GEOLOGICA BELGICA (2004) 7/3-4: 313-318

PALEOTEMPERATURES OF UPPER CARBONIFEROUS SEDIMENTARY ROCKS IN THE NW PART OF THE UPPER SILESIAN COAL BASIN, POLAND

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(5 figures and 2 tables)

ABSTRACT. Paleothermal conditions of Upper Carboniferous sedimentary rocks in the strongly folded north-western part of the Upper Silesian Coal Basin (USCB) are characterized in this paper. NS-oriented narrow folds predominate, with amplitudes ranging from 100 to 800 m, often dislocated by axial faults. The paleothermal conditions, i.e. maximum paleotemperatures and paleothermal gradient were calculated according to Bostick's nomogram and Barker and Pawlewicz's method on the basis of studies of 115 samples of coal taken from depths between +17 and -368 m b.s.l. The paleotemperatures range from 135 to 220°C and the paleothermal gradients from 2.4 to 5.9°C/100 m. The coalification process probably has a synorogenic character.

Keywords: Carboniferous sedimentary rocks, paleotemperature, paleothermal gradient, Upper Silesian Coal Basin

1. Introduction

An attempt to characterize the paleothermal conditions which prevail in Carboniferous massif was undertaken in the present study. The area studied is located in the northwest part of the Upper Silesian Coal Basin (USCB) within the area of fold tectonics (Fig.1). Numerous, meridian-orientated, narrow folds of amplitude from 100 – 800 m predominate there. Mostly they are inclined folds, rarely overthrown, asymmetric with eastern vergence and frequently cut by faults in axial zones. The Orlova-Boguszowice dislocation has been considered as the eastern border of the USCB fold tectonics zone. This dislocation in the south in the Czech part of the basin, has a fold character (Orlova fold), which on Polish territory transforms into an overthrust and fold IV in the Sosnica Colliery is regarded as its equivalent in the area studied. Only the oldest layers of Upper Carboniferous, those included to the Namurian A, occur in the lithological profile of the area studied. In this area, Carboniferous deposits have a thickness of a few kilometers, which is characteristic for mobile basins of the geosynclinal character. In contrast to this, in the eastern part of the USCB, the thickness of Upper Carboniferous deposits does not exceed a few hundred meters and the profile includes deposits from the Namurian A to Westphalian D. The eastern part of the USCB has features that are more characteristic of the platform zones (Kotas, 1995).

In the overburden of the area studied, besides Quaternary formations, only Tertiary formations (Miocene) and Triassic (Muschelkalk, Buntsandstein) occur. Lack of the full Carboniferous profile and overlay, as well as the presence of Permo-mesozoic formations only in the north-eastern part of the basin, makes it difficult to reconstruct both the geological and thermal history of the basin.

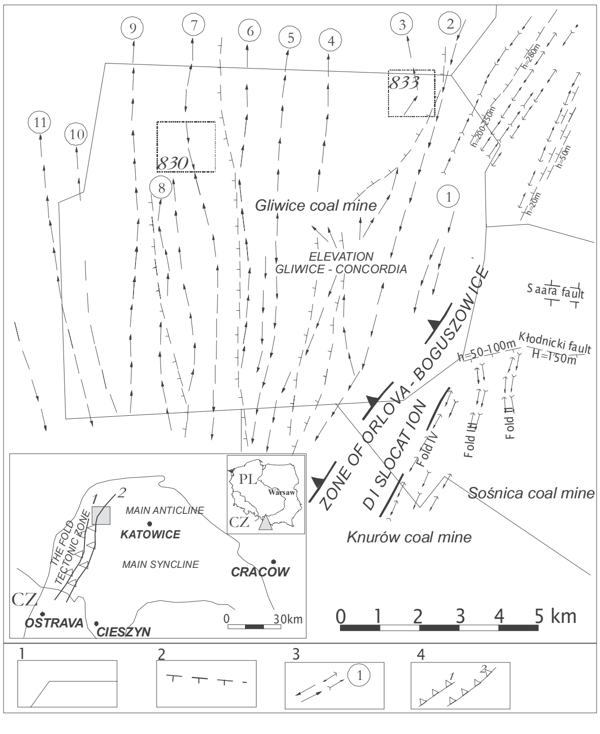

Figure 1. Tectonic sketch map
1 - boundary of coal mine, 2 - fault, 3 - axes of folds, 4 - Overthrusts; 1 - Michałkowice-Rybnik 2 - Orlova-Boguszowice.

2. Methodology

An assumption has been adopted in the present work that the coal rank straightforwardly reflects the maximum temperatures that occurred in the rock massif during its geological history. It should be stated that coal rank is controlled by both temperature and time frame, called in the literature the effective heating time (EHT), as well as by pressure. However, it is generally accepted that the pressure in rock massif has a greater influence at the beginning of the transformation process of organic substances, that is at the stage of lignite formation. At further stages of the coalification process pressure does not favor the increase of coal rank, as it counteracts temperature increase (Taylor et al., 1998).

The Bostick nomogram and the Barker-Pawlewicz method (Barker & Pawlewicz, 1986) were used to assess the values of paleotemperatures. The Bostick nomogram enables to calculate three variables, i.e. time, temperature and coal rank. Here time means a geological time, in which deposits underwent the “effective heating” process, that is, their temperature varied between 15°C and maximum temperature Tmax, which occurred in the geological history of the Carboniferous rock massif. At the same time the coal rank is determined by vitrinite reflectance, Rr. On the basis of previous research it was assumed that EHT = 20 million years. The main stage of the coalification process, which was undoubtedly shorter, a few to ten or so million years, took place after the end of Carboniferous sedimentation (Westphalian D) and before the Permian period (Lewandowska, 2001). It was also estimated that the amount of subsidence or depression of Carboniferous deposits, in the western part of USCB, did not exceed 10 km (Kotas, 1995).

Using the Barker-Pawlewicz method, it is possible to estimate the maximum paleotemperatures only if the coal rank, i.e. vitrinite reflectance, Rr, is known. The following equation gives the relationship between these two quantities:

$$\ln(Rr) = 0{,}0078Tmax - 1.2$$

Paleotemperatures of the rock massif were determined on the basis of testing 115 coal samples taken from depth ranging from +17 to –368 m b.s.l. (Table 1) (Probierz & Lewandowska, 2001). The analysed coal samples came from mine openings only - galleries and extraction workings. Samples from boreholes were not included. Despite the fact that mining activities have been carried out in the area studied from the end of XIX-the century, the site has not been sufficiently explored with boreholes. This is because of both strong folding and faulting of the Carboniferous strata, as well as because of the lack of deep boreholes.

3. Results and discussion

Coal from the studied area has very good coking properties which are well known in Europe, and a vitrinite reflectance (Rr) in the interval from 0.87 to 1.68% (s=0.03 - 0.07) (Table1).

By analysing, in the area studied, vitrinite reflectance and the depth from which samples were taken, the lack of any correlation between both parameters was shown. As was mentioned above, sampling of the area studied was not regular. This is due to the complicated tectonics, among others the occurrence of ten or so narrow folds of high amplitude, cut by faults. Such a geological structure enables to carry out mining exploitation only in some of the geological structures or their parts (e.g. in the axis or flanks of anticline or syncline). Thus, mining exploitation has an influence on the fragmentary sampling of geological structures in the area studied. This constrained method of sampling meant that on exploitation level maps the set of points, located not too far distant from each other, and sometimes significantly differing in vitrinite reflectance, were obtained. Sampling points were also located in different parts of the structures (axis or flanks of folds). Thus, the causes presented explain adequately the lack of correlation between reflectance and depth in the studied area. This does not mean, however, that there is no such correlation.

In order to determine relationships between vitrinite reflectance and depth, an attempt was made to determine it for seam portions located within one of ten or so folds, which occurred in the area studied. Two seams, 830 and 833, were selected, for which the biggest number of samples were easily accessible. All available, determined vitrinite reflectances were taken into consideration.

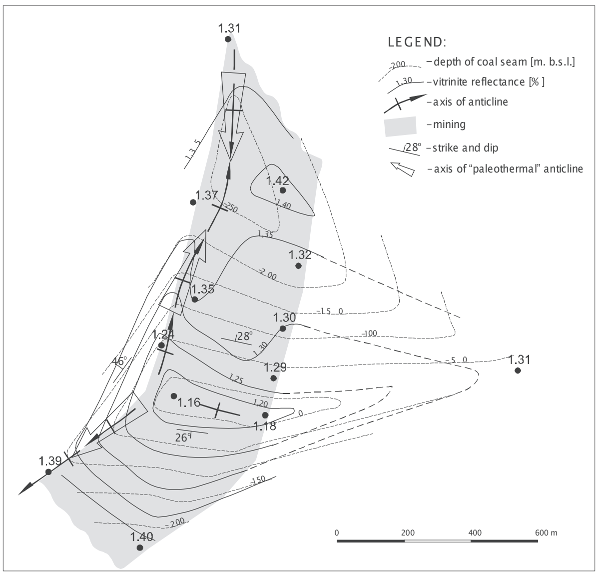

Figure 2. Map of vitrinite reflectance in coal seam 830.

COAL SEAMS	R_r [%]±SD [%]			VITRINITE [%] mmf[1]	LIPTINITE [%] mmf	INERTINITE [%] mmf	MINERAL MATTER [%]
618 (5)[2]	min.	0.92	±0.04	64	6	13	1
	max.	0.99	±0.06	80	10	30	3
620 (4)	min.	0.95	±0.03	60	7	15	2
	max.	1.00	±0.06	78	10	32	9
622 (3)	min.	0.87	±0.04	73	3	4	3
	max.	0.95	±0.05	93	10	17	21
624 (1)	min. max.	0.97	±0.04	70	12	18	9
625 (4)	min.	0.96	±0.04	62	7	11	3
	max.	1.03	±0.05	82	12	26	17
712 (2)	min.	1.01	±0.04	58	8	28	3
	max.	1.02	±0.05	64	9	33	6
803 (1)	min. max.	1.06	±0.05	74	8	18	9
805 (1)	min. max.	1.08	±0.05	76	4	20	7
807 (1)	min. max.	1.02	±0.05	77	5	18	6
808 (1)	min. max.	1.06	±0.05	78	6	16	3
823 (2)	min.	1.22	±0.06	82	0	9	8
	max.	1.32	±0.06	91	2	16	9
827 (1)	min. max.	1.32	±0.06	86	1	13	11
830 (29)	min.	1.14	±0.04	63	1	13	0
	max.	1.42	±0.06	85	11	29	9
833 (13)	min.	1.17	±0.04	63	0	13	1
	max.	1.49	±0.06	86	6	31	45
834 (1)	min. max.	1.38	±0.06	79	2	19	2
835 (2)	min.	1.28	±0.06	64	1	27	1
	max.	1.39	±0.07	68	5	35	2
837 (4)	min.	1.08	±0.04	64	4	23	4
	max.	1.30	±0.06	68	9	29	5
838 (1)	min. max.	1.48	±0.05	69	2	29	14
839 (2)	min.	1.25	±0.05	67	2	25	3
	max.	1.56	±0.05	73	5	28	7
842 (1)	min. max.	1.37	±0.05	68	2	30	4
843 (8)	min.	1.33	±0.03	66	0	16	1
	max.	1.55	±0.07	83	7	30	20
844/1 (3)	min.	1.34	±0.06	67	1	27	2
	max.	1.65	±0.06	72	3	30	19
845 (11)	min.	1.28	±0.05	67	0	13	1
	max.	1.68	±0.07	87	4	31	16
846 (4)	min.	1.41	±0.05	72	0	16	1
	max.	1.60	±0.07	80	5	26	9
918 (1)	min. max.	1.03	±0.04	69	6	25	3

Table 1. Optical properties and petrographical composition of coals from the study area's coal seams.
[1] mineral matter free; [2] seam No. 618, in parenthesis showed number of coal samples.

REGION	Depth range sampled [m.b.s.l.]	Rr [%]	Gradient Rr [%Rr/100m]	after Bostick EHT = 20 m.y.		after Barker & Pawlewicza	
				T max [OC]	Paleothermal Gradient [OC/100m]	T max [OC]	Paleothermal Gradient [OC/100m]
GLIWICE coal mine	+17 _ -368	0.87 – 1.68	–	135 – 179	-	136 – 220	-
anticline 7 coal seam 830	+26 _ -246	1.16 – 1.42	0.047	156 - 169	2.4	173 – 199	4.8
anticline 3 coal seam 833	-38 _ -234	1.11 – 1.28	0.055	153 - 163	3.3	167 – 185	5.9

Table 2. The values of paleotemperatures and gradients in research depth-level of the study area.
[1] EHT –effective heating time in m.y.
[2] From the given range of temperature lower value was assigned for lower value of vitrinite reflectance (Rr) and refers to upper part of the examined profile section. Respectively, higher value of temperature was assigned for higher value of vitrinite reflectance and refers to lower part of the examined profile section.

However, many of them were not satisfactory since the measurements were made sporadically only in recent years and the mine has been shut down.

Seam 830 was best sampled in the area of anticline 7, the axis of which is characterized by transverse undulations (Fig. 2). Here mining activities enabled to sample the eastern flank of fold 7 within the depth interval between +26 and –246 m.b.s.l. It allowed for the preparation of the vitrinite reflectance map of that fold flank. Seam 833 was sampled in the area of anticline 3 (Fig.3). Samples were located in the SE flank of the fold within the depth interval between –38 to 234 m.b.s.l. For the folds analyzed, a correlation between reflectance and depth has been found with the correlation coefficient equal to 0.69 for the seam 830 and 0.81 for the seam 833.

The suggested procedure enabled to obtain good correlations between vitrinite reflectance and depth, and also it enabled to determine reflectance gradients and maximum paleotemperatures and paleogradients (Table 2). The reflectance gradients determined on the basis of correlation equations equal to 0.047% Rr at the depth of 100 m for anticline 7 and 0.055% Rr at the depth of 100 m for anticline 3. The values of paleotemperatures, estimated on the basis of the Bostick nomogram, vary in the area studied, from 135 to 175°C, and those obtained by the Barker and Pawlewicz method, vary from 136 to 220°C. The determined paleothermal gradients are equal, respectively, to 2.4 and 4.8°C/100 m in fold 7 and to 3.3 and 5.9°C/100 m in fold 3.

The obtained equations which correlate vitrinite reflectance and depth also enabled to determine the

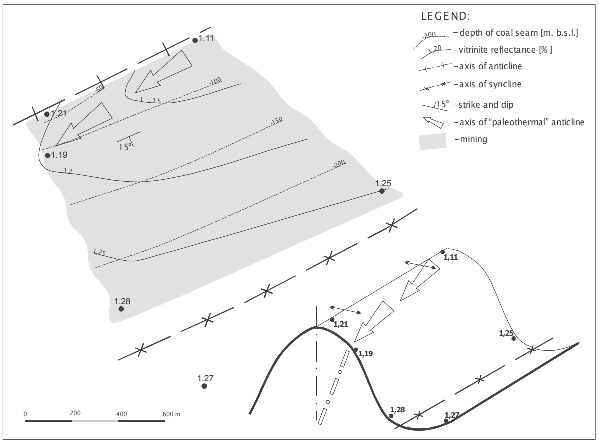

Figure 3. Map of vitrinite reflectance in coal seam 8331

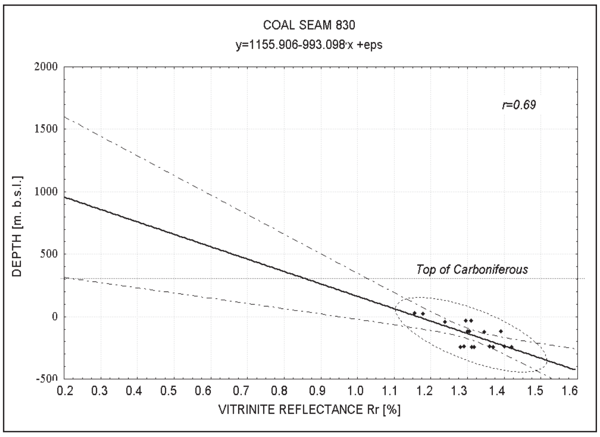

Figure 4. Relationship between vitrinite reflectance and depth in coal seam 830. Thickness of eroded Carboniferous beds, equal to about 700 m, was determined under the assumption that the top of the Carboniferous strata occurs at a depth of 250 m (~950 m - 250 m = ~700 m).

minimum erosion, i.e. the thickness of deposits removed by erosion. In the area of anticline 7 the thickness of eroded layers was estimated at ≥700 m (Fig.4), while in the area of anticline 3 the thickness of removed deposits was estimated at ≥800 m (Fig.5). The estimated values may contain significant errors as large standard deviations, as well as lack of certainty as to the linearity of the correlations, indicate. The low accuracy of the estimation is due to missing lithostratigraphical series in the overburden, as well as to a lack of vitrinite reflectance data.

The determined values of paleotemperatures are, independently of the method used, the highest of those determined in the area of the USCB. In that part of the basin, research work on paleothermal conditions using the Rock-Eval method has already been carried out. The values of paleotemperatures, obtained from two boreholes on the basis of reflectance values from 1.12 to 1.25% are, however, slightly lower (Ney & Kotarba, 1995) than those determined in the present work. High values of paleotemperatures, characteristic for the western, folded part of the basin, found at relatively shallow depth, can be explained by the amount of erosion. The erosion, estimated by the authors for 700 - 800 m, is probably greater. Ney & Kotarba (1995) gave the value of 1700 m and Kotas (1995) estimates it even at a few kilometers. Vitrinite reflectance mapping in seams 830 and 833 (Fig. 2, 3) enabled a determination of conformity of the reflectance with the seam position. It was found that vitrinite reflectance isolines show a good fit to the seam floor isolines. This can be treated as evidence of the synorogenic character of the coalification process, i.e. of the fact that a seam was coalified during the folding process. Faults that dislocate folds would probably have been formed after the main stage of coalification, which probably occurred after the Westphalian D and before the Permian period. Multi-stage coalification character

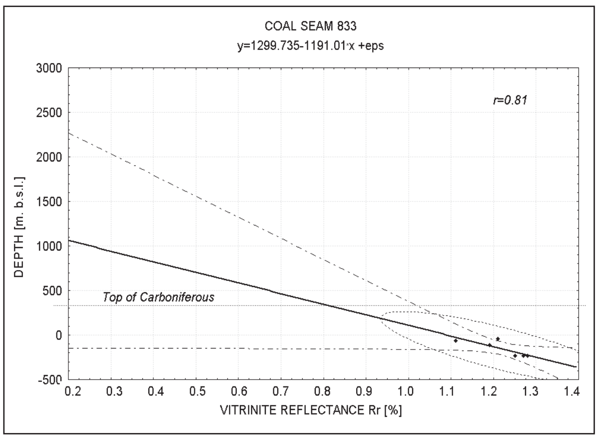

Figure 5. Relationship between vitrinite reflectance and depth in coal seam 833. Thickness of eroded Carboniferous beds, equal to about 800 m, was determined under the assumption that the top of the Carboniferous strata occurs at a depth of 250 m (~1050 m - 250 m = ~800 m).

(syn- and postorogenic), found in other parts of the basin, can not be excluded.

While comparing the NW part of USCB with other European basins, it should be remembered that the synorogenic coalification process is also characteristic of the Donets Basin (Sachsenhofer et al., 2002). A slightly different preorogenic character of the coalification process was found in the Ruhr Basin in Germany (Littke et al., 1994; Robert, 1989) and in the Mons Coal Basin in Belgium (according to Pillement in Robert, 1989). However, some publications hypothesize a multi-stage coalification process in the Ruhr Basin (Juch, 2002). A totally different character of the coalification process was found in the South Wales Coal Basin (Robert, 1989), as well as in the Carboniferous strata of Ibbenbüren, Germany (Teichmüller & Teichmüller, 1985), as the coalification process was closely connected with large intrusive bodies in those basins.

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Manuscript received 7.10.2002 and accepted for publication 1.12.2003.