage area (model GS), and for its broader vicinity in the Central Bohemian Pluton (model BP). Both models are composed of 8 homogeneous layers. We shall not reproduce all the model parameters here, but we give only their values at selected depths (Table 3).

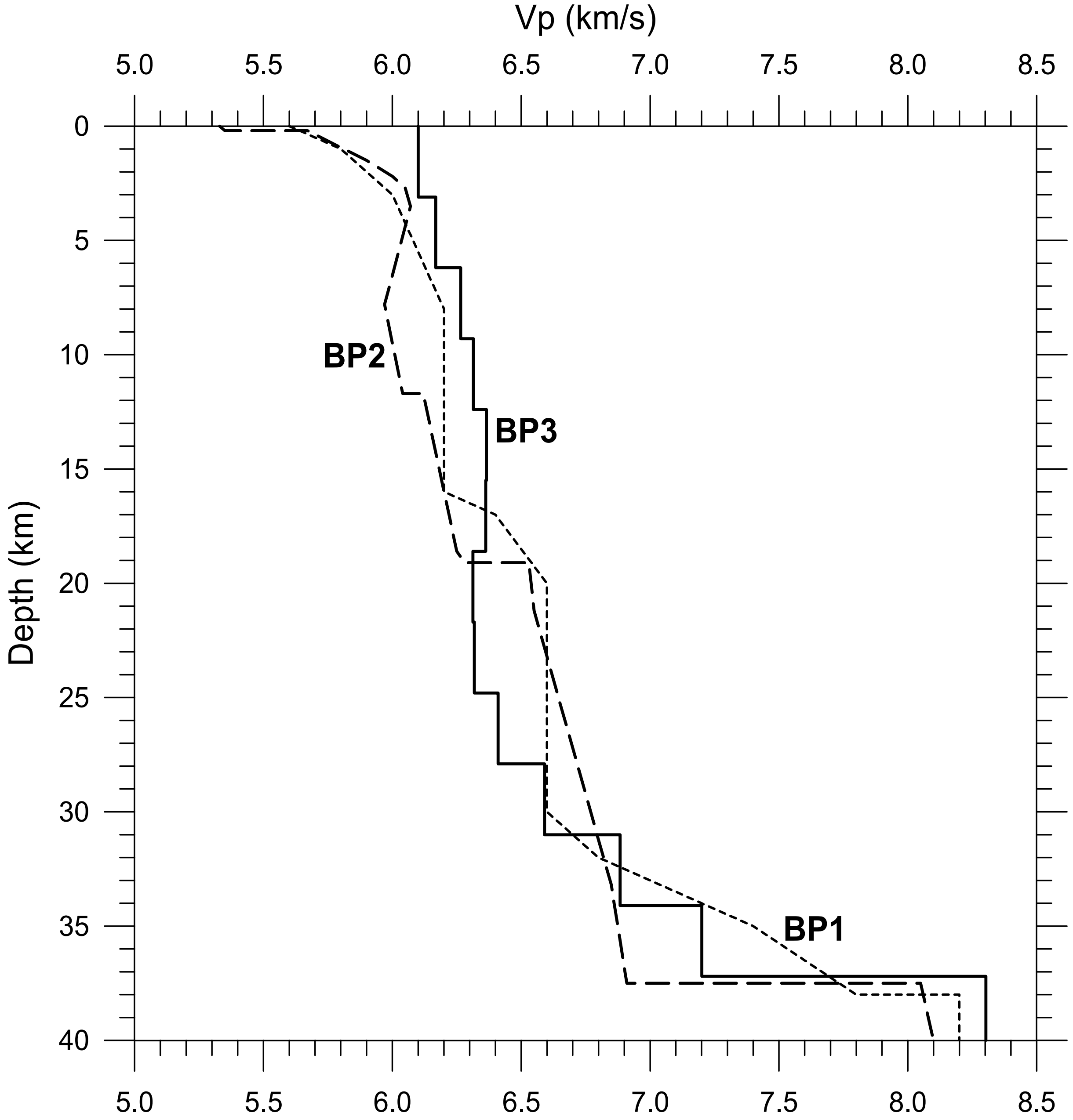

Fig. 2 Velocity cross-sections for crustal models of the Central Bohemian Pluton given in Table 1: dotted line - model BP1 along DSS Profiles VI and VII; dashed line - model BP2 along Profile CEL09; solid line – a new model BP3 along Profile CEL09.

Table 3 Approximate *S*-wave velocities at selected depths of the models derived by Gaždová et al. (2008): GS – local model of the Příbram-Háje gas storage area; BP – model of the Central Bohemian Pluton. For symbols, see Table 2.

GS		BP	
H	v_S	***H***	v_S
0.0	2.3	0.0	2.8
0.5	3.4	0.5	3.2
1.0	3.1	1.0	3.3
1.8	3.7	1.8	3.2

Table 4 Shot and observation points: code, northern latitude and eastern longitude in degrees, altitude, locality.

Code	Latitude	Longitude	h(m)	Locality
		Shot points		
1	49.5553	14.2330	540	Lašovice
2	49.5552	14.2331	550	Lašovice
3	49.5556	14.2342	550	Lašovice
		Profile Lašovice-Drsník		
PLA1	49.5633	14.2213	465	Planá
PLA2	49.5661	14.2162	445	Planá
LHO	49.5701	14.2087	430	Koubalova Lhota
KLE	49.5765	14.2002	445	Klenovice
SPA	49.5963	14.1682	375	Spálenka
BOH	49.6048	14.1325	450	Bohostice
DRS	49.6262	14.1055	480	Drsník
		Network Příbram-Háje		
PAL	49.6440	14.0713	552	Palivo
BUK	49.6492	14.0614	572	Buk
JES	49.6632	14.0547	563	Jesenice
KON	49.6514	14.0364	562	Konětopy
JER	49.6630	14.0414	548	Jeruzalém
HAJ	49.6747	14.0491	560	Háje
LES	49.6453	14.0114	560	Lešetice

Table 5 Travel times of refracted waves for the individual shots, and the respective mean values: r is the epicentral distance in km; t is the P-wave travel time in seconds; Δt is the maximum deviation from the mean travel time.

Station	Shot 1		Shot 2		Shot 3		Mean		
	r	T	r	T	r	T	r	T	Δt
PLA1					1.27	0.255	1.27	0.255	-
PLA2					1.75	0.328	1.75	0.328	-
LHO					2.45	0.449	2.45	0.449	-
KLE	3.35	0.618	3.36	0.629			3.35	0.624	0.006
SPA	6.54	1.204	6.55	1.219			6.54	1.212	0.008
BOH	9.12	1.661	9.13	1.672			9.12	1.667	0.006
DRS	12.13	2.132	12.14	2.149	12.18	2.156	12.15	2.146	0.014
PAL	15.30	2.643	15.31	2.666	15.34	2.676	15.32	2.662	0.019
BUK	16.22	2.803	16.23	2.786	16.26	2.826	16.24	2.805	0.021
JES	17.61	3.003	17.62	3.046	17.65	3.046	17.63	3.032	0.029
KON	17.78	3.053	17.79	3.066	17.83	3.056	17.80	3.058	0.008
JER	18.31	3.133	18.32	3.136	18.35	3.156	18.33	3.142	0.014
HAJ	18.79	3.213	18.80	3.206	18.83	3.246	18.81	3.222	0.024
LES	18.89	3.243	18.90	3.266	18.95	3.266	18.91	3.258	0.015

3. REFRACTION MEASUREMENTS

In orde r to study the shallow crustal structure of the Příbram and Orlík regions in greater detail, refraction measurements were performed along a profile from the Lašovice quarry towards the Příbram-Háje network (Fig. 1). The measurements along the Lašovice-Drsník profile were performed with portable high-frequency seismographs using a sampling frequency of 256 Hz (Brož, 2000).

Three blasts at one quarry at Lašovice were used in the present study. The coordinates of the shot points and observation points are given in Table 4. The latitudes and longitudes refer to the WGS-84 ellipsoid (its equatorial semi-axis $a = 6\,378\,137$ m and flattening $f = 0.003\,352\,810\,6$). Epicentral distances on the ellipsoid were computed by means of expansions with respect to the flattening (Thomas, 1965; Novotný and Málek, 2003). Figure 3 shows the observed seismograms from the first shot.

Table 5 contains the epicentral distances and observed travel times of P waves. No topographic corrections of the travel times were introduced. Since

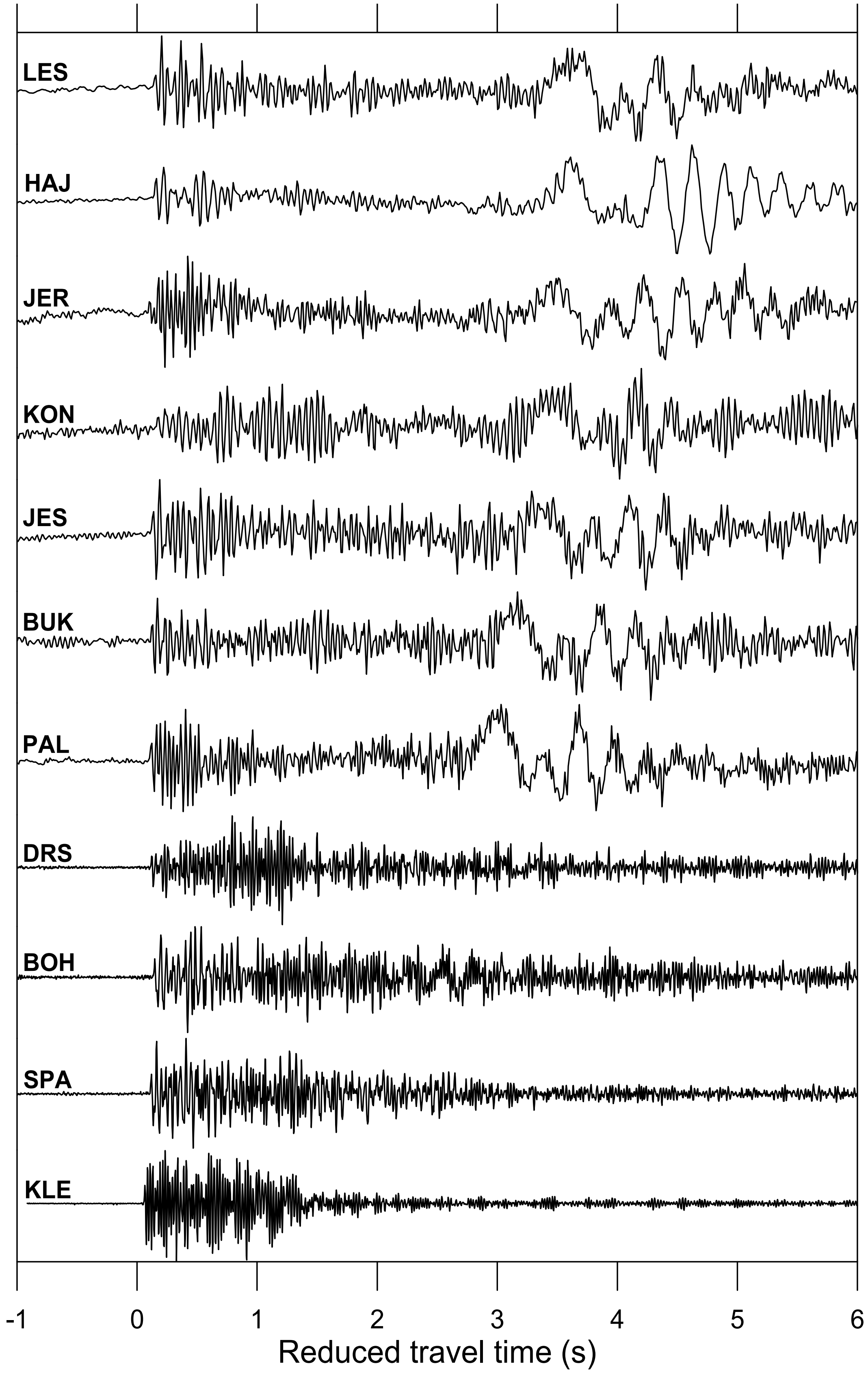

Fig. 3 Seismograms of vertical components from the first shot at Lašovice. The travel times were reduced using a reduction velocity of 6.0 km/s. All the seismograms were normalized to their maximum values.

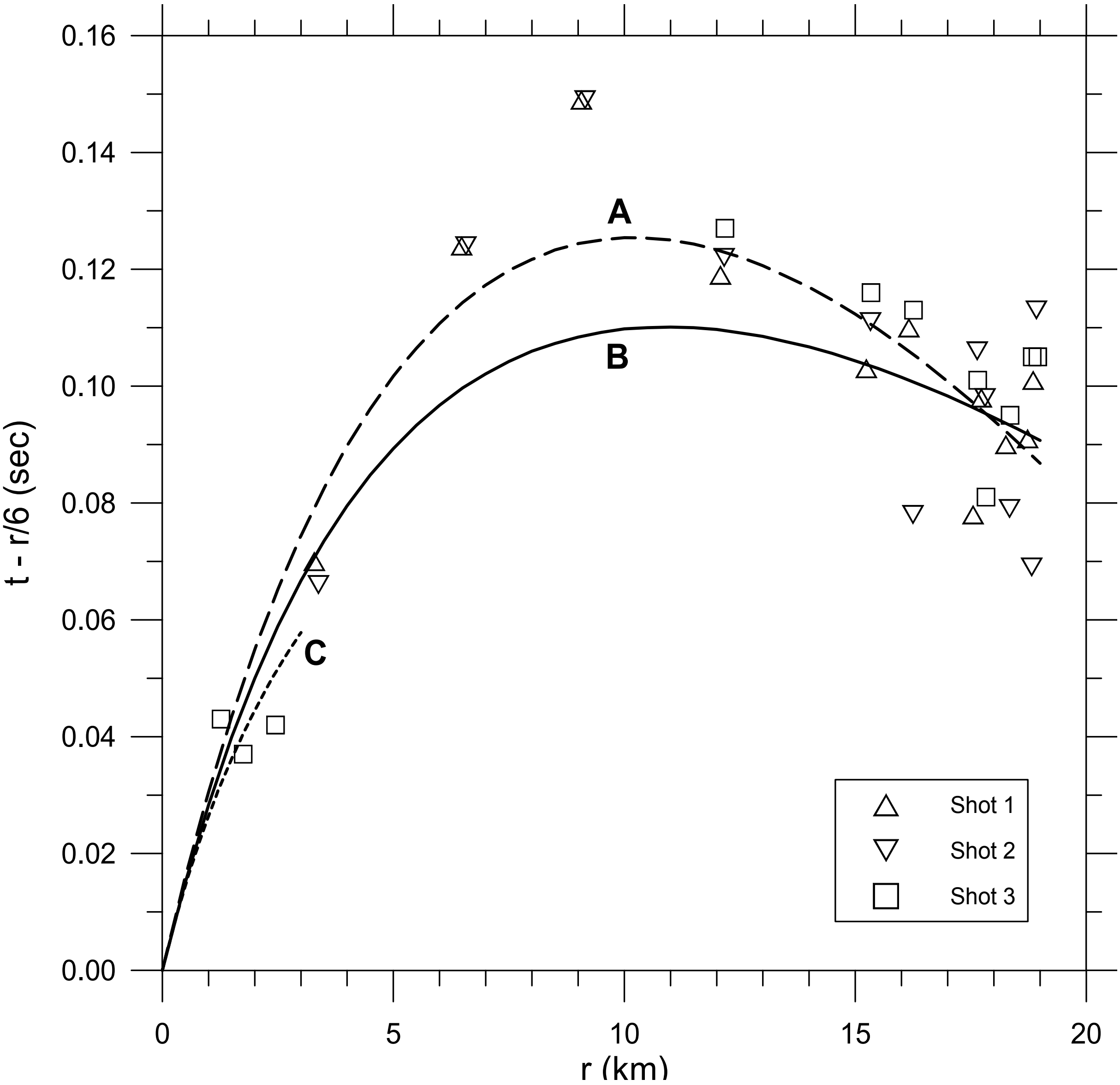

Fig. 4 Reduced travel times from the Lašovice shots (isolated points, $v_{red} = 6.0$ km/s). The lines represent the synthetic curves: A - for all data (dashed); B – for selected data (stations SPA and BOH excluded, solid line); C - for the beginning of the travel-time curve (dotted).

delay-fired quarry blasts were used as seismic sources, the determination of some onsets was complicated and rather inaccurate. The last column in Table 5 indicates that some travel times can contain considerable errors of nearly 30 ms, which is close to the usual time delay of 25 ms between the individual shots. The isolated points in Figure 4 show the observed travel times, reduced with a velocity of 6.0 km/s.

4. INTERPRETATION OF THE TRAVEL-TIME CURVES USING THE WIECHERT-HERGLOTZ METHOD

The Wiechert-Herglotz method is a classical method of studying the deep Earth's structure, but its application to studies of the whole Earth's crust encounters some problems. In particular, the Wichert-Herglotz method requires a smoothed travel-time curve with monotonous derivatives, which the DSS data usually do not satisfy. However, this method can successfully be used in some studies of upper crustal structures (Grad, 1985; Málek et al., 2004).

To smooth the experimental travel times, polynomial approximations are usually used (Grad, 1985). However, more general approximating functions are required in some cases (e.g., the curvature of polynomials may cause problems at large epicentral distances). Therefore, we have tested several variants of a rational approximation, i.e. a quotient of two polynomials. The results obtained with the rational approximation in the simple form

Table 6 Parameters of some rational approximations to the travel-time curve: approximation A – all data considered; B – selected data (stations SPA and BOH excluded); C – beginning of the travel-time curve. The R.M.S. is the root-mean-square deviation in seconds. For details, see the text.

Appr.	a_1	a_2	b_0	**R.M.S.**
A	2.68	0.158	13.4	0.012
B	1.79	0.158	9.00	0.009
C	8.17	0.168	4.10	0.008

Table 7 Numerical representation of the proposed velocity model (model B): H is the depth in km; v_P is the P-wave velocity in km/s.

H	v_P	***H***	v_P
0.0	5.02	0.7	5.85
0.1	5.31	1.0	5.97
0.2	5.46	1.3	6.07
0.3	5.57	1.7	6.15
0.5	5.73		

$$t(r) = \frac{a_1 r + a_2 r^2}{b_0 + r}, \tag{1}$$

t being the travel time and r the epicentral distance, are presented here. The coefficients of the polynomials were computed by the method of conjugate gradients (Málek et al., 2004). To obtain the smooth derivatives, required in the Wiechert-Herglotz formula, it is easy to differentiate function (1) analytically.

The depth of the turning point of the refracted ray was determined from the Wiechert-Herglotz formula for a vertically inhomogeneous medium in the form

$$H = \frac{1}{\pi}\int_0^r \operatorname{ar}\cosh\frac{p(\xi)}{p(r)}\,d\xi \ , \tag{2}$$

where $p(\xi) = dt/d\xi$ is the derivative of the smoothed travel-time curve with respect to the epicentral distance. The velocity at the turning point was determined as the reciprocal derivative of the travel-time curve at the point of observation, $v(H) = 1/p(r)$.

We applied this procedure to the data from the Lašovice shots in several steps, described below. To eliminate the different number of measurements at the individual observation points, only the mean epicentral distances and mean travel times from Table 5 were used in the interpretation.

4.1. INTERPRETATION OF ALL DATA

Consider the mean data for all seismic stations given in Table 5. Note that these mean values are not shown in Figure 4. We have performed many rational approximations to the data using various initial values of the parameters a_1, a_2, b_0. Of the results we prefer the parameters given in the first row of Table 6 (approximation A), yielding a low root-mean-square deviation of 12 milliseconds only. The units of the parameters a_1, a_2 and b_0 in Table 6 correspond to epicentral distances given in kilometres and travel times in seconds. The smoothed travel-time curve and the corresponding velocity cross-section are shown as lines A in Figs. 4 and 5, respectively. The P-wave velocity of model A increases from the surface value of about 5.0 km/s to about 6.27 km/s at the 2-km depth.

Although approximation A yields the low root-mean-square deviation, Figure 4 displays considerable difference between the observed and smoothed values at some points of observation. In particular, very late arrivals were observed at the points just behind the Orlík water reservoir, i.e. at points SPA and BOH at epicentral distances of about 6.5 and 9.1 km, respectively. Note that Málek et al. (2004) studied analogous plutonic structures also in western parts of the Bohemian Massif, but such time anomalies were not observed there. Despite many attempts, we were not able to derive a simple 1-D velocity model that would explain the time anomaly in the Orlík region. Finally, we arrived at the conclusion that the anomaly must be associated with a considerable lateral inhomogeneity. Thus, it seems that the Central Bohemian Pluton is not compact along the profile under consideration, but a low-velocity body or zone exists somewhere beneath the Orlík reservoir. For example, we could speculate about a prominent fault zone beneath the reservoir. The occurrence of weak earthquakes in the region seems to support such an interpretation. Nevertheless, it is evident that further detailed studies will be needed to recognize the nature of the travel-time anomaly.

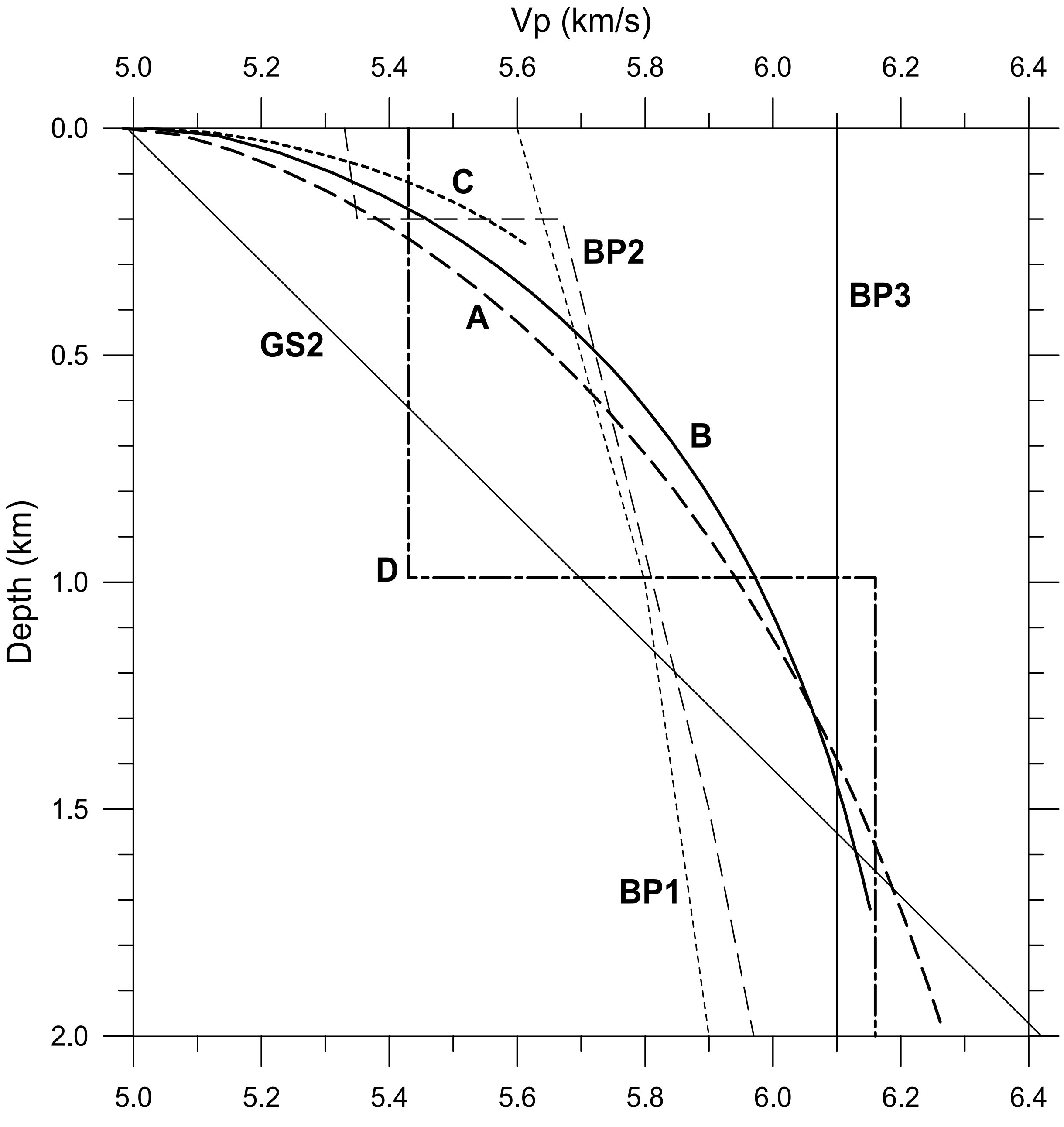

Fig. 5 Velocity models of the shallow structure: curves A, B, C and D are the models derived in the present paper; the other linear and piecewise linear functions represent some previous models. For notations, see Figure 4 and the text.

4.2. SELECTED DATA FOR A 1-D VELOCITY MODEL

To obtain a more representative 1-D velocity model, the effects of lateral inhomogeneities should be suppressed in the observed data. For this purpose we excluded the anomalous measurements at points SPA and BOH, and performed the interpretation of the remaining data. The corresponding rational approximation is given by the parameters in the row B of Table 6. The smoothed travel-time curve and the velocity cross-sections are shown as lines B in Figures 4 and 5, respectively. The numerical representation of this new model at several selected depths is given in Table 7.

We consider the new model B to be the representative 1-D velocity model of the region under study. The characteristic features of the model are relatively low *P*-wave velocities at the surface and prominent velocity increases within the superficial zone down to a depth of about one kilometre. In particular, the velocity in the model increases from the surface value of about 5.0 km/s to 6.15 km/s at a depth of 1.7 km. However, it is not evident how to join the new model with the previous DSS models at larger depths; compare Tables 1 and 7.

We should compare the new model B with the simpler model GS2 for the gas storage area (Table 2 and Fig. 5). The surface velocities are practically the same in both models. With increasing depth the velocities are higher in our model B, but both models again approach at a depth of about 1.6 km. The velocity of 6.42 km/s at the 2-km depth of model GS2 seems to be too high. Note that the velocity close to 6.4 km/s is attained in the DSS models in Table 1 at much larger depths.

The depth range of our model B is sufficient to be used in locating the shallow induced events in the area of the underground gas storage, e.g., instead of the simpler models GS1 and GS2 (Table 2). On the other hand, the depth range of model B seems to be insufficient for locating deeper natural earthquakes in the Orlík region. This problem will require further study.

Let us attempt to estimate approximately the velocity ratio v_P / v_S by comparing our model B for *P* waves with model BP of Gaždová et al. (2008) for *S* waves (Table 3). As the character of both cross-sections is rather different, we shall restrict ourselves to the values at the top and bottom of the models only. The approximate superficial velocities $v_P = 5.0$ km/s and $v_S = 2.8$ km/s yield the velocity ratio $v_P / v_S = 1.8$. At the 1.7 km depth we have approximately $v_P = 6.15$ km/s and $v_S = 3.2$ km/s, which yields $v_P / v_S = 1.9$. The latter value seems to be rather high, which may be caused by an inaccurate value of v_S at this depth. We hope that more accurate values of the v_P / v_S ratio will be obtained from seismograms of several local earthquakes in the Orlík region.

4.3. SHORT EPICENTRAL DISTANCES

To verify the value of the surface velocity, we also interpreted the beginning of the travel-time curve. For this purpose we considered only the first four observation points between the Lašovice quarry and Orlík reservoir, i.e. points PLA1 to KLE. The results for these data are given in the last row of Table 6, and are shown in Figures 4 and 5 (dotted lines C). The surface velocity of 5.02 km/s in model B was confirmed, but slightly higher velocities were obtained at depths of 0.1 and 0.2 km. Nevertheless, we prefer model B as the new 1-D model of the shallow structure in the region under consideration.

Compare the surface velocity of about 5.0 km/s, obtained in the present paper, with the results for other plutons in the Bohemian Massif. Martínková et al. (2000) performed laboratory measurements that yielded *P*-wave surface velocities between 3 and 4 km/s for granites from the Smrčiny Pluton, but velocities slightly above 5 km/s for the Karlovy Vary Pluton. Refraction measurements confirmed low superficial velocities of about 3.6 km/s for the Smrčiny Pluton (Málek et al., 2004). Thus, from the point of view of the superficial velocities, the Central Bohemian Pluton seems to be more similar to the Karlovy Vary Pluton than to the Smrčiny Pluton.

5. INTERPRETATION IN TERMS OF HEAD WAVES

In addition to the Wiechert-Herglotz method, another classical method consists in constructing a structural model composed of homogeneous layers from a piecewise linear approximation to the measured travel-time curve. The first linear segment is then interpreted as the travel-time curve of the direct wave in the first layer, the other segments as the travel-time curves of head waves.

The observed travel times in Fig. 4, resembling two straight lines, call for such interpretation. It is seen that the straight lines could cross somewhere close to an epicentral distance of 10 km. Therefore, consider the mean travel times in Table 5 and approximate them by the linear function

$$t(r) = ar \tag{3}$$

for epicentral distances r<10 km (up to the station BOH), and by

$$t(r) = br + c \tag{4}$$

for r>10 km. The parameters of the best fitting straight lines are as follows (if the epicentral distances are given in kilometres and travel times in seconds): $a = 0.1841$, $b = 0.1623$, $c = 0.1723$. These values yield a very simple structural model composed of a homogeneous layer over a homogeneous half-space with the parameters

$$v_1 = 1/a = 5.43 \text{ km/s}, \qquad v_2 = 1/b = 6.16 \text{ km/s}, \qquad d = 0.99 \text{ km}, \tag{5}$$

v_1 and v_2 being the *P*-wave velocities of the layer and half-space, respectively, and *d* the layer thickness. This model is shown as model D in Figure 5. Despite its simplicity, the model corresponds to the most models discussed above.

It is well known that the simple interpretation of travel times in terms of head waves is somewhat problematic from the dynamical point of view, as the head waves are usually much weaker than the observed ones. Consequently, we should rather prefer the interpretation in terms of refracted waves. Moreover, the model D is only formal, for example, it does not respect the increase of velocities with increasing pressure, known from laboratory experiments. We do not expect that an interface exists at a depth of about 1 km, since the pluton extends to larger depths, which is known from the Příbram deep mines.

Accurate location of the above-mentioned earthquake of January 13, 2007, will be the subject of another study. Nevertheless, without going into details, let us attempt to localise this earthquake using the simple structural model with its parameters given by Eqs. (5). Consider only the *P*- and *S*-wave arrival times recorded at the Příbram-Háje network (we do not present their numerical values here). Then, the new localisation method for layered media, elaborated by Novotný et al. (2008), approximately confirmed the hypocentre parameters mentioned in Section 1. The new epicentre is only slightly shifted to the north by about 0.7 km, and the focal depth may be close to 1.5 km.

6. CONCLUSIONS

The present paper summarises the *P*-wave travel times of refracted waves propagating in the Central Bohemian Pluton from the Lašovice quarry towards the Příbram-Háje seismic network. Both permanent and temporary seismic stations were used in the measurements. The most remarkable feature of the observed travel times is an anomaly (considerable time delays) in the central part of the profile, i.e. approximately in the area of the Orlík water reservoir. The recognition of this anomaly seems to be the main result of the present paper. In our opinion, the anomaly can indicate a fault zone of low seismic velocities beneath the Orlík reservoir. These preliminary structural conclusions should be verified by further studies.

We present a new model of the shallow structure down to a depth of 1.7 km (model B in Table 7 and Fig. 5). The superficial velocity in the model is close to 5.0 km/s, which is lower than the values in the previous DSS models. The model could be used in locating the shallow induced events in the area of the Příbram-Háje gas storage. However, it will be necessary to prolong the model to larger depths to be able to locate natural earthquakes from the vicinity of the Orlík reservoir.

Another simple model, composed of a layer on a half-space, has also been derived. Its parameters are given by Eq. (5), i.e. the approximate velocity and thickness of the layer are 5.4 km/s and 1.0 km, respectively, and the velocity of the half-space is about 6.15 km/s.

ACKNOWLEDGEMENTS

We are obliged to our colleagues from the Institute of Rock Structure and Mechanics for their help with field measurements. This research was partially supported by grants No. A300460602 and A300460705 of the Grant Agency of the Academy of Sciences of the Czech Republic, by the Institute of Rock Structure and Mechanics within the research project AVOZ30460519, and research project MSM0021620860. Data from the Příbram-Háje network were kindly provided by the RWE Transgas, s.r.o. We also thank two anonymous reviewers for their valuable comments and recommendations.

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