of PGE in coal ash were determined by the fire assay ICP-MS method. With the exception of samples from the Czech part of the Upper Silesian Basin (CPUSB), the analytical methods used to obtain the assays of most of the old samples were not specified. Kessler et al. (1965) only published the results of quantitative optical emission spectrochemical analyses (OES) of coal ash, whereas Dopita et al. (1997) used AAS, ICP, XRF or exceptionally even OES methods for analyses of coal ashes.

Results of previous analyses can be significantly influenced by the temperature of ashing. According to Ketris and Yudovich (2008) it is well known that some elements may be almost fully (Br, Hg, I) or partly (Ge, Mo etc.) volatilized by high-temperature ashing. Trace elements loss may be minimized only by low-temperature ashing (~ 130–150 °C).

Only quantitative analyses of old samples were incorporated in the database. However, problems arose when the numbers of samples analyzed were not specified. When such older samples were collected in adits or boreholes, the standard procedure was to subdivide a coal seam in 20 cm sections (i.e., a coal seam one meter thick was counted as 5 samples). The database incorporates the chemical and technological parameters of coal from the majority of the basins. As far as the distribution patterns of elements in continental basins is concerned, due to the known lateral variability of coal seams and also because the number of analyses was mostly small, the values obtained may not be statistically representative. Nevertheless, it is necessary to make the best use of the existing data so that we can learn as much as possible about coal deposits that are presently being mined and about resources now abandoned or exhausted.

4. Results and discussions

4.1. CZECH PART OF THE UPPER SILESIAN BASIN

The Czech part of the Upper Silesian Basin is filled by the paralic Ostrava Formation (Lower Namurian, i.e. Upper Mississippian) and the continental Karviná Formation (Middle Namurian to Langsettian, i.e. Lower Pennsylvanian). The clastic and volcaniclastic deposits in the basin were folded during the Variscan orogeny and also partly affected by Alpine orogenic processes. Altogether there are 86 coal seams with an average thickness of 83 cm that have been locally mined in the Ostrava Formation, whereas the Karviná Formation contains 55 coal seams of an average thickness of 176 cm.

RESULTS OF EARLIER STUDIES

Coal seams and their quality

Coking and steam coal is extracted in the CPUSB. Medium to low volatile coals of the Ostrava Formation with reflectance values R_o of 0.75–2.00 % but even anthracites with reflectance exceeding 2.00 % R_o were mined in the past from the western part of the basin. The rank of coal decreases eastward and southward. The average technological parameters of the local coal are as follows: volatile matter (V^{daf}) 3–38 %, moisture (W_t^r) 0.6–4.0 %, ash (A^d) 1–40 %, calorific value (Q_s^{daf}) 20.0–36.9 $MJ.kg^{-1}$ (Buchtele et al. 1995, Dopita et al. 1997, Sivek et al. 2005, Sivek et al. 2008). Bright banded coal and banded coal consisting of vitrite, clarite and trimacerite with a high proportion of vitrinite (50–95 vol. %), liptinite (0–35 vol. %) and inertinite (3–65 vol. %) prevail in coal seams of the Ostrava Formation, while the basal unit of the Karviná Formation – the Saddle Member – consists mostly of dull coal and dull banded coal characterized by an enhanced content of inertinite (10–83 vol. %), with variable amounts of vitrinite (3–90 vol. %) and liptinite (0–38 vol. %) (Fig. 3A). The proportion of banded and bright coal with a dominant proportion of vitrinite (45–90 vol. %), and a variable content of inertinite (7–65 vol. %) and liptinite (1–20 vol. %) increases upward to the hanging wall. This type of coal prevails in the upper part of the Karviná Formation (Buchtele et al. 1995, Dopita et al. 1997, Sivek et al. 2005). Clay minerals (Fig. 3B), quartz and carbonates (Figs 3C and D) are the most abundant inorganic components, whereas iron sulfides (Fig. 3E) are minor and iron oxides (Fig. 3F) are rare (Dopita et al. 1997). Generally, sulfur content in coal from the Czech part of the Upper Silesian Basin is lower than 1% S_t^d and recently extracted coals contain sulfur between 0.6 and 0.8 %. The higher sulfur contents up to 3.3 % in the Table 3 or up to 2.23 % S_t^d (Dopita et al. 1997) and some other elements (cf. Swaine 1990) are typical for thin coal seams below marine horizons (Bouška 1981). For the pyrite concretions are typical higher sulfur contents. The sulfur content in new samples studied from the Petřkovice, Hrušov and Suchá members varies from 0.49 % up to 1.96 % S_t^d in the Hrušov coal seams. Organic sulfur is prevailing form in most samples. Crystals and framboids and their clusters filling microfractures and microcavities are rare in majority of coal seams and dominate in sample from the Hrušov Member.

Numbers of studied samples

The comprehensive studies by Kessler et al. (1965) and Dopita et al. (1997), together with reports on calculated coal reserves and the results of nine new analyses of samples recently collected from several mines in this part of the basin, were used when compiling the database of coal ashes from the CPUSB. Because the database includes analyses by different methods of samples collected from various localities over a period of ca. 40 years, a wide range of concentrations of the elements under investigation is recorded. While Kessler et al. (1965) analyzed hundreds of samples from all units of the Ostrava and Karviná formations, Dopita et al. (1997) analyzed only from 1 to 37 samples from all the members of these formations, with the exception of uppermost unit – the Doubrava Member of the Karviná Formation. Authors of recent study analyzed one sample of coal ash from the Petřkovice and Hrušov basal members of the Ostrava Formation and seven samples from the Suchá Member of the Karviná Formation.

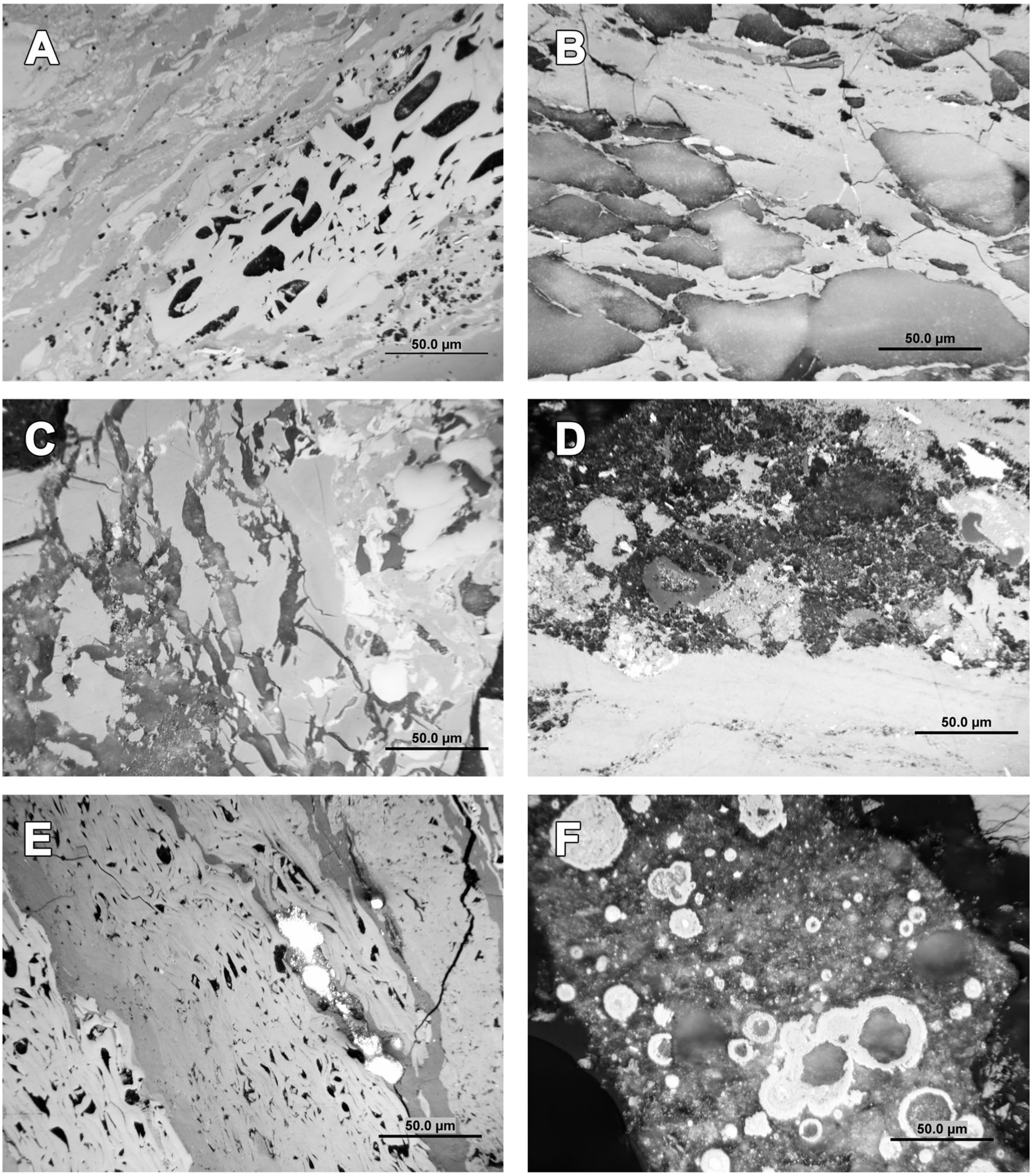


Fig. 3. Microphotographs of minerals in coal from the Czech part of the Upper Silesian Basin (Formations: 3A – E Karviná, 3F Ostrava). A – fusinite filled with fine grained black clay minerals dispersed in inertinite and vitrinite macerals of vitrinertite and trimacerite in coal from the Saddle Member, B – quartz grains in vitrinite with admixture of sporinite, macrinite and inertodetrinite in coal from the Suchá Member, C – calcite fillings of fissures in vitrinite in coal from the Suchá Member, D – sideritised detrite with sporinite and vitrinite and inertinite fragments in coal from the Hrušov Member, E – framboidal pyrite in vitrinite layer between semifusinite in coal from the Suchá Member; F – iron oxide-hydroxide in minerite from the Petřkovice Member. *Photos by I. Sýkorová.*

CHEMICAL AND TECHNOLOGICAL ANALYSES, CONTENTS OF SULFUR AND TRACE ELEMENTS

As shown by the study by Kessler et al. (1965), only small variations in the contents of individual elements were found in single members of coal formations (Tables 1 and 2). Higher contents were found in a part of samples when compared with the mean values given by Swaine (1990). The elements concerned are As, Ba, Be, Cr, Cu, Li, Pb and U in the Petřkovice Member, then As, B, Ba, Be, Cr, Cu and Pb

Table 1. Comparison of mean contents of trace elements (ppm) in coal ashes of the Petřkovice and Hrušov members, Ostrava Formation (Lower Namurian) in the Czech part of the Upper Silesian Basin according to studies by Kessler et al. (1965) – KES, Dopita et al. (1997) – DOP and newly analyzed samples – USGS

	USGS	KES	DOP	USGS	KES	KES	DOP
	Petřkovice Member			Hrušov Member	Lower Hrušov Member	Upper Hrušov Member	Hrušov Member
V ppm	447	235	13	65.3	257	268	19.2
Cr ppm	126	247	11.9	20.3	262	233	11.7
Mn ppm	1540	1470		3470	1085	543	
Co ppm	83.6	66	< 0.2	14.5	53	63	< 9.6
Ni ppm	154	166		63.9	128	116	16.7
Cu ppm	347	282	35.5	51.2	280	190	38.3
Zn ppm	63.8	162	21.6	74.9	201	55	16.9
Ba ppm	955	2800	40	742	2286	2090	97.4
Rb ppm	87.9	99	< 0.2	4.1	127	214	
Cs ppm	22.6	30		1.4	36	57	
Sr ppm	2980		98.7	781			152.8
Be ppm	30.2	38	1.61	3.5	42	57	1.52
Li ppm	237	200	1201.7	73.9	160	90	163.7
Ga ppm	32.5		2.7	4.5			2.7
Ge ppm	27.9	13	1.5	2.7	10	8	1.4
Nb ppm	22.3			1.5			
Sc ppm	50.5			< 4			
Sn ppm	60.5	5		4.1	5	4	
Y ppm	116			28.3			
U ppm	44			8.8			
Zr ppm	28.2		11.7	332			8.1
As ppm	8.2	137	< 1.08	7.9	244	132	0.99
Sb ppm	20.8			3.6			< 0.18
Hg ppm	0.06		0.029	0.03			0.051
Ag ppm	< 2	6		2.2	4	3	
Cd ppm	1.2		1.19	0.36			< 2.37
Mo ppm	16.2	14	0.93	5	12	15	1.43
Pb ppm	126	155	28	28.5	191	132	25.2
Se ppm	1		< 0.2	0.76			< 0.37
Te ppm	0.85			0.36			
Tl ppm	4.5			0.97			
S_t^d %	0.594			2.45			
A^d %	7.89			13.3			
B ppm	< 20	267		< 20	341	240	
Cl %	0.033			0.046			

in the Hrušov Member, and B, Ba, Be, Co, Cr, Cu, Li, Pb, U and Zr in the Suchá Member. In comparison with coal seams of the Karviná Formation (Table 4), coal seams of the Ostrava Formation as a whole (Table 3) show slightly higher concentrations of As, Ba, Be, Cd, Cl, Cs, Cu, Ga, Ge, Nb, Sr, W, Y, Zn and Zr. On the other hand, the Karviná Formation revealed slightly higher contents of Al, Fe, Hg, Mn, Th and Ti.

Numerous elements in the coal ash from the Poruba Member (the uppermost unit of the paralic Ostrava Formation) and from the Saddle Member (basal unit of the continental Karviná Formation) have similar contents, which reflect the gradual retreat of the paralic environment from the Ostrava Formation upward into the hanging wall (Pešek et al. 2005).

Basic differences. From the comparison of results from all three sources (Kessler et al. 1965, Dopita et al. 1997, and our new analyses) it is evident that due to different analytical

Table 2. Comparison of mean contents of trace elements (ppm) in coal ashes of the Suchá Member, Karviná Formation (Middle Namurian) in the Czech part of the Upper Silesian Basin according to studies by KESSLER et al. (1965) – KES, DOPITA et al. (1997) – DOP and newly analyzed samples – USGS

	USGS								KES	KES	DOP
	Suchá Member								Lower Suchá Mb.	Upper Suchá Mb.	Suchá Mb.
V ppm	347	15.1	746	124	281	219	610	281	349	362	35
Cr ppm	113	13.1	202	59.4	117	110	287	113	405	449	25
Mn ppm	56	3180	539	998	814	585	892	814	754	483	
Co ppm	45.7	10.6	55.7	38.7	42	21.6	37.5	38.7	110	134	10
Ni ppm	198	64.4	206	344	152	108	69.1	152	250	133	15
Cu ppm	220	52.8	653	253	227	180	830	227	230	170	20
Zn ppm	58.6	51.4	75.4	86.5	80.2	33.5	< 4	67	226	268	15
Ba ppm	541	537	2250	6170	1270	457	742	742	1820	2540	200
Rb ppm	218	5.7	135	12.6	94	13.2	214	94	5	5	
Cs ppm	38.4	1.1	19	4.5	17	2.5	24.7	17	30	29	
Sr ppm	238	472	1360	3760	1370	1240	358	1240			
Be ppm	14.2	< 1	16.2	10.4	9.4	14.5	8.4	12.3	31	32	2
Li ppm	382	48	316	173	207	410	160	207	121	145	10
Ga ppm	56.9	1.5	42.7	34.5	40.7	30.5	60.6	40.7			
Ge ppm	8.8	1.8	11	4.7	2.2	3.1	8.5	4.7	5	5	
Nb ppm	16.5	1	2.8	17.3	12.1	10.8	24.6	12.1			
Sc ppm	47.4	< 4	66.5	22.5	31.1	40.3	56.2	43.85			
Sn ppm	33.4	11.9	6.5	23	16.8	17.3	32.5	17.3	5	5	
Y ppm	55.6	13.1	125	56.3	70.3	75.6	69.8	69.8			
U ppm	34.5	1.1	34.7	23.5	19.4	20.7	39.9	23.5			
Zr ppm	305	17.9	155	826	127	264	332	264			
As ppm	28.3	13.6	21.2	20.2	5.8	6.2	7.9	13.6	91	26	
Sb ppm	9.3	1.1	6.1	7.8	9.3	3.9	26.1	7.8			
Hg ppm	0.08	0.02	0.06	0.04	0.05	0.08	0.08	0.06			
Ag ppm	2.1	< 2	< 2	< 2	< 2	< 2	2.2	2.15	4	5	
Cd ppm	0.26	0.15	1.5	0.21	0.5	0.5	0.18	0.26			
Mo ppm	9.1	19.5	38.6	12	19.1	4.5	10.6	12	29	332	2
Pb ppm	174	40.7	196	222	145	135	187	174	168	145	15
Se ppm	1.2	0.38	0.84	0.54	1	1.1	3.4	1			
Te ppm	0.59	0.22	1.2	0.72	0.54	0.57	1.9	0.59			
Tl ppm	2.6	0.5	3.4	4.8	2.6	0.53	3.4	2.6			
S_t^d %	0.705	0.902	0.593	0.508	0.466	0.424	0.826	0.593			
A^d %	22.1	8.9	5.79	2.81	8.78	9.98	14.9	8.9			
B ppm	< 20	< 20	< 20	140	< 20	< 20	< 20	140	870	1316	
Cl %	0.049	0.075	0.066	0.68	0.061	0.056	0.054	0.061			

methods and variation in sampling sites, the analytical results differ significantly. However, apart from these facts, similar trends in the pattern of distribution of the majority of elements can be seen (Tables 1 and 2) even though there are differences in the absolute values. Mean values given by DOPITA et al. (1997) for all the studied elements are in general one order lower but for Ba, Co, Mo and Sr can be as much as two orders lower. Relative to our analyses, only Li concentrations in the Petřkovice and Hrušov members and the Cd content in the Hrušov Member were found to be one order higher than values given by KESSLER et al. (1965).

It is evident from Figs 4–7, which include all available analyses from the CPUSB, that definite patterns of distribution and/or correlation between the following elements exist: Arsenic contents in the coal seams of the Ostrava Formation exceed or even strongly exceed those in the Lower Suchá Member and in the Saddle Member in particular

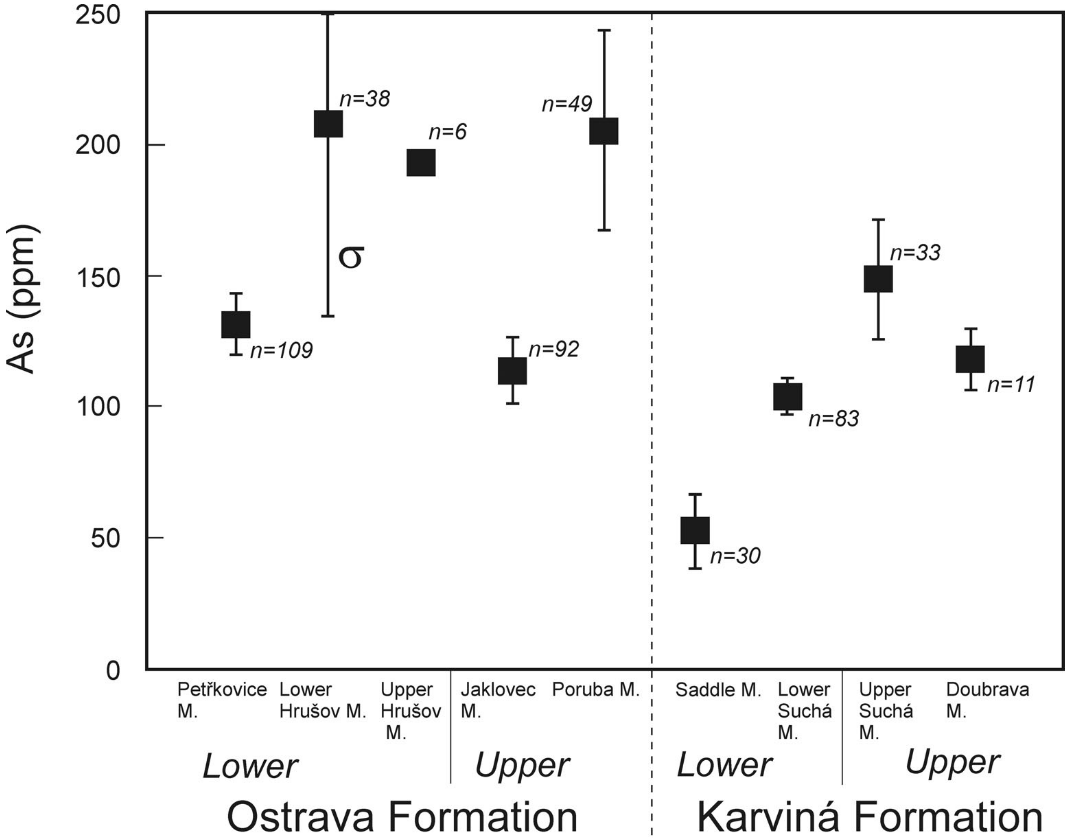


Fig. 4. Contents and distribution of arsenic in members of the Ostrava and Karviná formations of the Czech part of the Upper Silesian Basin (Lower Namurian to Langsettian). Full line – range of established values in Figs 4, 5, 6 and 7.

(Fig. 4). Concentrations of Ge are, with the exception of the Saddle Member, always lower or markedly lower than those of Be (Fig. 5). The proportion of Pb and Zn is often higher in sub-units of the Karviná Formation than in the sub-units of the Ostrava Formation. Such a correlation exists only in the Petřkovice and Poruba members of the Ostrava Formation but contents of these elements do not differ substantially (Fig. 6). It is necessary point out that both elements are mobile in diagenetic and katagenetic processes. Similar contents of Cr and Cl were found in all the studied units of both formations but Cr is always slightly less abundant than Cl (Fig. 7).

Comparison of the results of analyses of coal ashes with the average values given by Ketris and Yudovich (2008). The contents of the great majority of elements determined in coal ashes are considerably lower or only slightly higher than the average element concentrations in coal ash published by Ketris and Yudovich (2009). Only the mean values for Ag, Cs, La, Li, Pb, and Sr are on an average about by one order higher in coal ash from the Ostrava and Karviná formations and for As and W from the Ostrava Formation only.

4.2. CZECH PART OF THE INTRA-SUDETIC BASIN

The Czech part of the CPISB, like all other Upper Paleozoic basins, is filled exclusively by continental clastic and volcaniclastic deposits, mostly sub-horizontally bedded. Sedimentation in this part of the basin began in the Upper Viséan and continued with some hiatuses until the Triassic (Fig. 2). Of the ca. 85 coal seams of average thickness 1.3 m (max. 3.2 m) about one half of them has been mined. The great majority of coal seams (more than 60) are confined to the basal unit – the Žacléř Formation (Upper Namurian to Bolsovian). A few coal seams of this formation will be extracted from open cast mines at near future (several tens of tons a year).

RESULTS OF EARLIER STUDIES

Coal seams and their quality

Dull banded coals prevail in the coal seams of the CPISB but coals or dull banded coals with clayey admixture are also abundant, whereas bright banded coals and dull coals are less abundant. In general, they belong to the category of high volatile bituminous coals with V^{daf} 27–44 % and vitrinite reflectance (R_o) 0.8–1.2 % (Pešek et al. 2001). The major maceral constituent is vitrinite (43–82 vol. %), while liptinite (5–27 vol. %) and inertinite (8–35 vol. %) are less abundant.

These coals are characterized by variable mineralogical composition. Clay minerals (kaolinite, illite) are common as well as sulfides (pyrite/marcasite, chalcopyrite, bornite, sphalerite, galena), carbonates (calcite) and quartz. Less common are sulfates, feldspars and other minerals.

Table 3. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Ostrava Formation in Czech part of the Upper Silesian Basin (Lower Namurian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	2	0.6		0.6				0.6
C^{daf} %	68	85.6	3.48	77.1	82.3	86.3	88.6	91.0
H^{daf} %	68	5.2	0.44	3.7	4.9	5.3	5.4	6.0
N^{daf} %	68	1.4	0.47	0.34	1.3	1.6	1.7	2.0
O^{daf} %	64	6.8	3.08	2.3	4.7	5.9	9.6	15.7
V^{daf} %	473	26.3	9.45	4.09	17.8	26.3	34.9	47.2
R_o %	16	1.2	0.22	0.82	1.0	1.2	1.2	1.6
S_t^d %	152	0.9	0.437	0.19	0.650	0.840	1.093	3.3
A^d %	575	13.2	8.16	2.75	7.5	10.6	17.0	49.7
Ag ppm	218	5.7	5.44	2	3.0	3.0	5.0	30
Al ppm	4	9340		1830				18600
As ppm	397	158	240.9	1.2	100	100	100	2830
B ppm	400	352	390.6	50	200	300	400	5000
Ba ppm	473	239	738.4	0.2	2	3	5	7950
Be ppm	405	50.3	76.23	0.5	20.0	30.0	60.0	1340
Bi ppm	2	1.5		0.8				2.2
Br ppm	5	4.4		3				8
Cd ppm	6	2.6		0.4				8
Cl ppm	17	1560	924	330	850	1650	1900	3750
Co ppm	411	117	335.1	3	30	60	100	5300
Cr ppm	415	301	429.6	3	100	200	300	4970
Cs ppm	174	47.2	30.76	1.4	30.0	40.0	55.0	300
Cu ppm	468	347	745.3	10	200	250	300	12800
F ppm	4	145		10				300
Fe ppm	4	8200		3190				19700
Ga ppm	70	52.6	33.31	1.7	32.0	47.5	68.8	172
Ge ppm	283	43.0	105.30	0.6	10.0	15.0	30.0	1000
Hg ppm	11	0.042	0.027	0.011	0.022	0.038	0.054	0.096
K ppm	401	16400	9140	2407	10500	15400	21200	106000
La ppm	1	1000						
Li ppm	407	151	137.8	9	80	120	190	1440
Mn ppm	409	21.7	216.39	0.1	0.7	1.0	2.0	3470
Mo ppm	342	22.2	28.00	1.9	10.0	15.0	20.0	201
Na ppm	401	15400	6160	1279	11400	14700	18600	44900
Nb ppm	73	23.9	9.71	1.5	17.0	22.3	30.0	52
Ni ppm	475	249	907.4	10	100	113	200	17200
P ppm	304	36.4	266.32	0.5	3.0	5.0	8.6	3680
Pb ppm	463	194	435.7	3	70	120	200	6770
Rb ppm	416	131	72	4.1	80	117	160	470
Sb ppm	4	7.0	9.28	1.5	1.8	2.8	7.9	20.8
Sc ppm	1	50.5						
Se ppm	4	0.8		0.4				1
Sn ppm	248	8.6	12.44	0.4	3.0	5.0	10.0	100
Sr ppm	77	1550	1576	52	550	950	1750	6600
Te ppm	2	0.650		0.4				0.9
Ti ppm	405	16.2	79.04	0.3	6.0	10.0	10.0	1250

Table 3 – continued

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
Th ppm	1	24.1						
Tl ppm	3	2.5		1				4.5
U ppm	2	26.4		8.8				44
V ppm	407	281	130.7	3.1	200	300	300	1000
W ppm	34	98.7	142.08	2	43.3	71.0	102.8	838
Y ppm	73	167	91.3	19	102	152	203	544
Zn ppm	347	242	634.4	5.1	30	100	200	7000

CHEMICAL AND TECHNOLOGICAL ANALYSES, CONTENTS OF SULFUR AND TRACE ELEMENTS

Several published papers and unpublished reports describe the quantitative distribution of selected elements in coals of the CPISB. These include studies by Kudělásek (1959a, b), Lepka (1961) and Čadková (1971a, b and 1977). Kudělásek (1959b) who analyzed coal ash found that the Ge content decreased significantly from the youngest to oldest coal seams. The highest concentrations (max. 940 ppm) were found in the Radvanice group of seams (Jívka Member, Odolov Formation). In contrast, the average contents of Ag, Pb, U and Zn increase markedly from older to younger coals. Nickel showed the opposite trend. In contrast, Čadková (1971a, 1977), who analyzed coal found that the quantities of selected trace elements were distinctly different. Nevertheless, the trends in the increase and decrease of trace elements demonstrated by Kudělásek (1959a, b) were confirmed by Čadková (1971a, b and 1977). Středa et al. (1979) and Spudil et al. (1996) investigated the distribution of arsenic in the Žacléř coal seams. The content of As at the base of the Žacléř group of seams is relatively low, ranging between 4 to 16 ppm (on average 10 ppm) but a mean concentration of 23 ppm As was found in coal seams lying in upper parts of the sequence. Pluskal (1972) reviewed the uranium mineralization contained in coal seams of this basin. Extremely high concentrations of U must have existed in at least one coal seam of the Jívka

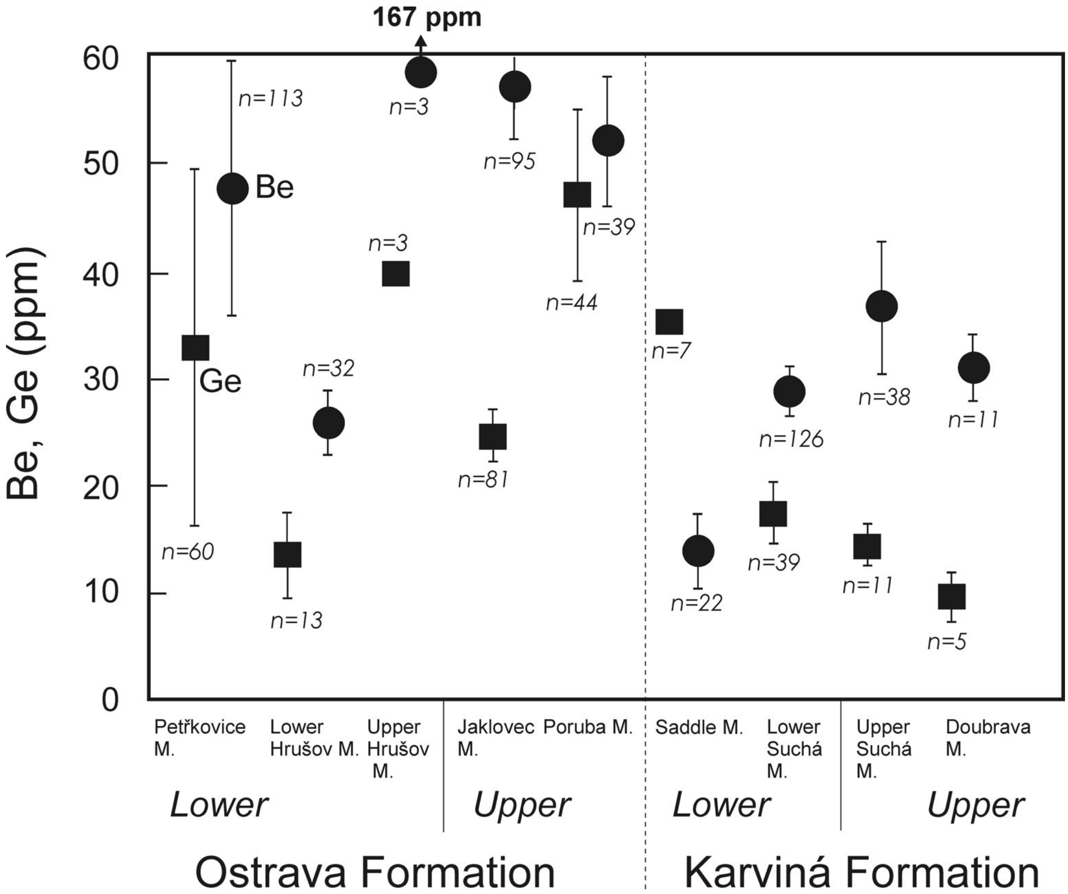


Fig. 5. Contents and distribution of beryllium and germanium in members of the Ostrava and Karviná formations of the Czech part of the Upper Silesian Basin (Lower Namurian to Langsettian).

Table 4. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Karviná Formation in Czech part of the Upper Silesian Basin (Middle Namurian to Langsettian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	7	0.9		0.7				1
C^{daf} %	49	82.6	5.31	61.9	82.0	84.3	85.7	88.3
H^{daf} %	49	4.9	0.42	3.7	4.6	5.0	5.2	5.4
N^{daf} %	49	1.3	0.13	1.1	1.2	1.3	1.4	1.7
O^{daf} %	49	7.9	4.27	4.1	5.0	6.8	8.3	21.0
V^{daf} %	231	31.8	6.46	3.0	31.0	33.4	34.9	41.8
R_o %	10	0.9	0.040	0.83	0.900	0.925	0.938	0.97
S_t^d %	143	0.7	0.305	0.24	0.485	0.580	0.720	2.0
A^d %	326	12.7	9.07	0.88	6.8	9.7	15.8	77.0
Ag ppm	121	6.0	9.25	2	3.0	3.0	5.0	100
Al ppm	8	98600		35500				190000
As ppm	173	97	87.84	0.4	20.2	100.0	100.0	800
B ppm	180	979	1199.5	45	500	500	1000	8000
Ba ppm	231	142	585.6	0.6	1	2	5	6170
Be ppm	208	28.1	27.30	0.1	10.0	20.0	30.0	220
Bi ppm	10	2.5	1.46	0.7	1.5	2.5	3.2	5.7
Br ppm	9	11.5		9.8				12.8
Cd ppm	26	0.6	0.611	0.2	0.200	0.300	0.500	2.2
Ce ppm	5	14.0		10				20
Cl ppm	38	555	240.8	200	400	550	700	1240
Co ppm	218	94.3	86.79	0.9	30.0	80.0	100.0	800
Cr ppm	224	308	237.4	2	100	300	500	800
Cs ppm	33	27.5	14.71	1.1	24.7	30.0	30.0	70
Cu ppm	231	193	258.1	4.9	100	200	200	3000
Fe ppm	5	161000		18000				308000
Ga ppm	23	20.8	20.75	0.6	3.9	8.9	40.7	60.6
Gd ppm	1	10.0						
Ge ppm	77	15.6	25.23	0.2	10.0	10.0	20.0	200
Hg ppm	22	0.7	0.583	0.02	0.065	1.200	1.200	1.2
K ppm	177	16700	6310	4360	12200	16800	21200	36200
La ppm	1	1000						
Li ppm	193	136	70.5	1.2	100	120	160	570
Mg ppm	8	36000		7400				101000
Mn ppm	193	249	984.6	0.1	0	1	3	6480
Mo ppm	192	27.6	22.27	1.5	10.0	20.0	30.0	100
Na ppm	177	21200	12250	10100	16200	19600	22300	151000
Nb ppm	20	7.9	6.73	0.7	2.7	5.3	11.1	24.6
Ni ppm	230	172	151.7	3.2	100	100	200	1000
P ppm	80	42.7	150.98	1	3.0	7.0	20.0	982
Pb ppm	225	152	217.4	2.7	100	100	200	3000
Rb ppm	164	123	101.5	1.3	70	110	160	1150
Sb ppm	41	3.6	6.72	0.2	0.7	1.1	2.9	34.4
Sc ppm	8	35.7		7.4				66.5
Se ppm	43	1.5	2.28	0.3	0.6	1.0	1.4	13.2
Sn ppm	175	6.5	10.10	0.4	3.0	3.0	10.0	119
Sr ppm	53	403	723.3	26.7	46	71	292	3790

Table 4 – continued

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
Te ppm	10	0.9	0.539	0.2	0.533	0.650	1.083	1.9
Ti ppm	194	83.9	577.01	1	5.0	8.0	10.0	6890
Th ppm	7	58.4		26.3				115
Tl ppm	12	2.4	1.44	0.23	1.6	2.6	3.4	4.8
U ppm	10	18.6	14.70	1.1	4.1	20.1	31.8	39.9
V ppm	225	276	191	1.7	124	300	300	1000
W ppm	9	3.8		0.9				20.2
Y ppm	23	52.8	60.23	4.1	9.7	38.7	70.1	234
Zn ppm	211	282	619.2	2.5	100	100	300	8000
Zr ppm	25	114	176	0.8	18	57	127	826

Member because it was mined for uranium during the period from 1951 to 1957. Uranium was present in the form of uraninite, also in poorly defined oxides, hydroxides and carbonates, as well as in Ti-U-Fe oxides in which Ti prevails over U and Fe (Fabianová 1987). High uranium mineralization was also identified in coal seams of the Svatoňovice Member (Odolov Formation) and in the so-called "V Rybníčku" coal seam at the base of the Chvaleč Formation. A certain amount of these coal seams was also extracted as a radioactive raw material in the late 1950s. The highest concentrations of Th (Pluskal 1972) were identified in coals of the Svatoňovice group of seams. Due to the secrecy of data on uranium mineralization in the former Czechoslovakia, details of the uranium content in the coal seam and its amount extracted are still not available.

RESULTS OF RECENT STUDIES

Two samples from the Žacléř Formation showed similar rank, maceral and chemical compositions and also basic

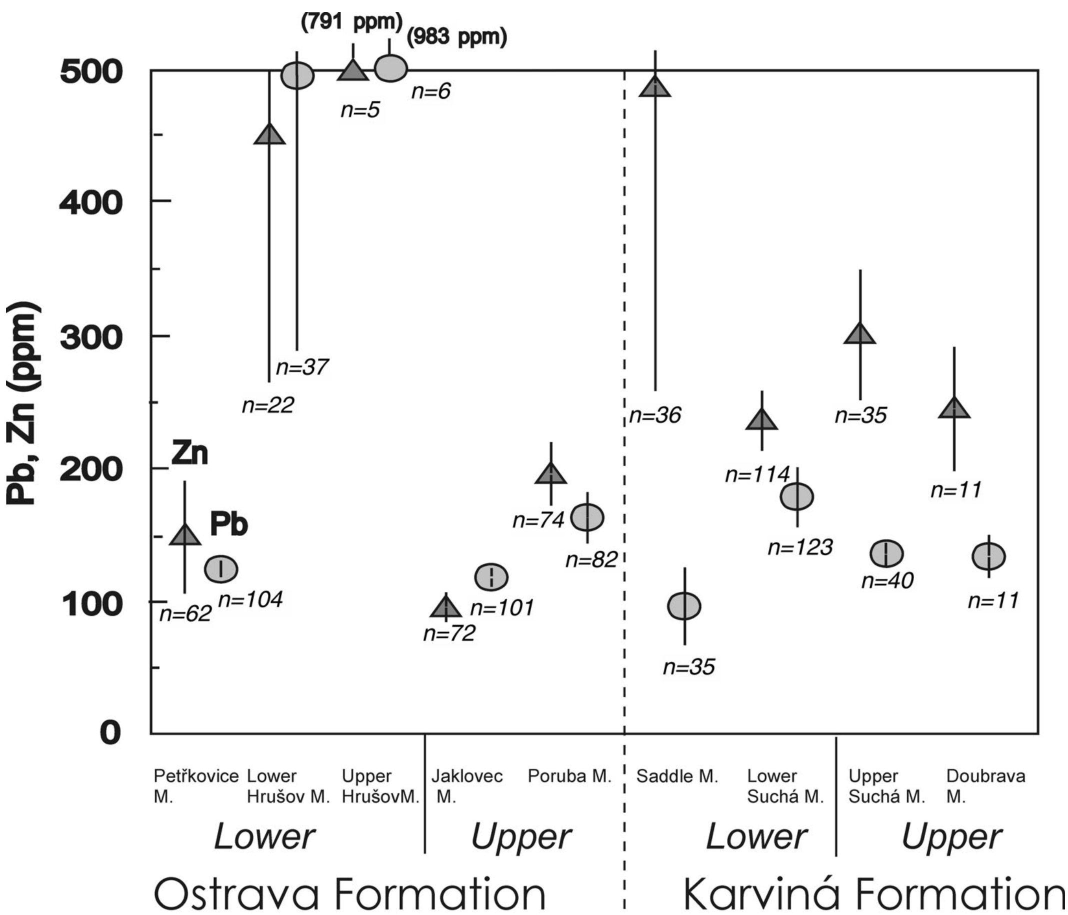


Fig. 6. Contents and distribution of lead and zinc in members of the Ostrava and Karviná formations of the Czech part of the Upper Silesian Basin (Lower Namurian to Langsettian).

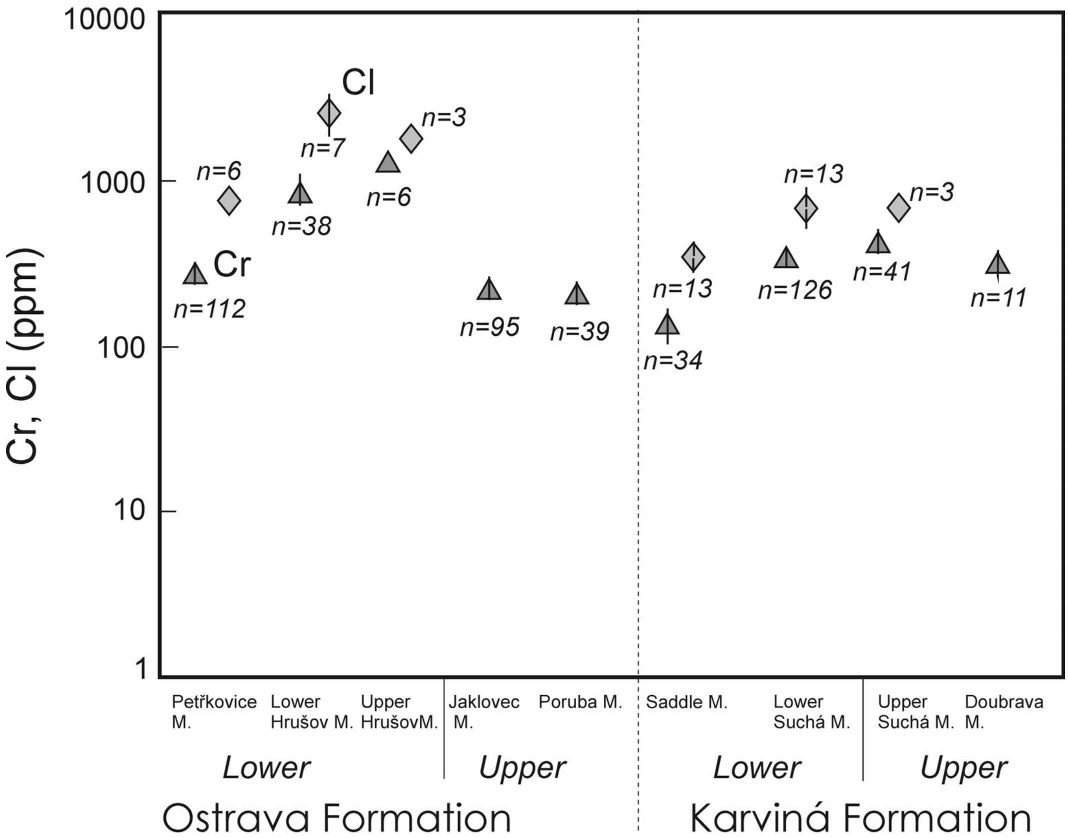


Fig. 7. Contents and distribution of chlorine and chromium in members of the Ostrava and Karviná formations of the Czech part of the Upper Silesian Basin (Lower Namurian to Langsettian).

technological parameters. These coals are relatively pure with A^d 7.1 and 3.5 % and low sulfur content (S_t^d) 0.6–0.8 %. Reflectance (R_o) 1.03–1.06 %, V^{daf} 29.4–34.66 %, and C^{daf} 83.6–85.3 % are typical for high volatile bituminous coal. It contains dominant vitrinite (49.8–62.0 vol. %), significant contents of inertinite (27.5–34.0 vol. %) and liptinite (10.4–15.7 vol. %) (Fig. 8A). Inorganic components are chiefly clay minerals (mostly kaolinite), followed by low contents of sulfides, quartz, carbonates and minor feldspars and muscovite. Mineralized coal in the Jívka Member (A^d 49.7 %), with vitrinite reflectance (R_o 0.87 %), is characterized by vitrinite content (29.2 vol. %), 14.2 vol. % of liptinite, 6.3 vol. % of inertinite, and abundant massive carbonate veins (mostly calcite 33.1 vol. %) and sulfides (4.5 vol. % – pyrite accompanied by other sulfides) filling fractures in the coal seams (Figs 8B and C). Besides carbonates and sulfides, some clay minerals (9.5 vol. %), and minor sulfates, silty quartz and other minerals form components (3.6 vol. %) of this coal.

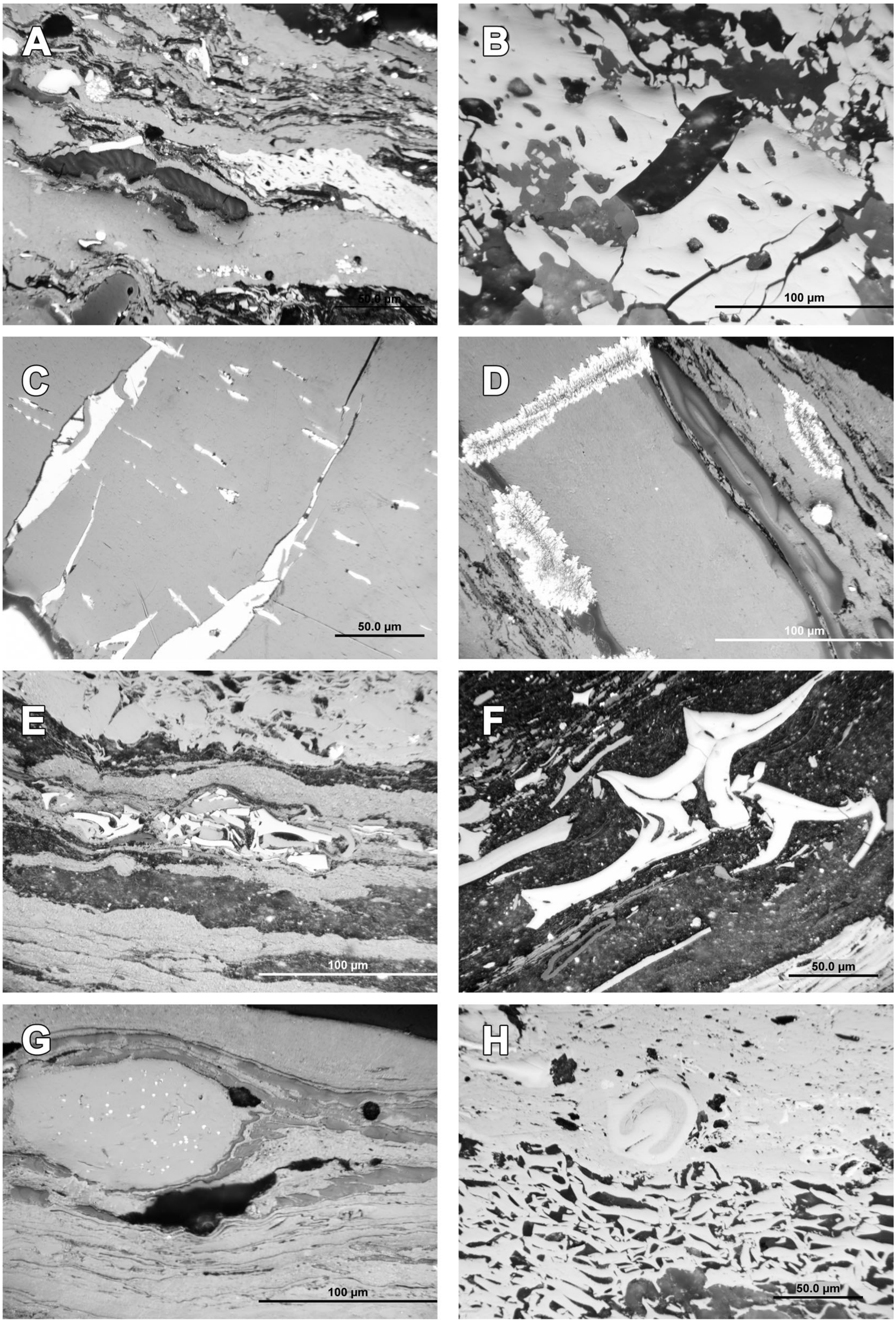
As shown in Tables 6–8, compared with average Clarke values (Table 5) estimated by Ketris and Yudovich (2008), mean contents of Ag, B, Be, Cd, Cr, Cs, Cu, Ga, Ge, Li, Mo, Ni, Pb, Rb, Sb, Sc, Th, V, Y, Zn, and Zr in coal ashes of the Žacléř and/or Odolov formations are rather high. In contrast, only Ge, Cu, Zn, Pb, and Ni are present in high mean concentrations in coal seams of the Jívka Member (Table 8).

4.3. KRKONOŠE PIEDMONT BASIN

Filling of the Krkonoše Piedmont Basin (KPB) began in Asturian time. The youngest clastics are of Triassic age. Coal seams occur in three formations of which the Syřenov Formation (Stephanian B) is the most important containing as many as four coal seams ranging from a few tens of centimeters up to 2.5 m thick. However, none of these has been ever mined because of their high average contents of arsenic. Two only locally important coal seams 0.1–1.0 m thick are confined to the Semily Formation (Stephanian C), whereas only one small coal seam 30 cm thick occurs in the Vrchlabí Formation (Autunian).

→

Fig. 8. Microphotographs of minerals in coal from the Czech part of the Intra-Sudetic Basin (8A–C), the Krkonoše Piedmont Basin (8D), the Mnichovo Hradiště Basin (8E), the Central and West Bohemian basins (8F), the Carboniferous relics south and west of the Central and West Bohemian basins (8G), the Blanice Graben (8H). A – crystalline and framboidal pyrite (light), clay minerals, and slatted black fragments of mica (dark) in trimacerite in coal from the Žacléř Formation, B – calcite and fusinite in coal from the Jívka Member, C – pyrite fillings of fissures of vitrinite in the coal from the Jívka Member, D – pyrite with admixture of chalcopyrite and



sphalerite in coal from the Syřenov Member, E – clay minerals layers (dark) and framboids and crystals of pyrite in coal from the Syřenov Member, F – fusinite, sporinite and vitrinite fragments in mixture of clay minerals and light fine grains of pyrite and accessory minerals in coal from the Radnice Member, G – pyrite crystals dispersed in corpogelinite, cutinite, collotelinite and collodetrinite in coal from the Radnice Member, H – clay minerals and carbonates dispersed in collodetrinite and fusinite in anthracite from the Blanice Graben. *Photos by I. Sýkorová*.

Table 5. Average Clarkes values for trace elements in hard coal ashes (1) and sedimentary rocks (2). Ketris – Yudovich (2009), adapted

ppm	1	2	3
Ag ppm	0.63 ± 0.10	0.12	5.1
As ppm	46 ± 5	7.6	6.2
Au ppb	21 ± 10	6	3.7
B ppm	260 ± 20	72	4.7
Ba ppm	980 ± 60	410	2.3
Be ppm	12 ± 1	1.9	4.9
Bi ppm	7.5 ± 0.4	0.26	23
Br ppm	32 ± 9	44	0.73
Cd ppm	1.20 ± 0.30	0.8	1.5
Ce ppm	140 ± 10	52	2.5
Cl ppm	2100 ± 300	2700*	0.53
Co ppm	37 ± 2	14	2.3
Cr ppm	120 ± 5	58	1.7
Cs ppm	8.0 ± 0.5	7.7	0.86
Cu ppm	110 ± 5	31	3
F ppm	580 ± 20	470	1.3
Ga ppm	36 ± 1	12	2.8
Gd ppm	16 ± 1	4	4
Ge ppm	18 ± 1	1.4	11
Hg ppm	0.87 ± 0.07	0.068	11
I ppm	12.2 ± 5.4	1100	0.01
In ppm	0.21 ± 0.18	0.043	3.7
Ir ppm	0.007 ± 0.003		
La ppm	76 ± 3	32	2.2
Li ppm	82 ± 5	33	2
Mn ppm	430 ± 30	830	0.59
Mo ppm	14 ± 1	1.5	9.3
Nb ppm	22 ± 1	7.6	2.6
Ni ppm	100 ± 5	37	2.1
P ppm	1500 ± 100	670	2
Pb ppm	55 ± 6	12	3.9
Pd ppm	0.007 ± 0.011		
Pt ppm	0.038 ± 0.018		
Rb ppm	110 ± 10	94	0.84
Sb ppm	7.5 ± 0.6	1.2	5.3
Sc ppm	24 ± 1	9.6	2.4
Se ppm	10.0 ± 0.7	0.27	33
Sn ppm	8.0 ± 0.4	2.9	2.2
Sr ppm	730 ± 50	270	2.7
Ta ppm	2.0 ± 0.1	1	1.7
Th ppm	23 ± 1	7.7	2.7
Ti ppm	5300 ± 200	3740	1.2
Tl ppm	4.6 ± 0.4	0.89	5.5
U ppm	15 ± 1	3.4	4.7
V ppm	170 ± 10	91	1.7
W ppm	7.8 ± 0.6	2	3.5
Y ppm	57 ± 2	29	1.8
Zn ppm	170 ± 10	43	3.3
Zr ppm	230 ± 10	170	1.2

Note: * Cl – Clarke value in sedimentary rocks according to Ronov et al. (1990)

RESULTS OF EARLIER STUDIES

Coal seams and their quality

Samples from old dumps (coal seams of the Semily Formation) and also from drill cores (Syřenov Formation) in the KPB were examined. Local coals are represented by banded coal, dull and bright banded coal and also dull to clayey coals with dominant vitrinite (65–80 vol. %), and variable contents of liptinite (3–0 vol. %) and inertinite (10–40 vol. %). Inorganic components include common clay minerals, sulfides (pyrite/marcasite, chalcopyrite, galena, sphalerite, arsenopyrite), quartz, sulfates (gypsum), carbonates (calcite, limestone, dolomite, siderite) and tuffaceous material.

CHEMICAL AND TECHNOLOGICAL ANALYSES, CONTENTS OF SULFUR AND TRACE ELEMENTS

Coal seams of the Semily Formation studied by Havlena (1958) show a relatively high rank. The analyzed sample of coal from a dump near Dolní Štěpanice has a V^{daf} 32.6 % and another sample from a dump of the Rohan adit near Nedvězí had a V^{daf} of only 25.3 %. According to Havlena (1958), the coalification of the second sample was affected by alkaline solutions that entered the precursor peat bogs. More data are available on coal seams of the Syřenov Formation. The local coal, having variable values of reflectance (R_o 0.85–1.49 %) (Pešek et al. 2001), is believed to have been affected by higher temperature. These were acquired from the study by Středa et al. (1981) who obtained chemical and technological parameters indicating that coalification of these coal seams was relatively weak (V^{daf} 38.78 %, C^{daf} 80.7 %) with a high content of ash (A^d 52.0 %) and a high proportion of S_t^d (2.8 %). These authors (Středa et al. 1981) also found high concentrations of As and higher contents of Co, Cu, Pb, V, and Zn.

Results of recent studies

Only one analysis of coal ash from the Syřenov Formation was available, which was obtained from strongly fractured mineralized coal with an ash content of 42.1 % A^d and sulfur 4.45 % S_t^d, containing fissures often filled by sulfides (S_p^d 2.13 %), sulfates (S_{SO4}^d 1.82 %) and carbonates. The reflectance of vitrinite (R_o) is 0.88 vol. %. Inertinite (56.7 vol. %) appears to be the dominant constituent of the coal, whereas vitrinite is less abundant (38.0 vol. %) and the content of liptinite is low (5.3 vol. %). In the inorganic part dominate clay minerals, pyrite with admixture of chalcopyrite, sphalerite, galena (Fig. 8D), calcite and siderite. Contents of quartz and other minerals are low.

Very limited data are available for coal seams of the Syřenov Formation, which is characterized by a high average arsenic content of 206 ppm in their ashes, and also high contents of Ag (61.9 ppm), Be (25 ppm), Co (111 ppm), Cu (1,420 ppm), Mo (35 ppm), Ni (110 ppm), Pb (1,170 ppm), V (1,500 ppm), and Zn (549 ppm). It is to be emphasized that these values were obtained in a single analysis (Table 9).

Table 6. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Žacléř Formation in the Czech part of the Intra-Sudetic Basin (Upper Namurian to Duckmantian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	1449	4.4	0.11	3	4.4	4.4	4.4	4.4
C^{daf} %	1455	81.8	0.66	75.1	81.7	81.7	81.7	86.4
H^{daf} %	1455	5.5	0.09	3.7	5.5	5.5	5.5	5.6
N^{daf} %	1445	1.1	0.05	0.58	1.1	1.1	1.1	1.6
O^{daf} %	1442	10.2	0.57	6.1	10.2	10.2	10.2	19.6
V^{daf} %	1489	35.2	0.91	27.2	35.3	35.3	35.3	43.6
S_t^d %	6963	0.8	0.485	0.02	0.5	0.7	1.2	11.6
S_p^d %	4630	31.1	3.01	0.41	30.0	30.9	32.0	82.5
S_{SO4} %	4	0.02		0.01				0.04
A^d %	7548	34.7	17.90	2.44	23.4	34.4	39.6	99.99
Ag ppm	1	27.7						
As ppm	1416	23.1	2.17	9.9	23.0	23.0	23.0	62
B ppm	1	827						
Ba ppm	1	503						
Be ppm	2	32.1		22.4				41.8
Bi ppm	2	0.7		0.11				1.2
Cd ppm	1	22.9						
Cl ppm	1	750						
Co ppm	522	98.1	60.86	14	92.0	92.0	92.0	1000
Cr ppm	2	311		302				320
Cs ppm	2	29.4		25				33.8
Cu ppm	30	454	360.2	27	180	380	705	1310
Ga ppm	1	70.7						
Ge ppm	617	43.9	20.44	1	50.0	50.0	50.0	280
Hg ppm	2	0.192		0.013				0.37
Ir ppb	1	3.9						
Li ppm	1	174						
Mn ppm	1	117						
Mo ppm	5	33.7		24				61.4
Nb ppm	1	10.3						
Ni ppm	535	603	102.7	24	620	620	620	1240
P ppm	1	60.0						
Pb ppm	505	4950	485	15	125	350.1	2776.9	5000
Pd ppb	1	10.8						
Pt ppb	1	48.5						
Rb ppm	2	255		217				293
Sb ppm	1	47.8						
Sc ppm	1	60.0						
Se ppm	1	1.9						
Sn ppm	1	4.8						
Sr ppm	1	383						
Te ppm	1	1.2						
Ti ppm	39	4100	3419	320	890	3600	6100	15600
Th ppm	1	37.7						
Tl ppm	1	4.0						
U ppm	1	8.9						
V ppm	536	202	199.6	69	154	154	154	1680
Y ppm	1	61.6						
Zn ppm	8	927		55				3770
Zr ppm	1	384						

Table 7. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Svatoňovice Member in the Czech part of the Intra-Sudetic Basin (Asturian to Cantabrian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	13	3.2	0.26	3	3.0	3.0	3.5	3.5
C^{daf} %	4	78.4		76.7				80.1
H^{daf} %	4	5.3		5.2				5.6
N^{daf} %	4	0.7		0.56				0.82
O^{daf} %	4	9.7		7.8				12
V^{daf} %	19	30.9		26.8	27.8	29.9	34.0	40.2
S_t^d %	2161	3.5	2.12	0.54	1.7	2.7	4.6	10.1
S_p^d %	2048	39.7	4.88	26.8	36.6	39.4	41.6	78.9
A^d %	2203	46.5	13.12	9.8	38.1	46.3	54.5	92.2
Cu ppm	8	2520		1300				3010
Ge ppm	19	25.8	29.10	4	11.0	15.0	44.0	100
Ni ppm	6	91		21				237
P ppm	4	523		38.5				1100
Ti ppm	7	6830		1500				21700
V ppm	6	203		61				301

Table 8. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Jívka Member in the Czech part of the Intra-Sudetic Basin (Stephanian B). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	1	5.0						
C^{daf} %	3000	76.5	2.48	72.9	74.5	76.3	79.5	79.6
H^{daf} %	3000	5.6	0.30	5.1	5.3	5.7	5.8	6.0
N^{daf} %	3000	1.2	0.17	0.83	1.2	1.3	1.3	1.34
O^{daf} %	3000	14.9	2.38	12.4	13.2	14.3	15.3	19.8
V^{daf} %	3012	35.0	2.06	32.6	33.4	35.7	36.2	41.5
S_t^d %	3019	1.0	0.34	0.8	0.8	1.0	1.0	3
A^d %	3043	49.7	6.18	12.7	48.7	52.0	53.7	88.8
As ppm	3001	27.3	6.07	18.5	20.0	30.0	33.0	109
Be ppm	1	6.7						
Bi ppm	1	0.2						
Cd ppm	1	3.9						
Co ppm	1	10.0						
Cr ppm	1	56.0						
Cu ppm	338	168	233.9	17	150	199	495	3200
Ge ppm	10	192	265.7	4	105	125	138	940
Ir ppb	1	0.2						
Mo ppm	1	6.0						
Ni ppm	337	20.4	6.12	20	20.0	20.0	20.0	132
Pb ppm	336	547	492.6	222	315	379	520	9550
Pd ppb	1	0.7						
Pt ppb	1	44.7						
Rb ppm	1	2.0						
Rh ppb	1	0.2						
V ppm	337	100	12.2	24	36.3	88.2	100	310
Zn ppm	336	721	9.3	720	720	720	720	890

Table 9. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Syřenov Formation in the Krkonoše Piedmont Basin (Stephanian B). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	184	8.0		8	8.0	8.0	8.0	8
C^{daf} %	3	80.7		80.1				81.0
H^{daf} %	3	5.4		5.3				5.5
N^{daf} %	3	1.7		1.4				2.0
V^{daf} %	182	38.8	3.36	26.5	37.5	39.2	41.3	46.1
S_t^d %	199	3.4	1.99	0.24	2.0	3.2	4.8	10.7
A^d %	252	56.4	22.37	12.0	41.1	49.0	72.9	99.99
Ag ppm	1	61.9						
As ppm	13	206	175.6	19.7	93	148	418	536.4
Be ppm	1	25						
Cd ppm	1	7.1						
Co ppm	1	111						
Cr ppm	1	96						
Cu ppm	3	1420		100				2900
Hg ppm	1	0.012						
Mo ppm	1	35						
Ni ppm	1	110						
Pb ppm	3	1170		111				3100
Rb ppm	1	11						
V ppm	1	1500						
Zn ppm	2	549		297				800

4.4. MNICHOVO HRADIŠTĚ BASIN

The basin is filled by a clastic and volcaniclastic sequences of Asturian to Autunian ages. A maximum five coal seams 0.1–1.9 m thick were found in the Syřenov Formation (Stephanian B). Other three coal seams, reaching a maximum thickness of 20 cm, occur in the Semily Formation (Stephanian C).

RESULTS OF EARLIER STUDIES

Coal seams and their quality
Only limited chemical and technological parameters were established during exploration of the Mnichovo Hradiště Basin: the Main Mělník coal seam at the base of the Syřenov Formation shows A^d 22–31 % (on average 26 %), Q_i^r 19–27 MJ.kg^{-1} (on average 23 MJ.kg^{-1}), S_t^d 0.9–2.2 % (on average 1.6 %). A coal seam 20 cm thick in the Semily Formation gave Q_i^r 36.5 MJ.kg^{-1}, and A^d 26.5 %. Contents and distributions of trace elements in coal ashes were not studied in the past.

RESULTS OF RECENT STUDIES

One sample of banded coal from the Mělník group of seam, which was available to be studied, was formed by vitrinite (60.0 vol. %), liptinite (7.7 vol. %) and inertinite (2.8 vol. %). This coal is characterized by content of 29.5 vol. % of mineral mater with predominance of clay minerals (Fig. 8E) and with admixture of pyrite, quartz and accessory minerals.

4.5. CENTRAL AND WEST BOHEMIAN BASINS

The Central and West Bohemian basins (the Plzeň, Radnice, Manětín, Žihle, Kladno-Rakovník and Mšeno-Roudnice basins) are filled by clastic aand volcaniclastic deposits of Bolsovian to Stephanian C ages. As many as 45 coal seams and seamlets were identified in the Kladno, Týnec, Slaný and Líně formations (Fig. 2). The coal seams within the Radnice Member (Bolsovian) and also the Nýřany Member (Asturian to Cantabrian) of the Kladno Formation, and locally even the Kounov Member in the uppermost part of the Slaný Formation (Stephanian B), were found to be economic and locally mined until 2000s. One to three coal seams (Mělník group of seams) a few cm up to 4.5 m thick occur at the base of the Slaný Formation in the Mšeno-Roudnice Basin (MRB). None of these seams have been mined as yet. A maximum of eight coal seams, 1.5–14 m thick were extracted in the Radnice Member, whereas more than 20 coal seams with thicknesses varying from a few tens of cm up to almost 3.5 m were found in the Nýřany Member. Only one coal seam (0.7–1.5 m thick) was extracted in the Kounov Member. Some small coal seams only a few tens of cm thick occur locally in the Týnec and Líně formations. None of these have ever been exploited.

RESULTS OF EARLIER STUDIES

Coal seams and their quality

Coal seams of the WCBB consist of locally slightly caking, bright, banded, dull banded to dull dirty coals with A^d 15–50 % and S_t^d 0.3–3.5 %. The highest contents of sulfur ($S_t^d \cong 8$ %) were found in coal seams of the Nýřany Member in the Kladno-Rakovník (KRB) and MRB (Table 15). Based on the values V^{daf} 35.0–42.0 %, C^{daf} 70.32–78.25 %) and R_o (0.7–0.8 %), the local coals can be ranked as high volatile bituminous coals. In petrographic terms, humite coals with vitrinite content exceeding 60 vol. % prevail, whereas liptinite (3–15 vol. %) and inertinite (3–25 vol. %) constituents are less abundant. Vitrite, clarite, carbominerite, trimacerite and durite are most abundant among the microlithotypes. Liptobiolites and sapropelites were found forming irregular bands and layers in coal seams. More massive horizons of liptobiolites coal are known from several coal seams of the Radnice Member in the Rakovník region of the WCBB, also in the Mělník group of seams in the bottom part of the Slaný Formation in the MRB and in the Kounov group of seams in the upper section of the Slaný Formation in the Kladno region (KRB). Interlayers of sapropelites a few tens of cm thick that may in exceptional cases form the whole coal seam are known from the Nýřany group of seams in the Plzeň Basin (PB). Abundant clay minerals (kaolinite), silty or sandy quartz, tuffaceous material (mostly close to interbeds), carbonates (dolomite, calcite, ankerite, siderite) are the inorganic components in these coal seams. The content of sulfides varies but pyrite prevails over other sulfides such as galena, sphalerite, chalcopyrite and arsenopyrite, which is very rare.

CHEMICAL AND TECHNOLOGICAL ANALYSES, CONTENTS OF SULFUR AND TRACE ELEMENTS

Numerous data on the occurrence of elements in the WCBB (Plzeň, Žihle, Radnice and Kladno-Rakovník basins) can be found in published papers and also in archive reports. However, due to the small number of analyses only the results of chemical and technological analyses and determinations of sulfur and of only a few trace elements can be considered reliable. In the late 1950s and early 1960s attention was paid mainly to the contents of Ge and Ga, which at that time were considered strategic materials in the former Czechoslovakia. Their distribution and contents were tested in all coal seams exploited at that time. The results of the search for germanium in coal seams of the Radnice Formation in the PB were summarized and published by Tyrolerová-Skybová (1958). Concentrations of germanium were found to fluctuate between 3.8 to 52 ppm depending on the grain size fraction subjected to analyses. Zahradník et al. (1962) found 6.0–6.9 ppm Ge in a coal seam of the Radnice Member, whereas the Nýřany coal seams at the base of the Nýřany Member showed 130–986 ppm Ge. Zahradník et al. (1962) proved that Ge was enriched in the base and the roof of coal seams, and also close to their dying out. Only one chemical-technological analysis of coal from the Nýřany Member is available from the Žihle Basin (ŽB) (Hubáček 1941) showing high S_t^d (> 4 %). Tyrolerová (1959) studied Ge in 125 samples collected from the Radnice group of seams at five mines located in various parts of the Radnice Basin (RB). The content of Ge in coal seams of the Radnice Member varies from 0 up to 65 ppm with the exception of samples close to coal seams wedging out and/or near some major faults where they reach as much as 240 ppm. Coal seams of the Radnice Member and those at the top of the Slaný Formation in the KRB were investigated. Tomaňa (1957) studied the occurrence of uranium in four samples of coal from the Radnice Member (1–9 ppm U) in the same basin. Votavová and Král (1959) investigated the distribution of Ge in coal seams of the same provenance from eight mines in the KRB. Germanium was analyzed in 131 samples from the Main coal seam (= Upper Radnice seam) in the KRB and found to range from 0.1 to 4,400 ppm. Somasekar (1971) found high contents of B (194–476 ppm) in coal ashes from the Radnice Member. Kadaňková-Votavová (1960a) analyzed Ge in 34 borehole samples of coal of the Kounov seam collected near the roof of the Slaný Formation and found contents of this element ranging between 22.5 and 168.7 ppm but some samples with concentrations exceeding 200 ppm were also recorded. Lepka (1980) studied the contents of U and Th in 11 samples from the upper part of the Slaný Formation (4.3 ppm U, 5.5 ppm Th) and 7 samples taken from coal seams of the Radnice Member (3.3 ppm U and 3.0 ppm Th) but the exact location of these samples was kept in secret, though perhaps they were from the KRB. Havelka and Rozložník (1990) described uranium mineralization of economic grade close to coal seam wedging out in the Radnice Member and in the upper section of the Slaný Formation in the KRB.

RESULTS OF RECENT STUDIES

The content of vitrinite varies from 32 to 81.3 vol. %, that of liptinite from 6.6 to 16.1 vol. % and inertinite from 8.1 to 24.2 vol. % in the studied coals. Inorganic admixture includes mostly clay minerals (mainly kaolinite) and sulfides, syngenetic pyrite in particular (Fig. 8F). Elemental sulfur is rare but was identified in coal samples from the Nýřany Member.

The database of coal analyses compiled by ourselves showed some very high contents of Ge (7,110 ppm in the PB, 1,850 ppm in the RB and 4,440 ppm in the KRB). The mean concentrations of Ge, however, are much lower (111 ppm in the Plzeň region and 70 ppm in the Kladno-Rakovník region – see Tables 10–12). High contents of Ge in coal ashes from seams of the Nýřany Member at the Důl Dobré štěstí mine in the PB (3–7,110 ppm, on average 111 ppm – see Table 12) led to the extraction of this element from fly ashes produced from coal burned in the Holýšov power plant. Extremely high mean contents of As were identified in ashes from coals of the Radnice (182 ppm) and Nýřany members (1,260 ppm, Tables 11 and 13) in the KRB. The studied samples from coal seams of the Radnice Member in the RB showed enhanced mean contents of Ag, Be, Cr, Cs, Ge, Ir, Pt, Rb, V, and Zn (Table 10) and As, B, Be, Co, Cr, Cs, Cu, Ir, Li, Mo, Ni, Pb, Pd, Pt, Rb, Sb, Sn, U, V, Zn, and Zr in the KRB (Table 11) with

Table 10. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Radnice Member in the Radnice Basin (Bolsovian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	247	12.9	2.73	4.9	11.1	12.5	14.9	18.8
C^{daf} %	12	72.9	2.50	71.1	71.1	71.1	74.6	77.3
H^{daf} %	12	4.3	0.69	3.8	3.8	3.8	4.9	5.4
N^{daf} %	12	1.1	0.05	1.1	1.1	1.1	1.2	1.2
O^{daf} %	5	17.2		15.2				19.6
V^{daf} %	43	39.6	3.00	35.5	37.5	37.5	43.0	49.8
S_t^d %	113	1.7	1.09	0.06	1.1	1.4	2.6	4.8
A^d %	632	33.5	14.79	4	26.5	33.3	39.0	85.2
Ag ppm	1	4.7		4.7	4.7	4.7	4.7	4.7
As ppm	20	39.2	30.12	3.4	3.4	43.2	63.4	63.4
Be ppm	1	30.8						
Bi ppm	1	0.1						
Co ppm	1	16						
Cr ppm	1	185						
Cs ppm	1	52						
Cu ppm	1	93						
Ge ppm	125	110	314.8	1.4	7	14	20	1850
Hg ppm	1	0.009						
Ir ppb	1	0.4						
Mo ppm	1	11						
Ni ppm	1	56						
Pb ppm	1	87						
Pd ppb	1	2.5						
Pt ppb	1	17.8						
Rb ppm	1	245						
Rh ppb	1	0.1						
V ppm	1	192						
Zn ppm	1	226						

a relatively high mean concentration of Ag, As, Be, Co, Cr, Cs, Cu, Ge, Ir, Mo, Pb, Pd, Pt, Rb, Sn, and Zn in a coal seam from the Nýřany Member in/or the PB and KRB (Tables 12 and 13). A single analysis of coal ash of the Nýřany Member in the ŽB revealed slightly enhanced contents of Ag, Be, Co, Cr, Cs, Cu, Pb, and Rb (Table 14) and higher concentrations of Pd (6 ppb), and Pt (24.9 ppb), V (753 ppm), and Zn (869 ppm). Enhanced mean contents of As (151 ppm), Be (35 ppm), Cl (77.5 ppm), Cr (128 ppm), Cu (269 ppm), Ge (95.1), Mo (18 ppm), Ni (122 ppm), and Pb (266 ppm) were found in coal samples from the Kounov group of seams of the Slaný Formation in the MRB (Table 15).

4.6. CARBONIFEROUS RELICS SOUTH AND WEST OF THE CENTRAL AND WEST BOHEMIAN BASINS

Several Carboniferous relics of the Kladno Formation (Bolsovian to Cantabrian) containing a few hundred metres of clastic and volcaniclastic deposits occur south and west of the WCBB. Two, exceptionally even three, coal seams of the Radnice Member (Bolsovian) with a thickness reaching 4 m, were extracted from relics near Merklín, Tlustice (Žebrák), Lísek and Malé Přílepy. From one to three coal seams of the Nýřany Member (max. 2 m thick) were exploited near Skapce, Těchlovice, Vranov, Letkov and Mirošov.

RESULTS OF EARLIER AND RECENT STUDIES

Only sporadic results of chemical and technological analyses of coals from the Carboniferous relics (Lísek, Malé Přílepy and Mirošov) are available. For this reason, some new samples of coal were collected from old dumps where possible. Their maceral compositions and their contents of sulfur and trace elements in their ash were determined. Only some fragments of coal were acquired from the Radnice Member of the relics near Malé Přílepy (Bolsovian), Merklín, Lísek and from the Nýřany Member (Asturian) near Vranov and Mirošov. The results of chemical and technological analyses, the contents of S and of trace elements from Lísek, Malé Přílepy (Table 16) and from

Table 11. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Radnice Member in the Kladno-Rakovník Basin (Bolsovian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	4281	11.3	2.59	1.9	9.6	11.0	12.4	28.7
C^{daf} %	2033	76.9	1.57	56.5	76.7	76.7	78.9	92.3
H^{daf} %	2033	5.5	0.15	2.8	5.4	5.4	5.5	5.7
N^{daf} %	2033	0.904	0.264	0.45	1.000	1.060	1.080	1.7
O^{daf} %	2032	15.4	1.27	1.2	13.8	15.0	16.1	16.7
V^{daf} %	2069	35.6	1.53	9.2	34.6	35.9	37.0	52.1
S_t^d %	3431	0.6	0.474	0.03	0.290	0.390	0.830	4.2
S_p^d %	1	0.2						
S_{SO4} %	1	0.01						
A^d %	6788	38.4	14.51	2.48	33.7	35.4	38.6	99.99
Ag ppm	2	1.9		1				2.7
As ppm	9	182		2.6				1000
B ppm	16	655	880	183	300	412	485	3650
Ba ppm	6	456		56				779
Be ppm	9	88.6		10				364
Bi ppm	7	1.7		0.22				2.9
Cd ppm	4	1.1		0.38				2.2
Co ppm	9	69.6		10				214
Cr ppm	7	204		116				324
Cs ppm	7	89.1		23				164
Cu ppm	9	191		70				284
Ga ppm	4	101		29.6				231
Ge ppm	131	70	449.75	0.1	1.8	9.0	19.8	4440
Hg ppm	5	0.2		0.007				0.37
Ir ppb	2	0.5		0.3				0.7
K ppm	7	1000		1000				1000
Li ppm	4	180		146				239
Mn ppm	4	391		157				604
Mo ppm	6	16.6		6				26.1
Nb ppm	4	18.5		9.1				32.3
Ni ppm	9	254		100				758
Pb ppm	9	136		58				250
Pd ppb	3	4.2		1.5				6.4
Pt ppb	3	35.6		16.9				70.2
Rb ppm	7	208		63				351
Rh ppb	2	0.2		0.1				0.3
Sb ppm	4	990		25.9				2210
Sc ppm	4	36.4		23.9				61.2
Se ppm	4	1.2		0.39				2.7
Sn ppm	6	16.3		9.6				36.1
Sr ppm	4	292		126				579
Te ppm	4	0.5		0.25				0.74
Th ppm	11	12.9	14.06	3.9	3.9	3.9	18.8	42.2
Tl ppm	4	16.3		3.1				47.2
U ppm	26	21.4	23.49	1	3.3	12.4	31.5	90
V ppm	9	329		20				735
Y ppm	4	112		50.2				207
Zn ppm	9	199		90				331
Zr ppm	4	304		207				420

Table 12. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Nýřany Member in the Plzeň Basin (Asturian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	1060	10.7	1.52	3.45	11.2	11.2	11.2	11.2
C^{daf} %	2	80.7		80.13				81.31
H^{daf} %	2	5.5		5.49				5.54
N^{daf} %	2	1.4		1.26				1.48
O^{daf} %	2	11.0		10.59				11.43
V^{daf} %	2364	37.9	2.75	22.61	35.6	37.6	39.2	48.76
S_t^d %	2728	1.0	0.93	0.01	0.6	0.7	1.3	9.2
A^d %	2983	38.6	20.82	4.37	24.0	32.7	49.1	91.12
Ag ppm	42	0.7		0.7	0.7	0.7	0.7	0.7
As ppm	150	19.2	18.90	2.1	11.0	12.0	17.0	73
Ba ppm	312	644	219.6	340	362	702	862	1060
Be ppm	2	52.6	16.12	41.2				64
Bi ppm	2	0.9	0.488	0.55				1.24
Co ppm	2	27	9.90	20				34
Cr ppm	314	85.5	18.41	63	70.0	83.0	95.0	255
Cs ppm	2	55.5	14.85	45				66
Cu ppm	314	86.8	92.42	12	15.0	40.0	206.0	290
Ga ppm	312	30.6	17.94	12	22.0	26.0	30.0	74
Ge ppm	259	111	561.9	3	12	29	44	7110
Hg ppm	1	0.006						
Ir ppb	2	0.65		0.4				0.9
Mo ppm	155	1.3	0.45	1	1.0	1.0	2.0	2
Nb ppm	312	18.3	4.75	8	19.0	20.0	22.0	23
Ni ppm	314	37.2	10.19	21	29.0	35.0	42.0	72
Pb ppm	314	39.9	17.62	19	21.0	38.0	58.0	154
Pd ppb	2	2.4		2.4				2.4
Pt ppb	2	53.2		35.5				70.8
Rb ppm	314	171	30.5	114	165	181	186	266
Rh ppb	2	0.1		0.1				0.1
Sn ppm	312	11.8	3.36	6	9.0	12.0	12.0	19
Sr ppm	312	113	52	27	51	137	152	177
U ppm	42	13		13	13.0	13.0	13.0	13
V ppm	314	127	34.5	70	101	122	141	445
Y ppm	312	47.5	5.22	39	43.0	46.0	52.4	57
Zn ppm	314	99.6	35.24	41	49.0	121.0	127.0	180
Zr ppm	312	192	103.4	50	93	200	231	516

Vranov (Table 17) differ only slightly from one another. Investigated samples can be linked as high volatile bituminous coals (R_o 0.62–0.75) with rather low ash contents (A^d 13.5–18.5 %). One strongly mineralized sample comes from the Carboniferous relic near Lísek (A^d 8.9 %) (Pešek et al. 2001). Based on their petrographic properties, these are humite coals with vitrinite contents of 45.4–67.5 vol. %, in which liptinite varies from 5.4 to 25.2 vol. % and inertinite from 9.0–28.2 vol. %. Inorganic components are dominantly clay minerals, kaolinite in particular, while syngenetic pyrite (Fig. 8G), carbonates (calcite, dolomite, sporadic siderite) and quartz were proved in all samples in varying concentrations. Little is known about the coal from Mirošov. It seems to be more coalified (R_o 0.7 % and C^{daf} 73.16–78.6 %), and has a higher content of V^{daf} (39.8–42.11 %), the content of O^{daf} varies between 9.4 and 19.4 % and that of S_t^d between 0.62 and 5.2 %. It is not clear why it was possible to produce high quality coke from the coal of the Mirošov outlier, as opposed to other localities in Central and West Bohemia. Coal samples from Merklín, Lísek and Malé Přílepy have very high contents of Be, Cr, Cs, Cu, Pb, Pt, Rb, and V (Table 16). The sample of coal from the Vranov Carboniferous relic has

Table 13. Selected chemical and technological parameters and petrographic character and contents of selected major and minor elements in coal ashes of the Nýřany Member in the Kladno-Rakovník Basin (Asturian). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
S_t^d %	3	2.8		2.8				2.8
A^d %	41	41.2	23.28	13.9	25.2	29.9	46.3	99.99
Ag ppm	1	2.0		2				
As ppm	1	1260		1260				
Be ppm	1	122		122.1				
Bi ppm	1	0.26		0.26				
Co ppm	1	49		49				
Cr ppm	1	191		191				
Cs ppm	1	17		17				
Cu ppm	1	351		351				
Hg ppm	1	0.009		0.009				
Ir ppb	1	19.5		19.5				
Mo ppm	1	66		66				
Ni ppm	1	205		205				
Pb ppm	1	121		121				
Pd ppb	1	11.2		11.2				
Pt ppb	1	72		72				
Rb ppm	1	64		64				
Rh ppb	1	1.6		1.6				
V ppm	1	204		204				
Zn ppm	1	254		254				

a Co content one order higher than that of the Mirošov coal, and also enhanced concentrations of Be, Cr, Cu, Mo, Ni, V, and Zn (Table 17).

4.7. CARBONIFEROUS OCCURRENCE (RELIC) NEAR BRANDOV IN THE KRUŠNÉ HORY MTS.

This Upper Carboniferous relic lies in the Krušné hory Mts. on the border with the Federal Republic of Germany. Its clastic and volcaniclastic fills are divided into two units of which the lower one (Bolsovian) is coal-bearing. There are four seams of anthracite that reach a maximum thickness of 3 m. The high rank was ascribed by Purkyně (1930) to heat released from intrusions of the Krušné hory granites. Středa et al. (1958) are of the opinion that high rank of coal was a result of pressure imposed during deformation.

RESULTS OF EARLIER STUDIES

Coal seams and their quality
Micropetrographic studies show that the coal mass at Brandov is coalified to the rank of anthracite (R_o 3.86–4.30 %) with a vitrinite content ranging between 86.5 and 96 vol. % and an inertinite content from 4 to 10.5 vol. %. Inorganic components are carbonates, mostly calcite, that fill fractures in the coal, whereas sulfides (pyrite) are less abundant. Other minerals form mixtures with clay minerals (Daněk et al. 1998).

CHEMICAL AND TECHNOLOGICAL ANALYSES AND CONTENTS OF TRACE ELEMENTS

Trace elements in this Upper Paleozoic relic were studied only by Leutwein and Rösler (1956). In five samples, from which the results were averaged, extremely high and/or enhanced contents of Ag, Be, Co, Cu, Ga, Ge, Ni, Pb, Sn, V, and Zn (Table 18) were found. Variability in chemical and technological parameters is shown in analyses made by Středa et al. (1958): V^{daf} 2.8–10 %, A^d 18.8–61.6 %, W_t^r 4.8–13.7 %.

4.8. BOSKOVICE GRABEN

The Boskovice half Graben (BOG) is almost 100 km long and 3–10 km bride. The Rosice-Oslavany coal-bearing Formation (Stephanian C) is steeply inclined along this structure. A maximum of three coal seams occur at the Carboniferous and Permian boundary. The uppermost of those (coal seam No. I) is the best developed reaching 6.5 m in thickness (it is exceptionally as much as 22 m thick).

RESULTS OF EARLIER STUDIES

Coal seams and their quality
Ranks of the majority of these coals are of medium volatile to anthracite with A^d 8.3–67.5 % and also varying S_t^d (max. 5.2 %). The rank of coal expressed by the content of vola-

Table 14. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Nýřany Member in the Žihle Basin (Asturian). Compiled from earlier and recent data

	numb. samples	content
C^{daf} %	1	72.0
H^{daf} %	1	4.8
N^{daf} %	1	1.3
O^{daf} %	1	17.9
V^{daf} %	1	43.6
S_t^d %	1	4.0
A^d %	1	10.8
Ag ppm	1	1.4
Be ppm	1	22.8
Bi ppm	1	0.5
Co ppm	1	58
Cs ppm	1	37
Cr ppm	1	257
Cu ppm	1	327
Hg ppm	1	0.005
Ir ppb	1	0.6
Mo ppm	1	63
Ni ppm	1	261
Pb ppm	1	247
Pd ppb	1	6.0
Pt ppb	1	24.9
Rb ppm	1	125
Rh ppb	1	1.1
Ru ppb	1	1.0
V ppm	1	753
Zn ppm	1	869

tile matter (V^{daf} 15–29 %) and reflectance (R_o 1.24–2.24 %) is to a large extent governed by the depth at which the sample was collected (Franců et al. 1998). Coal seams at a depth of 1,400 m were mined in the second half of the last century. The maceral composition of these coals is chiefly vitrinite ranging from 87.8 to 90.4 vol. %, while inertinite forms 6.5 to 14.4 vol. % of the organic matter. Inorganic components are chiefly clay minerals, carbonates and sulfides.

CHEMICAL AND TECHNOLOGICAL ANALYSES, CONTENTS OF SULFUR AND TRACE ELEMENTS

A few thousand analyses of the main chemical and technical parameters and sulfur contents come from the Survey Department of the former Rosice uhelné doly (Rosice Coal Mines) (Table 19), from data published by Hubáček (1941) and Franců et al. (1998). Of the trace elements only Ge was studied by Kadaňková-Votavová (1960b) and the content of this element in coal ash turned out to be very low.

RESULTS OF RECENT STUDIES

A sample of anthracite with vitrinite reflectance (R_o) 2.05 % contains 74.5 vol. % of vitrinite, 10 vol. % of inertinite and 15.5 % of inorganic components (Fig. 8) consisting mostly of clay minerals, fine-grained syngenetic pyrite, carbonates, quartz and accessory gypsum, apatite and Na-Ca feldspars and decomposed potassium feldspars.

The recently analyzed sample shows only enhanced content of Ag (2.8 ppm), As (220 ppm), Be (19.8 ppm), Cs (13 ppm), and Pt (44.1 ppb).

4.9. BLANICE GRABEN

The Blanice Graben (BG) is a tectonic structure almost 120 km long and 3 to 12 km wide that extends from Český Brod (BGa) in the north through Vlašim (BGb) as far as the environs of České Budějovice (BGc) to the south. It is filled only by clastic deposits of Stephanian C and Lower Permian (Autunian) ages. Coal seams of Stephanian C and Autunian ages reaching a max. thickness of 1.2 m are confined to the Peklov and Lhotice members in the Český Brod region and to the Lhotice Member of Lower Autunian age in the Vlašim and České Budějovice regions.

RESULTS OF EARLIER STUDIES

Coal seams and their quality
Havlena (1960) who made detailed petrographic studies of the local coal reported contents of A^d 2.8–32.5 % and C^{daf} 88–93.8 %. The maceral substance consists mostly of vitrinite with the reflectance (R_o) 2.80–4.77 % (Pešek et al. 2001). The content of inertinite does not exceed 15 vol. %. Abundant clay minerals, sulfides and carbonates constitute the inorganic admixture.

CHEMICAL AND TECHNOLOGICAL ANALYSES, CONTENTS OF SULFUR AND TRACE ELEMENTS

Anthracites from mines near České Budějovice were studied in the 1940s and 1950s by Hubáček (1940 and 1941) and Koblic (1950). The samples examined showed A^d 14.9–22.2 % and S_t^d max. 3.4 % (mostly pyrite sulfur).

Bouška (1966) analyzed five samples of anthracitic coal from the České Budějovic relic in which he found 1 ppm U in coal and 9.5 ppm U in the ash. Optical spectrochemical analysis revealed the occurrence of Ag and enhanced contents of V that are accompanied by a little Ga. No germanium was detected in this coal (Vlášek 1958, Bouška 1966). One notable analysis of a sample collected by F. Ragsky in 1821 near the village of Úsilné in the České Budějovice relic was published by Helmhacker (1874). The sample reportedly contained 78 ppm Ag and 35 ppm Au.

RESULTS OF RECENT STUDIES

Two samples were recently analyzed – one comes from a dump of an abandoned mine near České Budějovice,

Table 15. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of the Slaný Formation in the Mšeno-Roudnice Basin (Stephanian B). Compiled from earlier and recent data

	numb. samples	arithm. mean	stand. deviation	min	Q1	median	Q3	max
W_f^r %	781	13.0		13	13.0	13.0	13.0	13
C^{daf} %	42	79.8	4.67	66.6	78.9	79.5	83.8	83.8
H^{daf} %	42	5.3	0.35	4.9	4.9	5.3	5.6	6.0
N^{daf} %	34	2.5	0.63	1.6	1.9	3.1	3.1	3.1
O^{daf} %	29	11.4	5.79	7.7	7.7	7.7	13.7	25.7
V^{daf} %	629	43.5	4.07	30.0	41.4	43.3	45.0	89.0
S_t^d %	692	2.1	2.10	0.04	0.9	1.5	2.5	18.4
A^d %	775	32.7	19.20	3.6	19.4	30.6	39.6	96.8
As ppm	21	151	268.6	17	27	87	123	1076
Be ppm	1	35						
Bi ppm	1	0.9						
Cd ppm	1	2.8						
Cl ppm	19	77.5		25.1	38.3	65.7	126.9	160
Co ppm	1	36						
Cr ppm	1	128						
Cu ppm	1	269						
F ppm	19	40		12.3	18.6	25.3	33.3	40
Ge ppm	3	95.1						
Hg ppm	1	0.012						
Mo ppm	1	18						
Ni ppm	1	122						
P ppm	8	0.08						
Pb ppm	1	266						
Rb ppm	1	36						
V ppm	1	522						
Zn ppm	1	577						

the other one was collected from a dump near Vlašim, now totally leveled (Table 20). Anthracites from the České Budějovice relic (V^{daf} 13 %) has an enhanced content of A^d (6.5–25.1 %), which is mirrored by a decreased concentration of C^{daf} (81.3–93.8 %). The organic component is mostly vitrinite (70.0 vol. %) with the R_o equal to 3.5 % and inertinite (9 vol. %). The inorganic component (26.5 vol. %) consists chiefly of abundant clay minerals, carbonates (Ca, Mg, Fe and calcite), quartz and accessory chlorite (Fig. 8H). The recent analyses revealed slightly higher mean contents of Ag, As, Au, Mo, Pt, Rb, and V.

4.10. IDENTIFICATION AND LOCATION OF SOURCE AREAS

After assessment of the occurrence of individual elements in Upper Paleozoic hard coal basins in the CR the question arose as to whether there is any possibility of defining the source from which they were derived. Numerous ore deposits are situated in a close proximity or at greater distances from the coal deposits studied. These could have been the source of a number of the elements found in local coals. It is notable that the Bohemian Massif covers a substantial part of the Czech territory. It is a unit consolidated during the Variscan orogeny, being formed of Precambrian, Paleozoic, Mesozoic and Cenozoic rocks. The Lower Autunian sediments contain the youngest hard coal seams and at least 290 Ma have elapsed since that time during which parts of the Bohemian Massif were by turn sedimentary source areas and also areas covered by deposition of clastic and volcaniclastic sediments. Between the Saxonian and the Upper Cretaceous (Cenomanian up to Santonian) and also during the Paleogene and Neogene the greater part of the Bohemian Massif was not covered by sediments and was often exposed to relatively intense erosion and denudation. This can be documented through exposure of high-grade metamorphic rocks in the whole of the southern part of the Bohemian Massif, and numerous Variscan granitoid plutons are also exposed in many parts of the massif. For instance, Sattran (1957) estimated that at least 6.5 km of rocks had been denuded from the eastern part of the Krušné hory crystalline complex during the interval of time from the Lower Carboniferous until the Recent. There is good evidence that the sediments of the Upper Paleozoic basins, the Mesozoic, Paleogene and

Table 16. Contents of selected minor elements in coal ashes of Carboniferous relics at Merklín (MeR), Lísek (LiR) and Malé Přílepy (MP) (Bolsovian)

	MeR	LiR	MP
Ag ppm	0.8	0.8	0.8
As ppm		34.7	
Be ppm	50.6	23.3	10.5
Bi ppm	0.6	0.2	0.3
Cd ppm	0.8	0.8	0.8
Co ppm	71	75.0	19
Cr ppm	187	43.0	213
Cs ppm	104	242	49
Cu ppm	193	293	121
Hg ppm	0.005		0.005
Ir ppb	1.8	0.6	
Mo ppm	5	19.0	11
Ni ppm	91	152	107
Pb ppm	120	81.0	73
Pd ppb	10.6	11.5	
Pt ppb	12.0	24.1	
Rb ppm	241	246	196
Rh ppb	1.0	0.2	
Ru ppb	1.0	1.0	
V ppm	344	454	354
Zn ppm	137	118	118

Neogene covered much larger areas than can be seen at present.

For these reasons it is a problem to draw inferences about the source areas of elements identified in numerous samples of coals and their ashes. Although some Pb-Zn deposits with high Ag in galena lie in the close vicinity of coal-bearing Carboniferous relics near Vranov and Merklín, the contents of the above-mentioned elements in the Nýřany and/or Radnice coal seams can hardly be considered high. Similarly, the low contents of Pb and Zn found in the coals of the České Budějovice relic of the BG are difficult to relate to a base metal deposit in the close vicinity that was already being mined in medieval times. Perhaps only enhanced contents of Ag in ash from the local coal could be connected with this deposit. Such examples and other inconsistencies led us to the conclusion that it was not feasible to make credible predictions about the origins of trace elements in the coals of the Bohemian basins.

5. Discussion and conclusions

The inorganic components play an important role in determining the chemistry of coal since they are the major source of trace elements. Sulfides in our bituminous coals and anthracites are the source of As, Cu, Ni, Pb and Zn, whereas clay minerals absorb, for instance, Ga, Sc, Sr and

Table 17. Basic chemical and technological characteristics and contents of selected major and minor elements in coal ashes of Carboniferous relics near Vranov (VR) and Mirošov (MiR) (Asturian)

	VR	MiR
W_f^r %	3.7	
C^{daf} %	76.9	78.6
H^{daf} %	5.0	5.2
N^{daf} %	1.5	1.5
O^{daf} %	16.1	9.4
V^{daf} %	35.3	39.8
R_o %	0.7	
S_t^d %	1.1	5.2
$S_p^{\ d}$ %	0.4	
S_{SO4} %	0.2	
$S_0^{\ d}$ %	0.5	
Q_s^{daf} MJ.kg^{-1}	29.5	
A^d %	16.8	11.3
Ag ppm	0.8	1.8
As ppm	48.3	
Be ppm	49.0	17.6
Bi ppm	0.9	5.3
Cd ppm	< 0.8	
Co ppm	296	22
Cr ppm	153	145
Cs ppm	20	
Cu ppm	593	113
Hg ppm	0.011	< 0.005
Ir ppb	0.2	
Mo ppm	26.0	22
Ni ppm	684	65
Pb ppm	72.0	286
Pd ppb	4.5	
Pt ppb	11.5	
Rb ppm	24.0	60
Rh ppb	1.0	10
Ru ppb	0.5	< 10
V ppm	775	350
Zn ppm	409	109

Rb. In the case of a number of elements (As, Be, Co, Ge, Ni, Sb, Sr, U, V and Zr) it is often a problem to establish unambiguously their affinity with the inorganic or organic component of the coal or even with a specific mineral.

Statistical treatment of data from more than fifty thousand chemical and technological analyses of coal and coal ashes from the Upper Paleozoic basins of the CR have contributed to a better knowledge of the quality of coals, with regard to ash and sulfur contents and the distribution of trace elements. Because of the diversity of samples and analyses included in the database (older and newly analyzed samples, various analytical methods, etc.) and the