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Tectonogenesis of the Orava Depression in the light of latest biostratigraphic investigations and organic matter alteration study

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Abstract: The Orava Depression and its continuation in southern Poland, the Nowy Targ Depression, originated after the Early Sarmatian. Before this period, in the present area of the Nowy Targ Depression an Oligocene-Middle Miocene marine basin had been situated in piggy-back position.

The Orava-Nowy Targ Depression was previously considered to be a retroarc basin, however, the burial history of the depression and its position in the Periklippen mobile zone point to pull-apart origin.

The coal seam cropping out at low water level in the Orava Dam near the village Ústie nad Priehradou belongs to humites of the brown coal stage of alteration. Predominant coal lithotypes are xylito-detritic and detrito-xylitic ones, with low ash content. The vitrinite reflectance R_o of 0.35-0.43% and the results of technological analyses allow to classify the coal with the metaphase of the brown coal.

Coal altered in this way must have been buried in a depth of approx. 1150 m. Later on, the depression rose and erosion removed a considerable part of the basin filling. The depression is rising at present at the rate of +0.5 mm/y, or between 0.0 and +0.5 mm/y.

Key words: Orava-Nowy Targ Depression, coal vitrinite reflectance, burial history, erosional removal, pull-apart basin

Introduction

The filling of the Orava Depression contains coal seams accompanied by coal clays. In the past, seams cropped out at the villages Hladovka, Čimhová, Liesek, Trstená, Ústie nad Oravou, Dolný Štefanov, Námestovo, Vavrečka, Bohov, Jelešna-Voda and Červený Potok. The coal was used by local people as fuel. The seams are numerous, but they have low thickness and they are small in area (ČECHOVIČ 1940). According to SENEŠ and TOMSKÝ (1953), in the southern part of the depression the frequency of seams is relatively great: in a borehole 184 m deep there were 12 seams, but only one of them had a thickness of 1.3 m. Later on, near the village Vavrečka, pits were made in which 1 and 1.3 m thick seams were found. The borehole prospection aimed at the determination of balance coal reserves carried out in 1958 ended without success (GAŠPARIK et al., in SLÁVIK et al., 1967). In 1988, near the village Ústie nad Priehradou, a coal seam about 0.8-1 m thick could be studied and sampled.

Basic features of the geological setting of the Orava Depression

The Orava Depression is lying predominantly on the Magura flysch unit of the Outer Western Carpathians. Its southern part is lying on the Klippen Belt and the Central Carpathian Paleogene. The Magura Nappe consists of silico-clastic flysch formations. The uppermost members of the Magura Nappe are usually formed of the Magura Formation (Upper Eocene) and the Malcov Formation (uppermost Eocene-Oligocene). On the southern margin of the Nowy Targ Depression, on the Polish territory, younger formations have been described above the Malcov Formation: the Waksmund Formation of flysch character (Oligocene-Lower Miocene), the Stará Bystrica Formation, also of flysch nature, the Kopaczysko Formation of flyschoid character and the predominantly claystone Pasiek Formation. The age of the last three formations is Middle Miocene, the youngest sediments are of Upper Badenian to Lower Sarmatian age (CIEZSKOWSKI 1992). Upper Oligocene and Miocene formations formed after the folding of the Magura Basin in the Oligocene, in a piggy-back type of basin, on the back of the Magura Nappe. Later they were folded and incorporated into the Magura Nappe (CIEZSKOWSKY l.c.). They thus do not form a

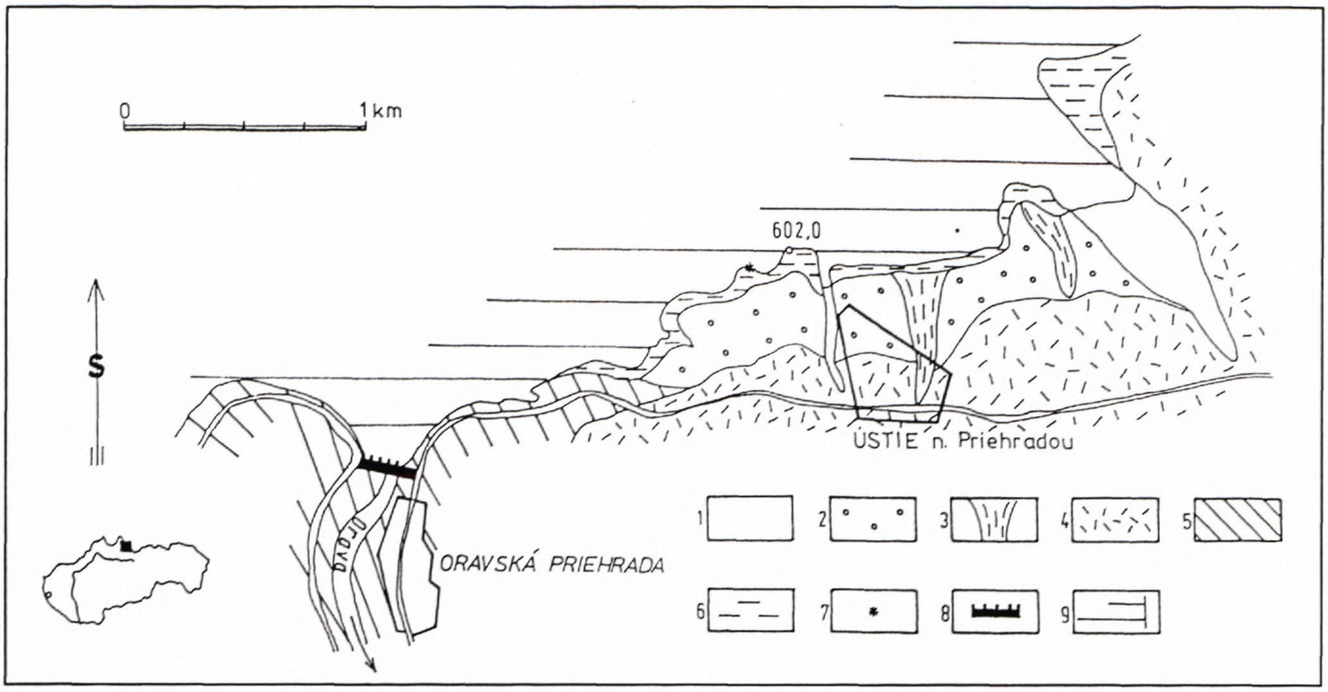


Fig. 1 Schematic geological map of the surroundings of the sampled coal occurrence near Ústie nad Priehradou
1 - proluvial sediments, 2 - fluvial sandy gravels and sands, 3 - alluvial cones, 4 - slope loams, 5 - Paleogene of the Magura Nappe, 6 - sandy clays and sands, Sarmatian in age, 7 - sampling location of coal, 8 - dam wall, 9 - dam lake water

part of the Orava-Nowy Targ Depression filling, but they are a part of its basement.

ROTH et a. (1963) thought that the formation of the depression was connected with a flexure bending of the crust which occurred in the Sarmatian, as the result of folding and back-thrusting of the Magura Nappe and, let us add, also of tectonic incorporation of the Oligocene-Miocene filling of the marine piggy-back basin into this nappe. From this point of view, the Orava Depression may be regarded as a retroarc basin. Another opinion on the genesis of the depression has been expressed by POSPÍŠIL (1990), who assumed that the depression formed on a mobile belt of the Periklippen zone by the pull-apart mechanism. The steep curves of sediment burial history during the Middle and Late Sarmatian and during the Pannonian (Fig. 7) are characteristic of the beginning of a horizontal displacement and for the subsidence in pull-apart type basins, which supports the opinion on the pull-apart mechanism of the basin opening. From the above it follows that the depression and its filling must be younger than the Lower Sarmatian, or that the depression filling is Sarmatian or younger. Opinions on the older age of the lower part of the filling must be in this sense corrected. Considerations on the presence of Lower Miocene and Badenian sediments in the depression (WATYCHA 1976, OSZAST and STUCHLIK in BIRKENMAJER 1978) originated probably as the result of insufficiently elaborated biostratigraphy of freshwater sediments, while marine sediments, which should certainly provide more suitable faunistic material for biostratigraphy, are missing in the basin filling.

Lithology

Sediments of the basin filling are lying discordantly on pre-Middle Sarmatian rocks. On the base of the basin filling there are coarse-clastic and pelitic sediments. Coarse clastics with their petrographic content are copying the basement. Maximum estimated thickness of basal beds is 250 m. At the margins of the depression they consist of medium-grained sands and fine gravels, the material of which came from the Paleogene basement. Towards the middle of the depression they disappear or they form irregular lenses among pelites (PULEC 1974).

The main part of the basin filling are grey monotonous clays and silts with variable content of the sandy admixture, or with sand layers. There are also present coal seams and layers of coal clays (NAGY in GROSS et al. 1993). Bentonite and acid tuff layers are rare. Above the grey clays there are lying grey rusty-brown-yellow spotted clays with sandy admixture. The thickness of the whole pelitic complex, according to the borehole OH-1 near the village Hladovka, exceeds 400 m (PULEC 1976). The estimated maximum thickness is approx. 500 m (NAGY l.c.). Towards the west the thickness of the formation decreases and near Vavrečka it is not greater than 10-20 m.

Above the clay formation there is lying a formation of polymict gravels containing material of the High Tatra provenance, together with sandstones of the Sub-Tatric unit of the Central Carpathian Paleogene. According to WATYCHA (1976), they are sediments of the Czarny Dunajec river, which, due to the uplift of the Gubala-Bukovina mountain range in the eastern part of the Orava-Nowy Targ Depression, was flowing into the Orava river.

In the grey clay of the main basin filling there were found ostracods: *Candona compressa* and representatives of the genus *Ilyocypris*, indicating Sarmatian to Pannonian age of the sediments (BRESTENSKÁ in PULEC 1976). WOZNY (1976) identified in the freshwater and land mollusc community the following species: *Xerophila sóosi* GAÁL, *Pisidium steinheimense* GOTTSSCHICK, *Clausilla* af. *grandis* KLEIN, confirming the Sarmatian to Upper Miocene age of the sediments.

According to fauna found in the borehole OH-1 above the clay formation, namely the gastropods *Steklovia koehnei* SCHLICKU-STRAUCH and the genus *Oxychylus* sp., ONDREJIČKOVÁ (in PULEC 1976) assumed Pliocene age of the upper part of the basin filling. She compared these sediments to the Pliocene of the Alpine fore-deep, the Rhine graben and the Vienna Basin, where they are considered to be Dacian.

The basin filling is slightly tectonically affected. It is not folded as the basement and the surroundings of the depression. Faults in the basin filling are interpreted on the basis of a gravity model. The more important ones have east-west direction and they participate in the asymmetric structure of the depression. Faults with greater throw restrict the depression in the north, i.e. in Poland. The southern margin of the depression is flatter, modelled by faults with lesser throw (POSPÍŠIL 1990).

Coal sedimentation and coal seams in the Orava Depression

The layers of coal clays and coal seams start to appear already in the lower part of the basin filling. They reached maximum extension and greatest thickness in the pelite formation. In Pliocene they are more rare.

In the Sarmatian sedimentation took place in freshwater environment with abundant influx from the surrounding rivers. In a closed space the depression degraded and numerous swamps formed here. The sedimentation environment and a favourable climate provided the conditions for the formation of coal clays and coal seams, creating in the basin filling lenses and irregular seams.

In the Orava Depression coal seams were best exposed in 1988, when the water was let out of the dam at Ústie nad Priehradou (Photo 1). The outcrop ceased to exist due to adjustments to the banks of the dam lake. The coal seam is 1 m thick, but small

Photo 1 General view of the coal seam exposed due to bank erosion near Ústie nad Priehradou

Photo 2 Detail of a coal seam with sample locations (ordered from Sample 1 at the base to Sample 4 at the cap)

in area, as in the immediate underlier there is already the Magura unit flysch.

The underlying grey clays exposed in the thickness of 1.5 m are passing into black-grey to black coal clays 0.5 m thick, which in turn pass into a coal seam. Above the coal there are lying grey, brown-spotted clays. Their contact with the seam is sharp, indicating sudden ending of conditions favourable for coal sedimentation and rapid burial of the coal seam.

The coal is in the lower, 20 cm thick layer considerably contamined by clays with Fe oxides (Photo 2). Higher up there is a 40 cm thick layer in which black, 5-7 cm thick coal intercalations alternate with coal permeated with Fe oxides. It is cohesionless and fractured. Above there is a 5-6 cm thick layer of grey clays with carbonised plant debris separating a 40 cm layer of compact shiny black coal. Fe oxides occur here only on the surface of fractures.

From the leaf impressions found in the near surroundings of the locality, KNOBLOCH (1968) determined three plant communities:

a) Community with representatives of the genus *Glyptostrobus* and *Myrica*, giving rise to the coal seam

b) Very hydrophilous, even swamp community with *Byttneriophyllum tiliaefolium* and *Alnus* sp.

c) Community of a mesophyllious forest with predominant beech *(Fagus* cf. *grandifolia* foss.) and plane-trees (*Platanus platanifolia*).

The above author presented the opinion that these communities are of Sarmatian age, not excluding their older or even younger age. To the same conclusion came also SITÁR (in PULEC 1976) who, on the basis of the occurrence of *Platanus aceroides* GREPP in the borehole OH-1, compared sediments of the Orava Depression to Late Miocene filling of the Turiec Depression.

Coal-petrographic characterisation of coal from Ústie nad Priehradou and its carbonisation

Occurrences of coal seams in the Orava Depression were known already in the past, however, their more detailed characterisation, with the exception of chemical-technological analyses presented by GAŠPARÍK et al. in SLÁVIK et al. (1967), has not been mentioned in literature.

Therefore, coal from Ústie nad Priehradou was subject of coal-petrographic study, chemical-technological tests were carried out and special attention was given to the carbonisation degree using the study of vitrinite reflectance. Sampling location is shown in Fig. 1 and Photo 1. As in Slovakia same problems are studied at several coal deposits and first results are available (PETRÍK 1994), the carbonisation degree of coal from Orava could be compared with coal of the Handlová-Nováky Formation in the Hornonitrianska Basin.

Coal in Ústie nad Priehradou belongs to humites of the brown coal stage, belonging mainly to xylito-detritic and detrito-xylitic lithotypes, with relatively low ash contents.

From the micro-petrographic point of view, the most frequent maceral group is huminite represented by the sub-group of humodetrinite with the macerals denzinite and attrinite, and the sub-group of humotelinite with the macerals ullminite and textinite. The humokolinite sub-group is relatively abundantly represented by gelinite. The inertinite group has not been found in the coal.

We based the determination of carbonisation degree on the fact that light reflectance is the basic indicator which, in contrast to other determinations like carbon content (C^{daf}) in combustible matter, volatile combustible (V^{daf}) and combustion heat (Q_s^{daf}), is not dependent on the maceral composition. It is determined on microscopic objects in natural state, which have not been, prior to the measurement, thermally or chemically attacked. The measurement is carried out on macerals the behaviour of which in the carbonisation process is known and which have a low mineral ash matter content. It is based on the fact that the carbonisation degree is irreversible. Thus, it characterises the highest temperature which the coal, or dispersed organic matter (MOD) reached in its geological history.

The study of organic matter carbonisation provides basic information on the geothermal history of sedimentary basins and gives thus valuable information for the understanding of tectonogenesis and tectonic effects in the basin. It affects in a decisive way the evaluation of the carbohydrate potential and prognoses of occurrences and deposits of natural carbohydrates in the basin.

The measurement conditions at micro-photometric determination of light reflectance of coal were as follows:

- microscope MPV Leitz-Wetzlar
- wave length of monochromatic light - 546 nm+4nm
- refractive index of the oil immersion - 1.516-1.518
- reflectance standard: Glasprizma - Ro=1.24%
- magnification: 500x

The results of the measurement are summarised in histograms with the basic characteristics (Figs. 2 to 5). From the histograms it follows that mean reflectance in the measured samples varies in the range from 0.35 to 0.43%.

The boundary between black and brown coal from the point of view of carbonisation degree is vitrinite reflectance of about 0.5%. From this it follows that the coal studied may be ranged with ortho- to meta-phase of the brown coal stage of alteration. The results of coal reflectance measurement are consistent with the chemical-technological analyses (Tab. 1). This follows especially from the high values of coal combustion heat in original and dehydrated state varying from 15.86 to 21.93 MJ/kg (original samples), or from 18.17 to 24.98 MJ/kg (dehydrated samples), and from the values of caloricity varying from 14.75 to 20.75 MJ/kg (original samples), or from 17.26 to 23.98 MJ/kg (dehydrated samples).

In Slovakia, practically all coal belongs, as far as carbonisation is concerned, to the brown-coal stage of alteration, with the exception of the Upper Carboniferous meta-anthracite at Veľká Tŕňa (Petrík et al., 1990, Petrík 1992). The Horná Nitra Depression, the filling of which contains the Handlová-Nováky coal-bearing formation, went through a complicated neotectonic development. The coal seams of the deposits Handlová, Cígeľ, Nováky represent the whole brow-coal stage - hemiphase, orthophase and metaphase. The carbonisation is increasing from the Nováky deposit towards the deposit Cígeľ and the highest degree of carbonisa tion is at the Handlová deposit. The reflectograms (Fig. 6) show that coal of the Orava Depression may be compared on the basis of alteration degree with the Handlová coal, or even with coal from the deposit Cígeľ.

Geothermal and geotectonic history of the Orava Depression

The Orava Depression, as mentioned above in detail, is relatively young. It formed after folding

Table 1 Chemical-technological analyses of coal from Ústie nad Priehradou (Orava Depression)

Determination	Unit	Original sample	Dehydrated sample	Combustible
Sample 1				
water	%	13.47		
ash	%	8.60	9.94	
combustible	%	77.93	90.06	
combustion heat	MJ/kg	20.94	24.20	26.87
caloricity	MJ/kg	19.76	23.22	25.78
volatile combustible	%	41.25	17.67	52.93
sulphur total	%	2.15	2.49	
Sample 2				
water	%	13.10		
ash	%	6.06	6.97	
combustible	%	80.84	93.03	
combustion heat	MJ/kg	21.71	24.98	26.85
caloricity	MJ/kg	20.52	23.98	25.78
volatile combustible	%	42.07	48.41	52.04
sulphur total	%	1.62	1.86	
Sample 3				
water	%	12.07		
ash	%	6.17	7.35	
combustible	%	81.46	92.64	
combustion heat	MJ/kg	21.93	24.94	26.92
caloricity	MJ/kg	20.75	23.93	25.83
volatile combustible	%	43.26	49.20	53.11
sulphur total	%	3.03	3.45	
Sample 4				
water	%	12.27		
ash	%	15.08	17.28	
combustible	%	72.20	82.72	
combustion heat	MJ/kg	15.86	18.17	21.96
caloricity	MJ/kg	14.75	17.26	20.86
volatile combustible	%	39.72	45.51	55.02
sulphur total	%	8.28	9.49	

Sample No	Range of Ro values in %	Number of date	Relative frequency
1.	0.24 - 0. 28	0	0
	0.28 - 0.32	0	0
	0.32 - 0.36	0	0
	0.36 - 0. 40	7	28
	0.40 - 0. 44	13	52
	0.44 - 0.48	5	20
		0	0
	number of measurements	25	
	middle reflectivity	0,43	
	standard deviation	0.02	

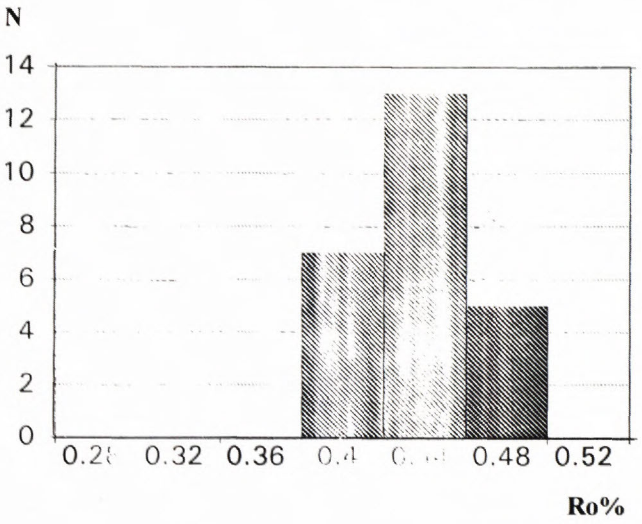


Fig. 2 Reflectograme

Sample No	Range of Ro values in %	Number of date	Relative frequency
2.	0.24 - 0. 28	0	0
	0.28 - 0.32	0	0
	0.32 - 0.36	0	0
	0.36 - 0. 40	9	36
	0.40 - 0. 44	10	40
	0.44 - 0.48	6	24
		0	0
	number of measurements	25	
	middle reflectivity	0,39	
	standard deviation	0.03	

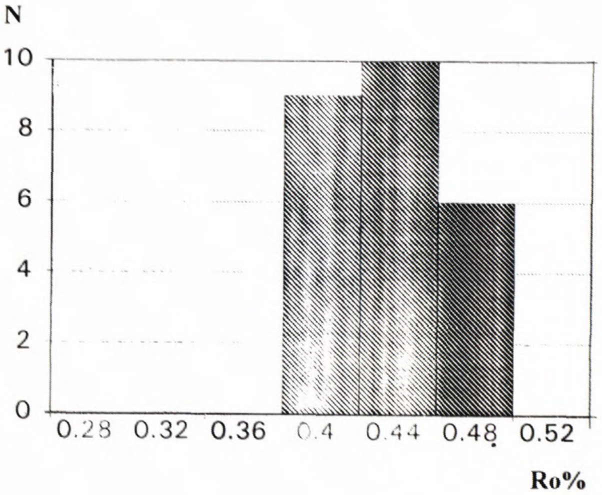
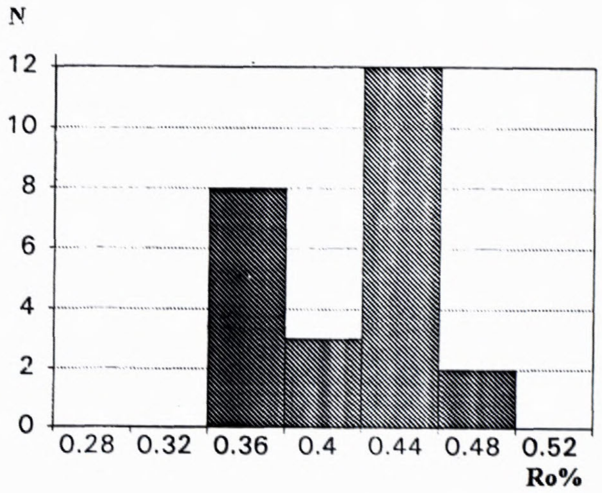


Fig. 3 Reflectograme

Sample No	Range of Ro values in %	Number of date	Relative frequency
3.	0.24 - 0. 28	0	0
	0.28 - 0.32	0	0
	0.32 - 0.36	8	32
	0.36 - 0. 40	3	12
	0.40 - 0. 44	12	48
	0.44 - 0.48	2	8
		0	0
	number of measurements	25	
	middle reflectivity	0,35	
	standard deviation	0.04	

Fig. 4 Reflectograme



Sample No	Range of Ro values in %	Number of date	Relative frequency
1.	0.24 - 0. 28	4	16
	0.28 - 0.32	1	4
	0.32 - 0.36	3	12
	0.36 - 0. 40	13	52
	0.40 - 0. 44	4	16
	0.44 - 0.48	0	0
		0	0
	number of measurements	25	
	middle reflectivity	0,38	
	standard deviation	0.05	

Fig. 5 Reflectograme

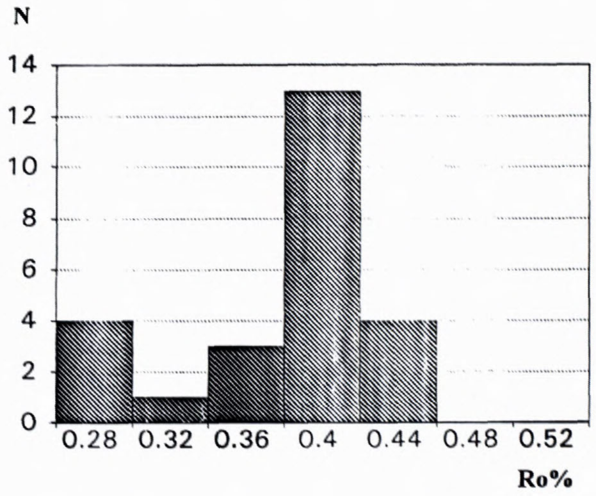


Fig. 2-5 Reflectograms of vitrine reflectance (R_o) of coal samples from Ústie nad Priehradou

processes in the Sarmatian. These processes led to the disappearance of the piggy-back type basin, which persisted from the end of the Oligocene to the Lower Sarmatian inclusive, on the back of the Magura Nappe. The Orava, or Orava-Nowy Targ Depression, formed probably as a pull-apart type

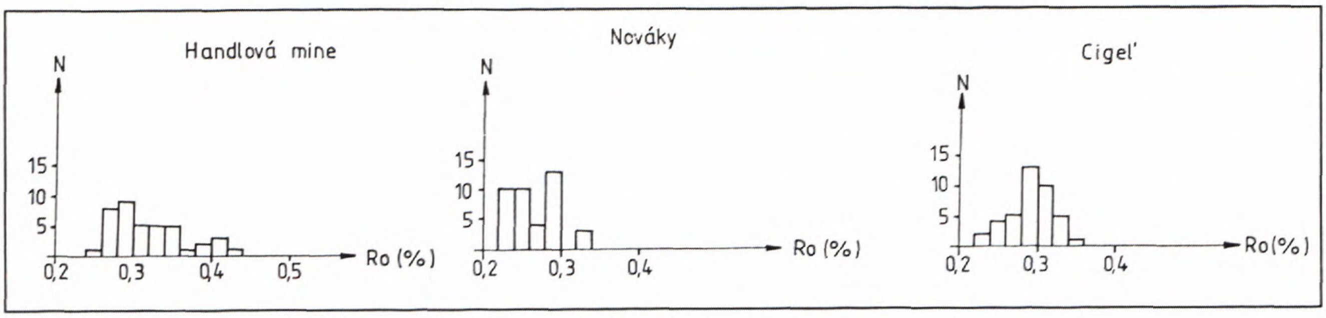


Fig. 6 Reflectograms of vitrine reflectance (R_o) of coal from the mines Handlová, Nováky and Cígel'

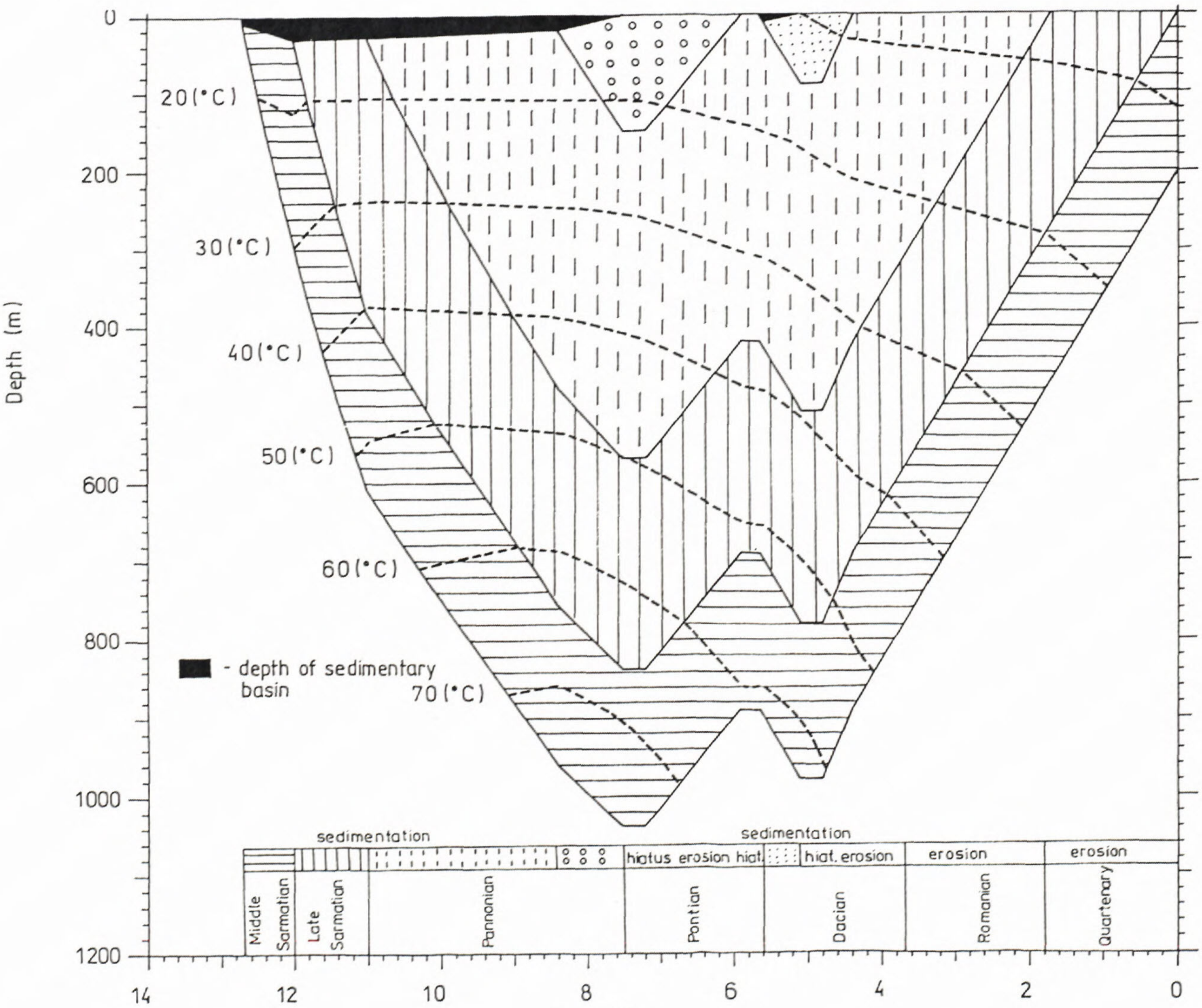


Fig. 7 Model of burial history of sediments in the Orava Depression

basin in the Late Sarmatian and it persisted to the Pliocene. The carbonisation degree of coal seams cropping out at present near Ústie nad Priehradou, with average vitrinite reflectance R_o 0.35 to 0.43%, is surprisingly high. In the depression there are absent any manifestations of local volcanism, i.e. there are no volcanic centres, or young intrusive magmatites which could provide heat for the given carbonisation degree of organic matter in the coal seams. The depression filling is not folded or metamorphosed, and so the carbonisation degree could not be caused by dynamometamorphic processes. The relatively high carbonisation degree of coal from Ústie nad Priehradou may be explained by the burial of the coal during the filling of the depression into a depth of approx. 1150 m (Fig. 7), where the temperature was sufficient for the coal to acquire the degree of thermal alteration which has been experimentally determined (Figs. 2-5), or calculated in the model (Fig. 8). Later on, maybe partly after the Miocene, but especially after the Pliocene, the depression must have been risen, its filling partly eroded so that coal in the surroundings of Ústie nad Priehradou reached the present surface

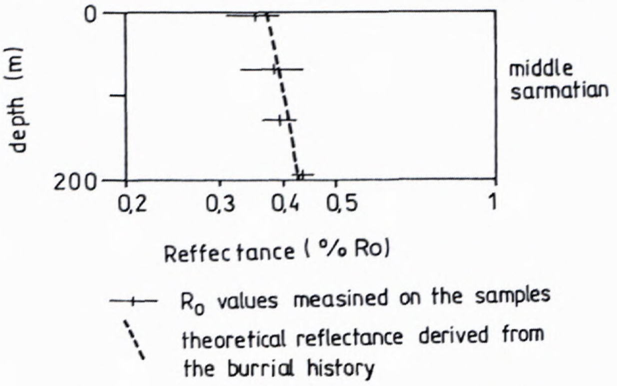


Fig. 8 Correlation of measured and modelled vitrinite reflectance values. The correlation indicates that the model of sediment burial history in the Orava Depression has been selected correctly.

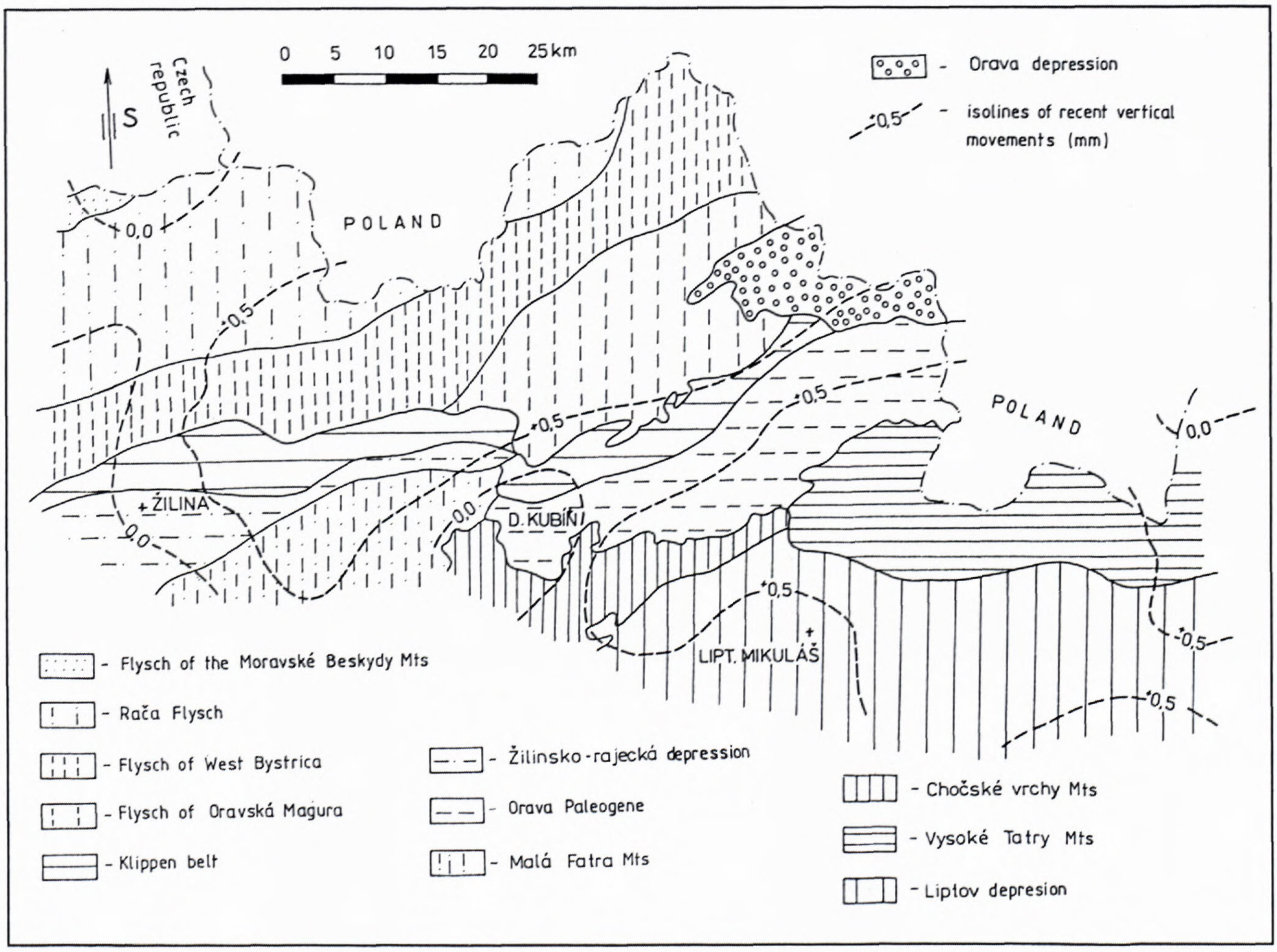


Fig. 9 Recent vertical movements in the area of the Orava Depression (after VANEK 1988)

of the depression. The rising the depression persists to the present, which is indicated by measurements of recent vertical movements of the Western Carpathians. According to VANEK (1988) the major part of the Orava Depression is lying in an area which is rising at an average rate of + 0.5 mm/year, or a rate between 0.0 to +0.5 mm (Fig. 9).

Average rate of rising of the depression from the Dacian to the recent times (0.18 mm/year) calculated from the model is in accordance with recent vertical movements.

During the Dacian the depression lost the basin geodynamics, i.e. it ceased to subside and, on the contrary, it started to rise together with its geological surroundings. The geomorphologic form of the depression has been preserved not due to continuing subsidence, but due to the lithologic contrast between the soft, to erosion more prone sedimentary filling of the basin and the much harder rocks surrounding the depression.

Conclusions

The Orava Depression, and its continuation in Poland, i.e. the Nowy Targ Depression, formed after the Early Sarmatian. Before the formation of this depression, a piggy-back type basin reached into the area of the present Orava-Nowy Targ Depression, with marine sedimentation during the Oligocene to Middle Miocene (including Early Sarmatian). This basin ceased to exist due to folding causing an inversion of the basin and the incorporation of its filling into the Magura Nappe of the Outer Flysch Carpathians. The young Orava-Nowy Targ Depression formed, according to ROTH et al. (1963), due to a flexure caused by the load of the Magura Nappe during its back-thrusting with southern vergency. This thrusting affected also the Klippen Belt, which is overthrust on the Central Carpathians. The steepness of burial curves in the basin however indicates pull-apart mechanism of depression opening and it supports the opinion of POSPÍŠIL (1990) on the formation of the depression on the mobile belt of the Periklippen zone with horizontal movements.

The coal of the Orava Depression, namely from the surroundings of Ústie nad Priehradou, belongs to humites of the brown-coal stage of alteration, with predominant xylito-detritic and detrito-xylitic lithotypes, and relatively low ash contents. According to light reflectance of vitrinite and chemical-technological tests it may be ranged with the ortho- to metaphase of brown coal. It may be compared with coal from the deposits Handlová and Cígeľ in the Horná Nitra Depression.

Coal with such thermal alteration degree must have been buried in the process of basin filling. It reached the surface after the Pliocene, when the whole depression started to rise and erosion removed a substantial part of the original filling. The basin, due to lithologic contrast between the filling and the surrounding rocks, preserved its depression morphology in spite of the uplift continuing to the present.

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