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Relationship between bed thickness, average ash content, and Zn and Pb content in coal in the Upper Silesian Coal Basin

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Varying frequency of the occurrence of coal interbeds and thin, medium and thick coal beds in the paralic and the limnic coal-bearing series was determined in the Upper Silesian Coal Basin. Thin coal beds occur in the basin most frequently. Typically, the ash content and Zn and Pb content decrease with the increasing thickness of the beds. The highest ash content and content of Zn and Pb occur in thin coal beds, less than 0.3 m thick (especially in the limnic series) and thin beds of coal shales 0.3–0.7 m thick. The average ash content of coal and average content of Zn and Pb mainly reflect a content in thin beds (0.7–1.5 m in the limnic series and below 0.7 m in the paralic series), most frequently occurring in the basin. Variability of Zn and Pb content is closely associated with ash-forming substances in coal. The presently varying levels of concentrations of Zn and Pb in coal beds are assumed to result from sorption-diffusion processes of coal enrichment, which involved the entire thickness in thin beds, though affected only in near-top and near-bottom parts of thick beds.

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Key words: Upper Silesian Coal Basin, Zn, Pb, ash content, coal.

INTRODUCTION

V. Bouška (1981) and J. E. Judovich *et al.* (1985) estimated average content of rare and trace elements in brown and black coals in the world deposits, basing on results of about 1000 works of various authors. They also simultaneously determined the relationship between these elements and organic and mineral components of the coal and presented causes of their accumulation in coals. The authors referred determined that in black coal with high Zn and Cu contents, substances formed by sorption of sulphides predominate in the increasing concentration of these elements. In contrast, Pb and Cd in coal are typically associated with the organic components, especially when the average content of these element approaches the lithosphere clarks. Sulphides are the most important in coal with increased concentration of Pb.

V. Bouška (1981) and J. E. Judovich *et al.* (1985) emphasised the differences in content of trace elements in coals among few tens of basins in the world, and also often within a vertical profile or along the course of a bed. In many later publications these variabilities were confirmed, i.e. for coal deposits in India (H. S. Pareek, B. Bardhan, 1985; R. Ghosh *et al.*, 1987; K. N. Mukherjee *et al.*, 1988), England (G. O. Asuen, 1987, 1988), Germany (W. Pickhardt, 1989), USA, England and Australia (P. C. Lyons *et al.*, 1989), Canada (F. Goodarzi, 1987), Bulgaria (G. M. Eskanazy, 1990, 1992, 1995) and China (X. Querol *et al.*, 1997). Content variability of trace elements in coals in some areas of the Upper Silesian Coal Basin (USCB) were noted by B. Roga (1958), B. Roga *et al.* (1958), A. Idzikowski (1959), J. Winnicki (1964), J. Widawska-Kuśmierska (1973*a*, *b*, 1975*a*, *b*, 1981, 1984), S. Cebulak (1983) and authors of this paper (A. Różkowska, 1984, 1987, 1993; A. Różkowska, H. Parzentny, 1990; H. Parzentny, 1989, 1994, 1995).

Variability in content of trace elements, in a vertical profile as well as in the course of beds in USCB, is presented in the first and the only geochemical atlas of the USCB coal deposits (B. Ptak, A. Różkowska, 1995) published in Poland. This atlas was prepared basing on results of several years of research by the Polish Geological Institute, within the explor-

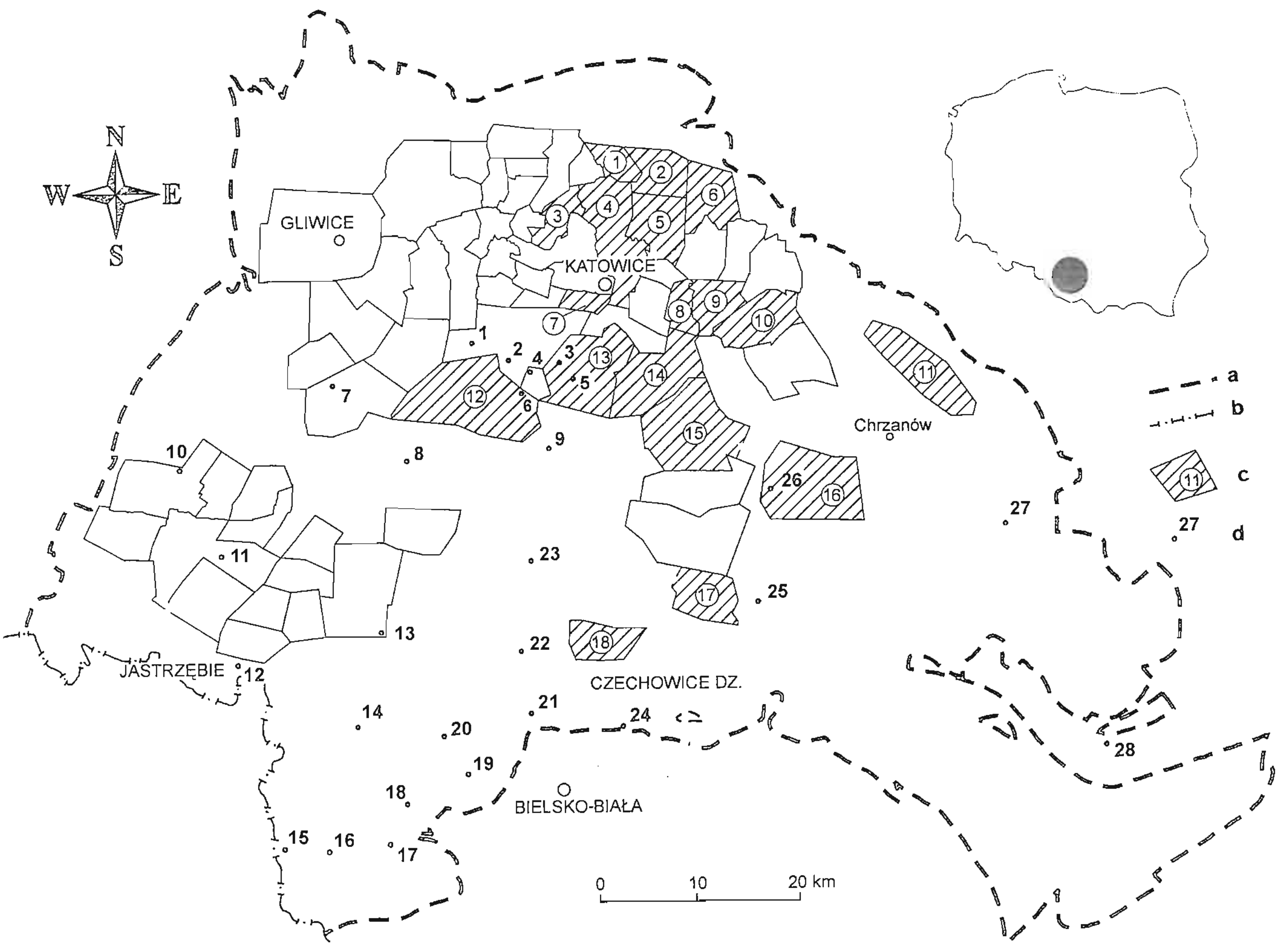

Fig. 1. Sampling locations of coal and coal shales in the Upper Silesian Coal Basin

a — boundary of the productive deposits (according to Z. Buła and A. Kotas, 1994); b — state border between Poland and Czech Republic; c — boundary of the mining areas sampled: 1 — Jowisz, 2 — Grodziec, 3 — Barbara-Chorzów, 4 — Siemianowice, 5 — Saturn, 6 — Paryż, 7 — Wujek, 8 — Mysłowice, 9 — Niwka-Modrzejów, 10 — Jan Kanty, 11 — Siersza, 12 — Bolesław Śmiały, 13 — Murcki, 14 — Wesoła, 15 — Ziemowit, 16 — Janina, 17 — Brzeszcze, 18 — Silesia; d — symbols of drill holes: **1** — Paniowy, **2** — Mikołów, **3** — Mikołów 9, **4** — Mikołów 5, **5** — Mikołów 10, **6** — Mikołów 8, **7** — Szczygłowice, **8** — Woszczyce, **9** — Wyry, **10** — Jejkowice, **11** — Niedobczyce, **12** — Rudzica, **13** — Studzionka, **14** — Drogomyśl, **15** — Cieszyn, **16** — Zamarski, **17** — Bielowicko, **18** — Dębowiec, **19** — Ruptawa, **20** — Chybie, **21** — Czechowice, **22** — Łąka, **23** — Piasek, **24** — Bestwina, **25** — Poręba Wielka, **26** — Chełmek, **27** — Poręba Żegoty, **28** — Leńcze

ation program of deep beds of the productive Carboniferous in the USCB. Continuing this subject, the authors attempted to find a relationship between variability of content of ash, Zn and Pb in the USCB and variability of coal bed thickness. These metals play an important role to assess coal usability for combustion and their chemical treatment with respect to ecological considerations. Based on the results of I. V. Riazanov, J. E. Judovich (1974, 1975) and V. Bouška, E. Stehlik (1980), the authors formulate a hypothesis that a decreasing content of ash, Zn and Pb in a coal of the USCB is associated with the increasing thickness of coal beds.

SUBJECT AND METHODS OF RESEARCH

Coals occurring in various (in terms of thickness) beds of the USCB were the subjects of this research. The investigations included 153 samples of coal sampled from beds (according to the Polish standard PN-81/G-04501) in the mining areas of 18 mines, and 1185 coal samples and 28 samples of coal shales collected from 28 drill holes. The drill holes were drilled by the Upper Silesian Branch of the Polish Geological Institute in 1975–1988 within research investigations of deep beds of the productive Carbonife-

Table 1

Statistical parameters of the ash, Zn and Pb contents in the studied coal

Coal	n	X_{arithm}	X_{geom}	X_{min}	X_{max}	Sx	$V = \frac{Sx}{X_{geom}} 100\%$
Ash content (%)							
USCB total	1338	13.47	11.46	1.48	37.94	7.93	59
limnic series	1069	13.77	11.86	1.85	37.40	7.97	58
paralic series	269	12.10	9.85	1.48	35.94	7.77	64
coal shales	28	49.81	49.40	40.94	69.07	7.54	15
Zn (ppm)							
USCB total	1338	67	46	2.4	1243	84.96	126
limnic series	1069	69	49	7.4	1243	88.71	128
paralic series	269	58	37	2.4	557	68.92	119
coal shales	28	163	115	54.5	1507	267.64	164
Pb (ppm)							
USCB total	1338	33	25	3.0	372	35.99	109
limnic series	1069	33	25	1.4	372	36.78	113
paralic series	269	35	25	3.0	239	32.65	94
coal shales	28	76	67	30.0	183	42.17	56

Explanations in the text

rous in the USCB (A. Kotas, 1974). Location of samples in the USCB is presented in Figure 1.

Ash content (500°C) and Zn and Pb content were determined in samples of coal and coal shales. Content of elements in 57 samples from coal beds were determined using the atomic absorption spectrometry (AAS). Analysis solutions were prepared by etching of coal ash with hydrogen fluoride and sulphuric acids (according to the Polish standard PN-77/G-04528/00). Concentrations of Zn and Pb in solutions were determined using an analytical curve technique, maintaining optimal conditions of atomisation and absorption measurements in spectrometer. These conditions and detailed results of the analysis were presented somewhere else (H. Parzentny, 1987). Detection limits using AAS for elements are 5 ppm for Zn and 7 ppm for Pb, respectively. In contrast, element contents in 96 coal samples from beds and 185 samples from drill holes were determined using X-ray fluorescence (XRF). Measurements of intensities of analytical lines Kα (Zn) and Lβ (Pb) in ash samples were conducted using X-ray spectrometer. Element concentration was determined through comparison to synthetic standards, prepared on the basis of coal ash. Detection limits of the determined elements using XRF are 2 ppm for Zn and 3 ppm for Pb, respectively. Specific results of analyses were presented in other reports (A. Różkowska, 1989; *Bank Danych*, 1995). The results of Zn and Pb concentrations in samples from drill holes in coals were earlier included to the result data base set ($n \cong$ 16 000), which was used to prepare the *Geochemical Atlas of the USCB Coal Deposits* (B. Ptak, A. Różkowska, 1995).

STATISTICAL ANALYSIS

Results of analyses were divided into subsets which represented beds of coal and coal shales < 0.3, 0.3–0.7, 0.7–1.5, 1.5–4 and 4–8 m thick. Coal beds were considered separately in the paralic and in the limnic series, and as a set representing the entire USCB area. Beds of coal shales, however, were analysed as a single set, representing the entire USCB area. This set is though smaller (n = 28) and additionally is not represented in thick beds (> 4 m).

In order to estimate an average ash content and average content of elements in such grouped beds of coal and beds of

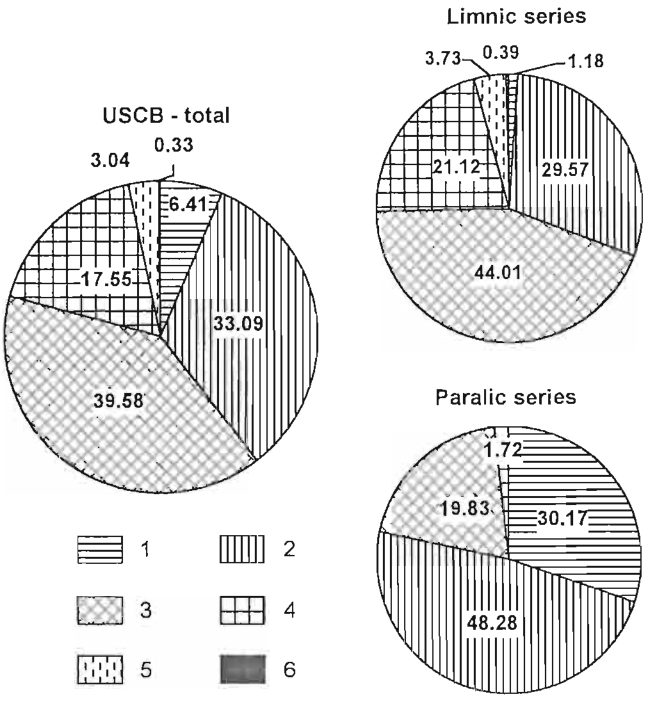

Fig. 2. Frequency of the occurrence of coal beds of different thickness in the Upper Silesian Coal Basin

Bed thickness (in metres): 1 — < 0.3, 2 — 0.3–0.7, 3 — 0.7–1.5, 4 — 1.5–4, 5 — 4–8, 6 — > 8

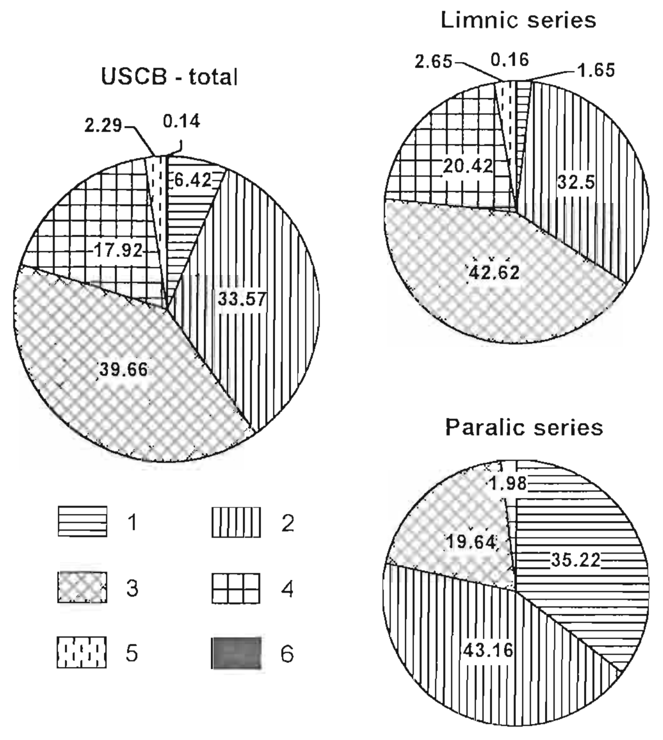

Fig. 3a. Content (%) of coal beds of various thickness and the average Zn content; 46 ppm for the USCB, 49 ppm for the limnic series and 37 ppm for the paralic series

Explanations as in Fig. 2

coal shales, "chi-square" Pearson test and Kolmogorov-Smirnov test were used to determine types of frequency distribution. The results indicate that ash content is characterised by normal frequency distribution and all frequencies are characterised by logarithmically normal distribution. Among the calculated mean values, geometric mean values (X_{geom}), in contrast to arithmetic mean values (X_{arithm}), were most similar to modal values, thus better representing the average value. Parameters statistically calculated for the considered sample subsets are included in Table 1. Statistical parameters such as minimum (X_{min}) and maximum (X_{max}) values, standard deviation (Sx) and variability coefficient (V) were also used in order to characterise variabilities of the ash content and of the occurrence of specific elements in the subsets.

A frequency (%) of the occurrence within the entire USCB and in the paralic and limnic series of coal beds of the thickness described above was determined. It is presented in a pie diagram (Fig. 2). A content (%) of coal beds of various thickness and of various average ash content and content of the considered elements was estimated in the entire USCB and its series. Therefore, weighted average and content of components in the weighted average relative to these groups of beds were determined. The results of computations are presented in pie diagrams (Fig. 3a–c).

Changes in the ash content and content of elements in coals and coal shales, representing the subsets of beds of the thickness range described earlier, were calculated basing on the geometric mean values (Fig. 4). Then, values of a correlation coefficient between their logarithms were calculated (Table 2), in order to investigate the following relationship:

— element content in coal to ash content in coal,
— element content in coal shale to their ash content,
— Zn to Pb contents.

DISCUSSION AND INTERPRETATION

There is a regularity expressed in the most often occurrence of thin coal beds 0.7–1.5 m (39.58%) and 0.3–0.7 m (33.09%) thick. Moreover, the beds of the first from the listed thickness intervals occur most often in the limnic series of the basin, however, beds 0.3–0.7 m thick form a predominant part of all beds in the paralic series (Fig. 2). A significant content of layers less than 0.3 m thick (6.41%), even larger in the paralic series (30.17%) is observed in the USCB. The occurrence frequency of beds in the USCB decreases with their increasing thickness. Thick beds (4–8 m and more than 8 m thick) are significantly less frequent (3.04 and 0.33%, respectively) than medium-thick beds 1.5 to 4 m (17.55%). Thick beds occur exclusively in the limnic series, however, medium-thick beds more often occur in the limnic series (21.12%), than in the paralic part of the basin (1.72%). In contrast, interbeds of coal of thickness below 0.3 m and thin beds 0.3–0.7 m thick, which constitute as much as 39.5% of coal beds in the studied basin, are not included in estimated reserves of the basin. Similar conclusions were presented earlier by E. Konstanty-

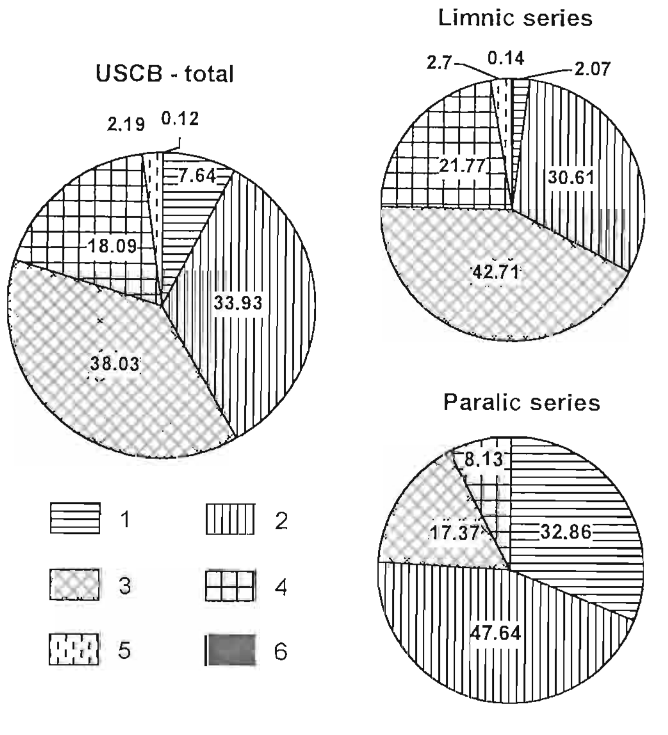

Fig. 3b. Content (%) of coal beds of various thickness and the average Pb content; 25 ppm for the Upper Silesian Coal Basin, the limnic and the paralic series

Explanations as in Fig. 2

nowicz (1994). Beds more than 4 m thick form only 14% of the reserves currently used in the USCB, though medium-thick beds form as much as 40% (E. Konstantynowicz, 1994). The predominant part, forming as much as 46% of the used reserves, consists of thin beds of thickness not exceeding 1.5 m. The presented frequency distribution of the occurrence of coal interbeds and thin, medium-thick and thick beds in the USCB results from a non-uniform development of the productive series in the basin. Specific bed series reach a maximum thickness in the western part of the USCB, however, they are significantly reduced toward the south and the north-east (K. Bojkowski, 1978; R. Szymoniak *et al.*, 1984). The eastern and southern parts of the sedimentary basin were a descending plate, thus more stable part of the basin, in comparison to the western and central parts, strongly mobile miogeosyncline type (Z. Dembowski, 1972). Some rock sequences and coal beds occur exclusively in the western part. Analysis of the occurrence of coals in the USCB indicates that a number of beds and their total thickness in the western part are greater, however, these beds are not so thick in the western than in the eastern part of the basin (H. Parzentny, 1987; A. Różkowska, 1989; *Bank Danych*, 1995). Thick beds predominantly occur in the Śaddle (501, 510) and Łaziska (208, 209) Beds. Thin beds predominate though in the paralic series and in the mudstone series of the basin. The results of analyses presented, confirm earlier observations of many authors, expressed by Z. Dembowski (1972) and E. Konstantynowicz (1994). Thin beds in other geosynclinal coal basins are the most frequent ones. In the Donieck Coal Basin about 200, out of about 300 identified beds and interbeds of coal, are below 0.45 m thick and are classified to reserves not included in the reserve balance. Also a predominant part of the coal beds are less than 0.7 m thick in the Ishikara-Jubar Coal Basin and the Ruhr Coal Basin.

46 ppm of Zn and 25 ppm of Pb were determined in the studied coal of the USCB (Table 1). These values are similar to average values determined by B. Ptak and A. Różkowska (1995) for the entire USCB (45 and 18 ppm, respectively). They were determined on the basis of the results of the largest set of coal samples studied up to the present time (n = 15 981) in the USCB. Zn concentration determined in the studied coal,

Table 2

Correlation coefficient of ash content logarithms (A), and Zn and Pb content in coal of the Upper Silesian Coal Basin

Variable	A	Pb
Zn in:		
coal of USCB total	0.96	0.96
coal of limnic series	0.91	0.97
coal of paralic series	0.86	0.92
coal shales	–0.18	0.24
Pb in:		
coal of USCB total	0.87	–
coal of limnic series	0.86	–
coal of paralic series	0.91	–
coal shales	0.74	–

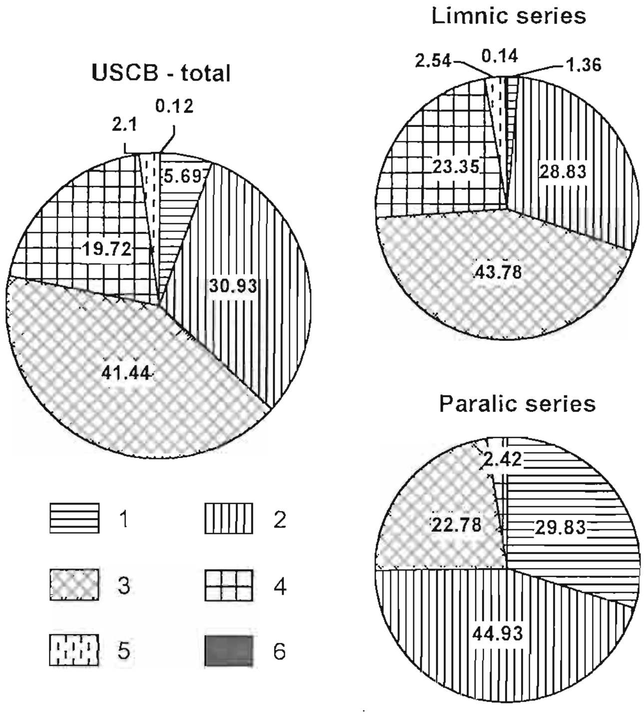

Fig. 3c. Content (%) of coal beds of various thickness and the average ash content; 11.46% for the Upper Silesian Coal Basin, 11.86% for the limnic series and 9.85% for the paralic series

Explanations as in Fig. 2

similarly to the average value for the entire USCB, are higher, and Pb concentrations are identical in comparison to Zn and Pb content in coals in the world basins (Zn = 224ppm, Pb = 253 ppm), as determined by J. E. Judovich *et al.* (1985). Statistical parameters characterising variability of the occurrence of Zn and Pb in the studied coals reach, however, lower values than these calculated by B. Ptak and A. Różkowska (1995). Mean values of the ash content determined in this work (11.46%) occur within a range of the ash content in the USCB (9.47–17.91%) presented by W. Gabzdyl (1987). They are also similar to a mean value determined by E. Konstantynowicz (1994). Larger ash content (49.4%), Zn (115 ppm) and Pb (67 ppm) concentrations than in coal were determined in the studied coal shales. Thereby, it confirmed a tendency, presented several times before, for a higher content of heavy metals in the coal shales (similarly to bituminous shales) to compare with black coals (E. Cook, 1973; R. M. Coveney, 1979; H. S. Pandalai *et al.*, 1983; J. E. Judovich *et al.*, 1988).

Analysing different coal beds with respect to their thickness, the average ash content, and average Zn and Pb contents in coals of the USCB, a large significance of thin beds 0.7–1.5 and 0.3–0.7 m thick, respectively, was observed (Fig. 3). Coals from the first listed thickness range, influenced significantly the average ash content and average element concentrations in the entire limnic series. Though beds 0.3–0.7 m, and also interbeds of coal below 0.3 m thick decide about the

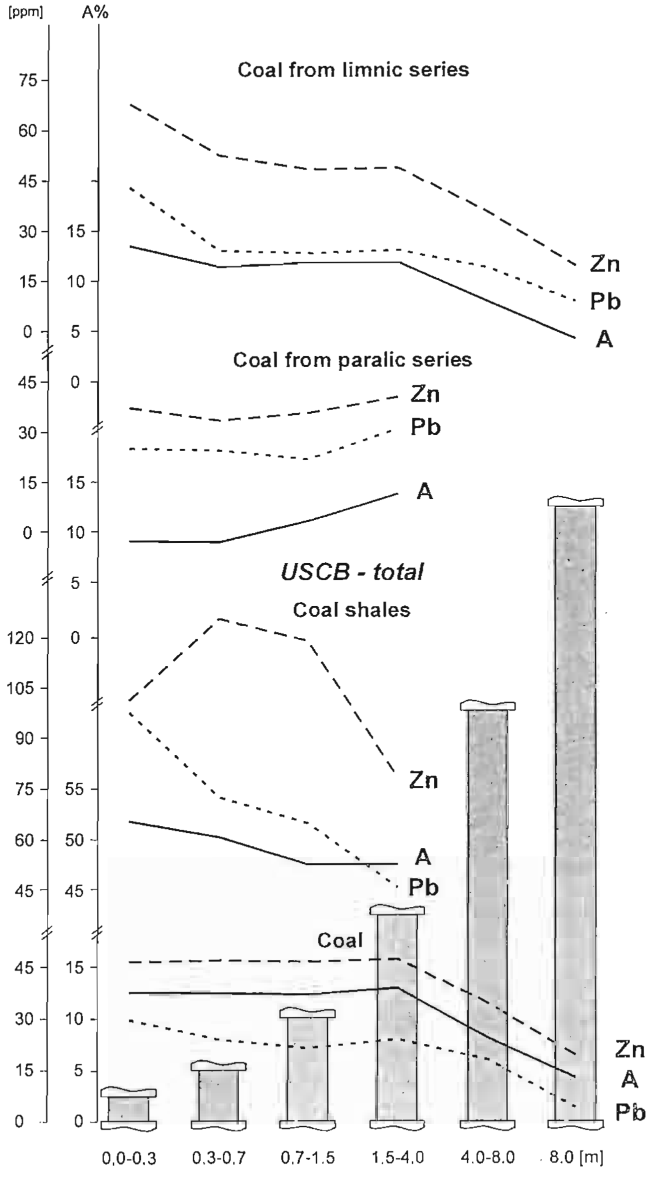

Fig. 4. Zn and Pb content (ppm) in differentiated coal beds and coal shale beds with respect to thickness from the limnic and the paralic series of the Upper Silesian Coal Basin

average values in the paralic series. Thus in the studied coal, beds of the most frequently occurring thickness in the USCB have the largest effect on the average ash, Zn and Pb contents.

Characteristic relationship between the ash content of coal and coal shales and their Zn and Pb contents, and a bed thickness were observed (Fig. 4). The ash content and Zn and Pb contents decrease with the increasing coal thickness in the USCB. A different character of this relationship was noted in the limnic series and in the paralic series, respectively. The ash content and the content of Zn and Pb slightly increase in the paralic series with increasing bed thickness (up to 4 m — coal beds of a thickness above 4 m do not occur in the paralic series, thus their ash content and content of elements was not provided). On the contrary though in the limnic series, the parameters determined decrease with increasing thickness from beds less than 0.3 m thick to beds of a thickness exceeding 8 m. The ash content and Pb content in coal shales also decreases with the increasing bed thickness. The Zn content though in the coal shales has parabolic distribution, with its maximum in the thickness interval 0.3–0.7 m. The relationships described above indicate differentiated degree of the enrichment of beds of coal and coal shales in heavy metals and ash-forming substances along the vertical profile in the USCB. Inclusions of both carbonised and not carbonised organic matter often interbedded by mudstone streaks in sedimentary rocks, adsorb intensively trace elements, provided by permeation of aqueous solutions. A few-millimetre thick bed of coal enriched in elements, with higher content of Zn and Pb to compare with coal from the central part of the bed as concentration of elements in the solution increases, forms then at the contact of the bed with the surrounding rocks. The resulting difference between concentrations at the surface of the bed and its central part causes diffusion of trace elements toward the centre of the bed. Near-surface beds of the thicker coal beds (10–20 cm) become enriched in these elements, however thin beds are enriched in their entire thickness. I. V. Riazanov, J. E. Judovich (1974) and V. Bouška, E. Stehlik (1980) earlier proposed this type of enrichment of the coal beds in trace elements and ash-forming substances. Higher concentrations of these elements in the marginal parts of the beds were determined up to the present time in several black and brown coal basins in the world (H. J. Gluskoter *et al.*, 1977; J. E. Judovich, 1978; V. Bouška, 1981; D. Birk, 1989). High concentrations of trace elements were also found in the near-top and near-bottom parts of coal beds in the USCB (A. Idzikowski, 1959; J. Winnicki, 1964; S. Cebulak, 1983; H. Parzentny, 1995). Apparently most of the studied thin coal beds, particularly beds in the limnic series, are enriched in Zn and Pb in their entire thickness. Coal interbeds, similarly to isolated inclusions of organic matter (tree trunks, branches) may have particularly high content of these elements. Sorption intensity in such forms of accumulation of organic matter is though few times greater than in thick beds (A. Gaweł, 1962; M. Inagaki, 1969; I. V. Riazanov, J. E. Judovich, 1975). In contrast, coal beds in the paralic series might have been penetrated by aqueous solutions of different chemistry to compare with water in the limnic series. It could lead to extraction of elements from the carbonised organic matter. This process occurred first in thin beds.

Analysis of variability of the ash content and content of Zn and Pb in the differentiated, with respect to thickness, beds of coal and coal shales additionally revealed the existence of significant similarities between the curves representing these changes (Fig. 4). They are represented by typically high correlation coefficients (Table 2). A strong correlation is observed between content of Zn and Pb and the ash content in coals of the USCB for both the entire basin and if divided into the limnic and the paralic series. A significant correlation is also observed between the Pb content in the studied coal shales and their ash content, and between determined elements coexisting in coals. This correlation indicates a significant effect of inorganic mineral substances on the average content of these elements in the studied coals and coal shales. A similar effect was earlier described for various coal beds in the world (H. J. Gluskoter, 1975; V. Bouška, 1981; J. E. Judovich *et al.*, 1985). Zn and Pb are typically associated with inorganic substances also in coals from various coal deposits in Poland (M. Marczak, H. Parzentny, 1985; H. Parzentny, 1990, 1994, 1995). These elements occur often together in coals, included in sulphide minerals of the syn- and epigenetic origin, dispersed in the marginal parts of the coal beds (D. Birk, 1989). Though low and negative values of correlation coefficients indicate lack of any correlation between Zn content in the studied coal shales and their ash content (Table 2) and between both elements considered in these shales. Zn is probably associated with an organic substance in coal shales but Pb with an inorganic part.

CONCLUSIONS

Studied coals are characterised by the ash content and content of Zn and Pb similar to the average values determined by B. Ptak and A. Różkowska (1995) for the entire Upper Silesian Coal Basin and to the average value characteristic for coals from different coal deposits in the world. Coals in the USCB differ with respect to the ash content and content of Zn and Pb. Higher, compared to coals, ash content and content of heavy metals is observed in coal shales of the USCB. These shales are also characterised by a large variability of the ash content and content of Zn and Pb.

The average ash content of coal in the USCB and content of Zn and Pb are associated with thin beds, most frequently occurring in the basin, and 0.7–1.5 m (particularly in the limnic series) and less than 0.7 m (particularly in the paralic series) thick.

The highest ash content and content of elements considered are observed in thin coal beds below 0.3 m (particularly in the limnic series) and in thin beds of coal shales 0.3–0.7 m thick. The ash content and concentrations of the determined elements decrease with increasing thickness of beds. Sorption of elements and the increasing content of inorganic matter occur from the top and bottom parts of a bed. Thin beds have relatively larger thickness of the enriched portions of coals and coal shales as compared to thick beds.

There is a correlation between content of Zn and Pb in coal and its ash content, indicating a significant effect of inorganic mineral matter in controlling concentrations of these elements in coal beds in the USCB.

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ZWIĄZEK MIĘDZY MIĄŻSZOŚCIĄ POKŁADÓW A PRZECIĘTNYM ZAPOPIELENIEM I ZAWARTOŚCIĄ CYNKU I OŁOWIU W WĘGLACH GÓRNOŚLĄSKIEGO ZAGŁĘBIA WĘGLOWEGO

Streszczenie

Badaniami objęto 153 próbki pokładowe węgli, 1185 próbek wiertniczych węgli i 28 próbek łupków węglowych, pobranych z obszaru Górnośląskiego Zagłębia Węglowego (fig. 1). W próbkach oznaczono zapopielenie (500°C) oraz zawartości cynku i ołowiu metodami AAS i XRF. Węgle i łupki węglowe scharakteryzowano z uwzględnieniem podziału pokładów na podzbiory o grubości: < 0,3, 0,3–0,7, 0,7–1,5, 1,5–4, 4–8 i > 8 m.

Ustalono, że w serii paralicznej GZW najczęściej występują pokłady o grubości 0,3–0,7 m (48,28%) i < 0,3 m (30,17%), natomiast w serii limnicznej pokłady o grubości 0,7–1,5 m (44,01%) i 0,3–0,7 m (29,57%). Pokłady grube (> 4 m) zalegają tylko w serii limnicznej zagłębia (fig. 2). Zapopielenie (11,46%) oraz zawartości w węglach cynku (46 ppm) i ołowiu (25 ppm) są zbliżone (tab. 1) do wartości przeciętnych, określonych dla węgli GZW (przez B. Ptak i A. Różkowską, 1995) i dla węgli kamiennych złóż świata (przez J. E. Judowicza i in., 1985). Przeciętne zapopielenie i zawartości oznaczonych metali odzwierciedlają głównie ich zawartości w najczęstszych w Zagłębiu cienkich pokładach (< 0,7 m — w serii paralicznej, 0,7–1,5 m w serii limnicznej; fig. 3). Odnotowano ponadto zależność między zapopieleniem węgli, łupków węglowych oraz zawartości w nich cynku i ołowiu a grubością pokładów (fig. 4). W serii paralicznej zapopielenie węgli oraz zawartości w nich cynku i ołowiu nieznacznie zwiększają się w miarę zwiększania się grubości pokładów. Natomiast w serii limmicznej jest odwrotnie, zapopielenie i zawartości metali zmniejszają się, idąc od wkładek o grubości < 0,3 m do pokładów o grubości > 8 m. W tym samym kierunku zmniejsza się zapopielenie i zawartość ołowiu w łupkach węglowych. Z kolei zawartości w nich cynku mają rozkad paraboliczny, z maksimum w przedziale grubości pokładów 0,3–0,7 m. Stwierdzono także silną korelację dodatnią między zawartością cynku w węglach oraz zawartością ołowiu w łupkach

węglowych a zapopieleniem (tab. 2). Brak zależności odnotowano między zawartością cynku w łupkach węglowych a ich zapopieleniem.

Stwierdzone prawidłowości empiryczne wskazują na wpływ dyfuzyjno-sorpcyjnych procesów wzbogacania pokładów węgli i łupków węglowych na kontakcie ze skałami otaczającymi w pierwiastki śladowe i substancje popiołotwórcze. W rezultacie tych procesów węgle i łupki węglowe w przystropowych i przyspągowych częściach pokładów grubych oraz pokłady cienkie w całej objętości mają większe zapopielenie i zawartości pierwiastków niż środkowe części pokładów grubych.

Przeważająca część cynku i ołowiu występuje w materii nieorganicznej węgli. Z kolei w łupkach węglowych cynk jest pochodzenia organicznego, a ołów nieorganicznego. Infiltracja wód w serii paralicznej prawdopodobnie wywołała wymywanie pierwiastków śladowych i substancji popiołotwórczych z węgli — z większym nasileniem w pokładach cienkich niż grubych.