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GEOCHEMISTRY OF FLYSCH SEDIMENTS AND ITS APPLICATION IN GEOLOGICAL INTERPRETATIONS

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Abstract: On the basis of very similar mineralogic-geochemical character of the sediments of the Subchert beds and the Menilite Formation of the Silesian and Ždánice units it is possible to state that the sediments of the Subchert beds which were in the past assigned to the Submenilite Formation belong to the Menilite Formation.

Results of the mineralogic-geochemical study of the Krosno beds of the Silesian unit and Ždánice-Hustopeče Formation of the Ždánice unit suggest that the source areas of the investigated sediments were similar and that the sediments originated from a single important source area. During the deposition of the Krosno beds and Ždánice-Hustopeče Formation, clastic material was not transported from the deeply eroded Bohemian Massif, but more probably it was supplied from the east – Magura zone area.

Key words: Western Carpathians, sediments, flysch, analytic and geochemical methods, geochemical correlations.

Introduction

In recent years I carried out mineralogic-geochemical research of flysch sediments in the western part of the Czechoslovak Carpathians. Significant tectonic units of the Carpathian Flysch Belt – Silesian, Ždánice-Subsilesian and Pouzdřany ones have been characterized in detail as regards their petrographic-mineralogical and geochemical properties (determination of geochemical characteristics of rocks based on the study of major and trace element concentrations, determination of their distribution, correlation relationships and geochemical background values in rocks of individual lithostratigraphic members of the studied tectonic units with possible application of geochemical evaluation for their distinguishing and stratigraphic correlation; Adamová 1983, 1986, 1988; Adamová and Stráník 1984).

This work is aimed at the application of geochemical data interpretation by the study of sediments of the Subcherty beds of the Menilite Formation of the Silesian and Ždánice units (the question of the assignation of the Subcherty beds) and at geochemical correlation of sediments of the Krosno beds of the Silesian unit and Ždánice-Hustopeče Formation of the Ždánice unit.

Research methodics

Chip samples for the study (1.5 to 4.0 *kg* depending on planned analyses) were continuously collected from superficial outcrops and deep drillholes. All the samples were divided into individual lithostratigraphic sets on the basis of lithology, stratigraphy and type of sample collection. List of sampling sites is given in Adamová (1983, 1986).

Analytic methods

All the samples were analysed at laboratories of Geologický průzkum n. p. (Geological Survey) Ostrava, plant Brno. Standard set of trace elements was termined by X-ray fluorescent spectral analysis (by the apparatus Philips PW 1410 with a 3 kW generator) with the following sensitivity (in *ppm):* As (5), Ba (50), Co (5), Nb (5), Ni (5), Pb (5), Rb (5), S (100), Sb (3), Sr (10), TiO_2 (20), U (10), V (5), Y (5), Zn (5), Zr (5). Emission spectral analysis (spectograph of the firm Zeiss, type PGS 2 with a plane screen) was employed to determine concentrations of Ag (0.66), B (9), Ga, Mo and Sn (1). Contents of Sm (1), La (1), Au (0.05), Ce (1), Yb (1), Lu (0.01), Th (1), Eu (0.1), Tb (1), Rb (10), Co (1), Hf (1), Sb (1) and U (3) were determined by the method of instrumental neutron activation analysis at laboratories of Geoindustria n. p. Prague (threshold of sensitivity in ppm). U, Th, Ra and K contents were determined by gammaspectrometric analysis (laboratories of Geofyzika n. p. Brno) in selected samples from individual lithostratigraphic members of studied sediments. The threshold of sensitivity of this method is following: U – 1.2 *ppm*, Ra – 0.13 *ppm* (expressed in U equivalent concentration), Th – 0.4 *ppm* and K – 0.07 %.

Complete silicate analyses were carried out at laboratories of Ústřední ústav geologický (Central Geological Institute)

Prague and Geologický průzkum n. p. Ostrava, plant Brno. All analyses were carried out in the samples in their original state (without separation).

Mineralogical composition of selected samples was studied by means of X-ray diffraction analysis and was compared with the results of differential thermic analysis. Some samples were analysed in detail by means of diffraction phase analysis (Ústřední ústav geologický, Prague) which is based on the determination of the best correlation between measured diffraction data of a sample and theoretical diffractogram of mixture (Moravcová and Fiala 1980). Heavy minerals were analysed in selected samples of studied sediments (laboratories of Ústřední ústav geologický, Prague).

Organic matter was analysed at laboratories of Moravské naftové doly (Moravian Petroleum Mines), Hodonín by a standard method determining individual genetic types of organic substance in a decalcinated rock.

Geochemical methods

Development of the chemical composition of flysch rocks is closely associated with the history of the geotectonic development of the geosynclinal area. Chemical composition of the sediments was controlled predominantly by the tectonic regime, composition of source areas and hydrodynamic regime of the basins. Complete recognition of the rock character requires the study of major chemical components of the rocks as well as study of concentrations, distributions and correlation relationships of trace elements supplemented by the research of their mineral composition and organic matter.

The principal classification criterion of statistical treatment was classifying of original data according to their assignation to a certain tectonic unit into individual lithostratigraphic populations. Basic statistical treatment within these populations was carried out in RVS Geoindustria n. p., Prague.

Average contents of evaluated elements thus obtained in the individual lithostratigraphic populations were:

a) compared to clark values of the corresponding lithological sediment type (Ronov et al. 1965; Wedepohl 1968; Kraft et al. 1969; Krauskopf 1967; Fairbridge 1972);

b) changes in element concentrations in individual lithostratigraphic members of the studied tectonic unit were observed;

c) data concerning sediments of the same lithostratigraphic position from the individual tectonic units were mutually compared.

In addition to the study of major and trace element concentrations, geochemical characteristics of rocks requires also comparison of ratios of selected pairs of studied elements and observation of changes in average values of these ratios between lithostratigraphic members of a tectonic unit or between individual tectonic units. For example, SiO_2/Al_2O_3 ratio in excess of 3 (Kukal 1962) indicates the share of clastic quartz or other SiO_2 forms of more than 25 %, whereas Al_2O_3/Na_2O ratio (Pettijohn 1957) expresses chemical maturity of pelitic sediments (in chemically most mature sediments the ratio may reach 125). $Al_2O_3 + K_2O/Na_2O + MgO$, K_2O/Na_2O, Rb/K_2O ratios represent, according to Taylor (1965), Bjørlikk (1974 a, b) and Dipvik (1977), other indices of pelitic sediment maturity. Lower values of $\Sigma\, Fe/P_2O_5$ ratio suggest possible enrichment of the sediment in phosphorus, e.g. of organic origin. Fe_2O_3/FeO ratio determined in fresh rocks from drillholes may be used to characterize redox of the environment. Increased values of Ti/Zr, V/Zr, Ni/Co, Mn/V and V/Cu indicate that mafic rocks were more significantly involved in the flysch sediment formation. On the other hand, prevailing high Ti/Cr, Cu/Ni, V/Cr, Zr/Ni and Zr/Cr values suggest that also fragments of acid and intermediate rocks were deposited.

Increased La/Th values and low Th/U values indicate presence of volcanogene material in the sediment (Mc Lennan 1980; Bhatia and Taylor, 1981).

Pliler and Adams (1962) give the average K/Th value for pelitic sediments of 2200. Increased values of this ratio may, for example, reflect very rapid (even abrupt) sedimentation leaving little time for sorption of Th (Adamová 1986 – Godula formation of the Silesian unit).

Determination of the character of sedimentary environment, particularly salinity, is significant not only for the paleogeographic studies but also as an indirect method of stratigraphic correlation. Geochemical methods make it possible to distinguish only substantial differences in the salinity of sedimentary environment. It results from works dealing with these problems (Ernst and Werner 1964; Tourtelot 1964; Walker 1968; Cody 1970; Reynolds 1965, 1972; Bouška 1980; Adamová 1988b) that boron (and so-called equivalent boron – Reynolds 1965) and Th/U ratio (Adams and Weaver 1958) are especially suitable for the determination of the original salinity of a given environment.

Geological characteristics

The Carpathian Flysch Belt constitutes part of nappes (Inner Carpathian allochthon) which were folded and overthrust onto the original foreland of the Bohemian Massif and onto the Oligocene foredeep filling in the course of Savian and Styrian orogenic phases (Menčík et al. 1983). The Outer Carpathian Flysch Belt in Moravia and western Slovakia is divided into peripheral, central and Magura group. The Silesian and Ždánice-Subsilesian units comprise to the central group (Fig. 1).

In the Silesian unit, only its succession of strata of the Godula development (Upper Jurassic–Oligocene) was studied. Because of its areal extent, this development plays a decisive role in the structure of the Silesian unit in northern Moravia and is of prime importance for understanding the principal geochemical factors. In the Ždánice-Subsilesian unit, most attention was paid to the investigation of the Ždánice portion in which the sedimentary filling of the original geosynclinal area reached maximum thicknesses with a complete succession of strata from the Upper Cretaceous to Egerian.

The Submenilite Formation, the uppermost part of which is represented by the Globigerina Marls, is developed in the Silesian as well as Ždánice unit (its stratigraphic range in the Ždánice unit is Campanian–Lower Oligocene, in the Silesian unit it spans Paleocene–Upper Eocene). The Globigerina Marls are overlain by the so-called Subcherty beds until recently regarded as part of the Submenilite Formation.

An important correlation horizon in the Flysch Belt outer units is the Menilite Formation (Lower and Middle Oligocene) overlying the Subcherty beds. The formation consists of a lithologically varied sequence in which following beds can be distinguished from bottom to top: Cherty beds, Dynów Marlstones and in the Ždánice unit Šitbořice beds (Stráník 1981; Brzobohatý and Stráník 1981).

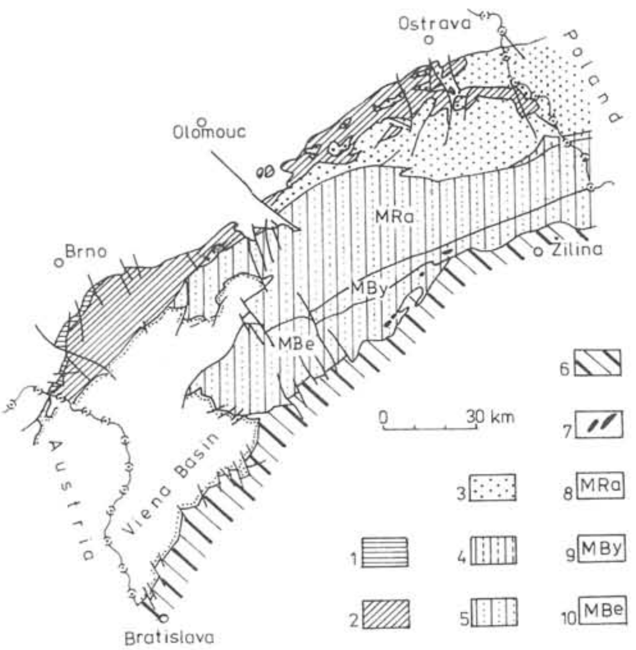

Fig. 1. Tectonic Flysch Units of the Moravian and West Slovakian region (Czechoslovakia).
1 – Pouzdřany unit; 2 – Ždánice-Subsilesian unit; 3 – Silesian unit; 4 – Fore-Magura unit; 5 – Magura flysch group; 6 – Mesozoic of the Klippen zone, Mesozoic of the Central Carpathians; 7 – Jurassic Klippes of the Pavlov Mts.; 8 – Račany unit; 9 – Bystrica unit; 10 – White Carpathians unit.

The youngest sediments of the Silesian unit are the Krosno beds (Oligocene), whereas in the Ždánice unit sedimentation represented by the Ždánice-Hustopeče Formation (Upper Oligocene–Lower Miocene) continued until the Miocene. The latter formation, which is areally the most extensive part of the Ždánice unit, is characterized by a great facies variability. Following developments have been distinguished within the formation: psammitic (so-called Ždánice Sandstones), psammitic-pelitic (flysch) and pelitic one (so-called Hustopeče Marls, Rzehak 1881). Laterally, the individual developments give way to one another. The Krosno beds in the Moravsko-Slezské Beskydy Mts. are present in incomplete thicknesses of less than 1000 metres and are characterized by alternating non-flysch and flysch, medium- to coarse-rhytmical sequence of gray calcareous claystones and thin- to thick-bedded micaceous calcareous sandstones.

Geochemical data interpretation by the study of sediments of the Subcherty beds and Menilite Formation of the Ždánice and Silesian units

Petrographic-mineralogical characteristics

Until recently the Subcherty beds were considered as the uppermost layer of the Submenilite Formation. They consist of brown variable-silty bedded noncalcareous as well as calcareous claystones, marlstones to clayey limestones. In addition to quartz, the minerals present include significant amounts of cristobalite which is always associated with zeolite (clinoptilolite) and montmorillonite. (Numerous authors: Hay 1966; Reynolds 1970; Mizutani 1970; Hurd 1973, regard joint occurrence of these minerals in sediments as a result of alteration of fine-grained volcanic material). Some samples contain small amounts of mica minerals, exceptionally also kaolinite. Feldspar contents are low, amphibole, jarosite, gypsum and barite occur locally. Contents of carbonates, particularly those of calcite, are very variable – from traces to 65 %. Organic matter and pyrite are present in increased contents.

The Cherty beds of the Menilite Formation are represented by brown and black-gray variable-silicified noncalcareous and slightly calcareous claystones with intercalations and thin bands of light-gray diatomites and diatom claystones. In addition to quartz, mainly cristobalite and montmorillonite are present. SiO_2 occurs also in the amorphous form as opal or chalcedony, in some samples tridymite was identified. Mica minerals are scarce or absent, kaolinite occurs even more rarely. Zeolite, jarosite, gypsum and barite were found in numerous samples. Contents of carbonates are low, with dolomite frequently predominating. Pyrite and organic matter contents are increased.

Geochemical characteristics

Rocks of the Cherty beds of the Menilite Formation and those of the Subcherty beds show highest SiO_2 contents (Tab. 1) as well as highest SiO_2/Al_2O_3 ratios (5.1 to 25) reflecting the intesity of their silicification, lowest Σ Fe contents (with FeO prevailing in drillhole samples), lower Na_2O contents and highest concentrations of P_2O_5 (P is somewhat enriched relative to Fe, the enrichment being in good correlation also with the highest contents of organic matter suggesting that P is partly of organic origin). The studied sediments are characterized by the highest contents of As, Ba, S (sulphur is likely to be in part of organic origin), Mo, V and U (Tab. 2). Higher Mo and U contents may be, according to many authors, increased due to the presence of pyroclastic material. This fact well corresponds to a high Mo content, particularly in the Silesian unit tuffite (intercalations of tuffitic deposits in the Menilite Formation which consist of quartz, cristobalite, montmorillonite, in the Silesian unit the tuffites contain also chlorite, sometimes zeolite and traces of amphibole and feldspar). The tuffitic sediments contain the highest amounts of Mn, As, Ni, U, increased amount of Mo and in the Silesian unit mainly V. Biochemical concentration of Mo depends on the character of plankton prevailing in the sedimentary basin. According to Aron et al. (1955), molybdenium is a biocatalyzer significantly activating transformation of nitrates to nitrites in blue-green and green algae. Calcareous-plankton-dominated sediments contain higher Mo concentrations. Important hosts to V are clay minerals, mainly montmorillonite-group minerals and Fe-oxidic ones. Vanadium also tends to concentrate biochemically in sediments dominated by siliceous plankton where it acts as a catalyzer in the photosynthesis process (Harvey 1939; Aron and Wessels 1953). This element is preserved in sediments because it forms solid metaloorganic complexes. Increased V contents may occur in pyroclastic material (high content of vanadium in the Silesian unit tuffite – 1121 *ppm*). Increased Mo and V contents in the Subcherty beds and Menilite Formation correspond to a mixed character of plankton. The study results suggest that Mo and V in the investigated sediments concentrated both biochemically (high positive correlations with Mo, U, Cu, Ni and organic matter)

Table 1. Mean contents (m — median) of major element oxides (in %) and mean rations of selected oxides of major elements in rocks of the Menilite Formation, Krosno beds and Ždánice-Hustopeče Formation of the Silesian and Ždánice units (samples from outcrops).

a) *Silesian unit*

Stratigraphic position and lithology			No. of samples	SiO_2 m	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	CO_2	P_2O_5	H_2O^+	SiO_2/Al_2O_3	Al_2O_3/Na_2O	K_2O/Na_2O	$(K_2O+Na_2O)/Al_2O_3$	MgO/Al_2O_3	CaO/Al_2O_3	Σ Fe oxides/Al_2O_3	Σ Fe oxides/P_2O_5
Krosno beds claystones			10	45.0	12.9	1.5	3.0	0.07	4.0	10.9	0.8	2.5	10.1	0.15	4.4	3.5	18.6	3.6	0.26	0.32	0.9	0.38	34.0
Menilite Formation	Cherty beds	cherts	1	80.2	4.1	2.17	0.35	0.03	0.53	0.81	0.1	0.65	0.15	0.49	11.4	19.9	40.3	6.5	0.19	0.13	0.2	0.65	5.2
Menilite Formation	Cherty beds	claystones	12	55.1	13.4	1.9	2.8	0.04	1.4	4.1	0.5	2.3	3.1	0.30	7.1	4.8	40.2	6.2	6.2	0.11	0.4	0.41	29.0
Menilite Formation	Subcherty beds marlstone		1	21.05	7.6	2.0	0.62	0.06	0.70	30.03	0.04	1.03	24.33	0.16	6.0	2.7	190	25.8	0.14	0.09	4.0	0.34	16.4

b) *Ždánice unit*

Stratigraphic position and lithology			No. of samples	SiO_2 m	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	CO_2	P_2O_5	H_2O^+	SiO_2/Al_2O_3	Al_2O_3/Na_2O	K_2O/Na_2O	$(K_2O+Na_2O)/Al_2O_3$	MgO/Al_2O_3	CaO/Al_2O_3	Σ Fe oxides/Al_2O_3	Σ Fe oxides/P_2O_5
Ždánice-Hustopeče Formation		flysch development, claystones	11	50.0	12.4	2.8	1.4	0.06	4.4	11.1	0.9	2.5	10.1	0.16	4.0	4.1	15.7	3.0	0.27	0.36	0.94	0.34	28.5
Ždánice-Hustopeče Formation		pelitic development, claystones	9	48.2	11.6	2.8	1.3	0.06	4.8	11.7	0.9	2.1	11.9	0.12	3.6	4.1	13.9	2.6	0.26	0.41	1.04	0.37	38.4
Menilite Formation	Cherty beds	silicites	7	81.1	4.8	1.4	0.6	0.04	0.55	0.6	0.2	0.7	0.3	0.12	4.2	25.1	24.1	3.4	0.21	0.10	0.19	0.39	16.2
Menilite Formation	Cherty beds	claystones	14	73.1	10.0	3.0	0.3	0.01	1.0	1.2	0.2	1.3	0.5	0.33	4.9	10.8	53.3	6.4	0.17	0.11	0.16	0.35	15.3
Menilite Formation	Cherty beds	tuffite	1	68.8	15.3	3.3	0.16	2.02	1.04	1.71	0.17	0.49	0.57	0.25	6.95	4.5	89.8	2.9	0.04	0.07	0.11	0.23	13.8
Menilite Formation	Subcherty beds	claystones	4	64.1	10.3	3.4	0.2	0.03	1.2	6.7	0.3	1.3	5.1	0.22	6.5	7.5	34.8	5.0	0.17	0.12	0.62	0.38	18.0
Menilite Formation	Subcherty beds	marlstones	3	21.0	6.7	3.4	0.2	0.08	0.8	35.0	0.2	0.9	27.1	0.24	2.9	3.0	39.0	5.2	0.16	0.12	5.5	0.55	20.5

Σ Fe oxides is expressed as Fe_2O_3

Table 2. Mean contents ($\bar{x}$, in populations of less than 25 samples — m) of studied trace elements (in *ppm*) in rocks of the Menilite Formation, Krosno beds and Ždánice-Hustopeče Formation of the Silesian and Ždánice units (samples from outcrops).

a) *Silesian unit*

Stratigraphic position and lithology			No. of samples	Ag $\bar{x}$ (m)	As	B	Be	Ba	Co	Cr	Cu	Ga	Mo	Nb	Ni	Pb	Rb	S	Sb	Sn	Sr	Th	U
Krosno beds — claystones			27	0.14	11.3	78	2.3	365	14	100	40	13.5	6.1	9.8	61	21	112	6 940	1.9	1.9	210	9.2	4.2
Menilite Formation	Cherty beds	cherts	1	< 0.06	18.0	32	—	269	< 5	34	36	5.0	15.0	< 5	18	< 5	21	3 800	< 1	< 1	85	3.1	2.1
		claystones	25	0.2	22.0	92	6.5	360	15	120	61	22.6	24.4	14.3	71	23	120	11 128	1.5	3.8	158	8.4	10.6
		tuffite	1	< 0.06	24	31	—	529	26	110	43	13.0	20	9	80	22	42	8 100	2.7	< 1	233	6.3	21.4
	Subcherty beds claystone marlstone		1 1	< 0.06	12 9	106 60	— —	339 219	22 5	122 60	94 59	26 2	7 2	14.0 9.0	69 57	30 6	94 41	17 000 8 800	2 < 1	1 < 1	209 1 000	11.5 3.5	10.2 4.7

b) *Ždánice unit*

Formation	Beds	Lithology	No. of samples	Ag $\bar{x}$ (m)	As	B	Be	Ba	Co	Cr	Cu	Ga	Mo	Nb	Ni	Pb	Rb	S	Sb	Sn	Sr	Th	U
Ždánice-Hustopeče Formation		flysch development — claystones	26	0.1	7.6	71	4.8	316	10	104	30	9.7	3.5	10.6	44	20	108	499	1.3	1.6	188	9.0	2.9
		pelitic development — claystones	25	0.1	4.0	97	2.4	312	8	110	27	13.3	3.0	9.6	34	17	101	274	3.8	1.6	242	7.0	2.4
Menilite Formation	Cherty beds	silicites	18	0.07	4.6	28	1.1	241	5.0	27	23	1.3	3.5	4.2	10	6	19	795	2.7	2.0	94	2.4	5.8
		claystones	23	0.12	10.0	74	1.2	452	10	72	58	7.8	16.5	9.1	34	15	55	2 451	2.3	< 2.3	148	5.9	7.3
		tuffites	2	< 0.06	34—47	35—58	3.0	158—186	5—15	30—36	50—69	4—5	5	8—10	108—110	5	20—25	< 100—200	1—8	< 1—3	22—85	5,0—6.2	21,4—26.2
	Subcherty beds	claystones	13	0.07	23.0	45	1.9	1010	14	76	69	10.7	16.0	8.0	83	11	51	678	3.0	1.1	852	5.0	10.2
		marlstones	3	< 0.06	16.7	48	1.3	267	10	80	52	5.7	20.3	5.0	69	14	32	533	3.3	< 1	1 179	5.1	9.8

Mean ratios of selected pairs of trace elements

a) *Silesian unit*

Continuation of Tab. 2

Stratigraphic position and lithology			No. of samples	Ti x̄ (m)	V	Y	Zn	Zr	B eq.	B/Ga	Sr/Ba	Ni/Co	Ti/Zr	V/Zr	V/Ni	V/Cu	V/Cr	Cr/Ni	Ti/Cr	Cu/Ni	Zr/Ni	Zr/Cr	Ga/V
Krosno beds claystones			27	3310	183	25	93	135	301	11.5	0.6	5.6	25	1.4	3.2	5.5	1.8	1.8	35	0.7	2.9	1.4	0.07
Menilite Formation	Cherty beds	cherts	1	1439	92	7	19	25	592	6.4	0.3	9.0	58	3.7	5.1	2.6	2.7	1.9	42	2.0	1.4	0.7	0.05
		claystones	25	4615	310	24	91	174	371	5.6	0.4	5.2	29	1.9	5.2	5.4	2.7	1.9	39	0.9	2.5	1.4	0.08
		tuffite	1	3777	1121	14	105	80	—	2.4	0.4	3.0	47	14.0	14.0	26.0	10.2	1.4	34	0.5	1.0	0.7	0.01
	Subcherty beds, claystones marlstones		1 1	4436 1829	247 204	26 18	102 53	150 28	448 370	4.1 18.0	0.6 4.5	3.1 11.4	30 65	1.6 7.3	3.6 3.6	2.6 3.5	2.0 3.4	1.8 1.1	36 31	1.3 1.0	2.1 0.5	1.2 0.5	0.09 0.01

b) *Ždánice unit*

Stratigraphic position and lithology			No. of samples	Ti x̄ (m)	V	Y	Zn	Zr	B eq.	B/Ga	Sr/Ba	Ni/Co	Ti/Zr	V/Zr	V/Ni	V/Cu	V/Cr	Cr/Ni	Ti/Cr	Cu/Ni	Zr/Ni	Zr/Cr	Ga/V
Ždánice-Hustopeče Formation		flysch development -claystones	26	3225	178	20	89	127	196	8.5	0.6	5.1	28	1.6	4.3	6.0	1.7	2.4	32	0.7	2.9	1.3	0.06
		pelitic development -claystones	25	2982	158	25	88	101	251	11.0	0.8	6.3	30	1.7	3.7	6.4	1.5	2.5	29	0.6	2.3	1.0	0.08
Menilite Formation	Cherty beds	silicites	18	1091	76	9	21	20	408	18.2	0.6	2.4	53	4.6	18.0	3.4	2.5	2.9	36	2.9	4.6	0.7	0.03
		claystones	23	2497	220	17	55	73	548	8.6	0.4	3.4	41	3.1	13.0	3.7	2.5	4.2	35	2.5	3.1	0.9	0.04
		tuffites	2	2639— 2758	108— 113	11— 16	145— 164	101— 121	241— 911	7.0— 14.5	0.2— 0.5	7.3— 21.6	22— 27	1.0— 1.1	1.0	1.6— 2.2	3.1— 3.6	0.3	73— 92	0.5— 0.6	1.0— 1.1	3.3	0.04
	Subcherty beds	claystones	13	2284	298	22	78	47	402	5.8	1.1	5.6	48	6.3	3.2	4.5	3.7	1.0	29	0.8	0.6	0.5	0.04
		marlstones	3	1700	312	17	53	38	378	8.2	4.7	7.8	45	8.2	4.2	5.7	3.8	1.1	22	0.7	0.5	0.5	0.02

Table 3. Mean contents (median — in *ppm*) of rare-earth elements (REE) and Hf, mean La/Th, Th/Yb, La/Ce, Th/U, Hf/Zr, K/Th, ratios, mean contents (median) of organic matter (given in C *wt* % in rock) and percentage of individual genetic types (expressed by so-called carbon balance) in studied sediments of the Silesian and Ždánice units.

a) *Silesian unit*

Stratigraphic position and lithology			No. of samples	La m	Ce	Sm	Eu	Tb	Yb	Lu	ΣREE	Th/Yb	La/Th	La/Ce	Th/U	Hf	Hf/Zr	K/Th	No. of samples	C_{org}	% C_{res}	% C_{hum}	% C_{bit}
Krosno beds — claystones			8	31.8	59	5.8	1.2	< 1	2.1	0.36	100	4.5	3.34	0.53	2.5	4.0	0.03	2372	10	0.741	94.4	0.80	4.9
Menilite Formation	Subcherty beds	chert	1	7.4	13.2	1.38	0.28	< 1	< 1	0.10	23	—	2.08	0.56	3.5	1.07	0.04	1052	1	3.694	93.2	1.1	5.7
		claystones	11	31.0	59.	5.9	1.3	< 1	2.2	0.36	105	3.9	3.7	0.53	0.8	4.5	0.03	2260	10	3.919	92.4	1.1	5.9
		tuffite	1	20.5	35.9	4.97	1.23	< 1	< 1	0.28	63	—	3.30	0.57	0.3	3.3	0.04	—	—	—	—	—	—
	Cherty beds	calcareous claystone	1	17.4	33.7	3.58	0.77	< 1	< 1	0.28	53	—	3.17	0.52	0.6	< 1	—	1704	1	4.522	94.6	0.8	4.4
		marlstone	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	8.434	95.8	1.1	3.4

b) *Ždánice unit*

Stratigraphic position and lithology			No. of samples	La m	Ce	Sm	Eu	Tb	Yb	Lu	ΣREE	Th/Yb	La/Th	La/Ce	Th/U	Hf	Hf/Zr	K/Th	No. of samples	C_{org}	% C_{res}	% C_{hum}	% C_{bit}
Ždánice-Hustopeče Formation		flysch development — claystones	5	28.0	53	5.1	1.13	< 1	1.9	0.31	90	4.6	3.0	0.53	3.1	3.4	0.03	2492	8	0.347	87.4	9.2	3.3
		pelitic development — claystones	4	22.5	44	4.2	0.9	< 1	1.9	0.27	75	3.9	3.0	0.51	2.4	3.1	0.04	2400	5	0.282	93.0	4.0	3.1
Menilite Formation	Cherty beds	cherts	4	7.2	15	1.3	0.26	< 1	< 1	< 0.01	24	—	3.1	0.50	2.3	< 1	—	3345	6	0,631	84.1	10.0	5.9
		diatomite	1	29.0	40	3.5	1.04	< 1	1.7	0.40	75	2.8	3.2	0.73	2.3	1.5	0.03	2320					
		claystones	7	24.0	40	4.2	1.0	< 1	1.8	0.24	72	3.8	3.3	0.60	0.8	2.8	0.03	2125	10	1.311	84.0	9.8	6.2
		tuffites	2	14.9— 16.3	33— 45	7.0— 7.4	1.39— 1.59	< 1	2.1— 2.5	0.35— 0.41	52— 73	2.0— 2.45	3.0— 3.3	0.36	0.22— 0.23	2.6— 3.7	0.03	817— 1032	—	—	—	—	—
	No. of samples	marlstone, calcareous claystone, claystone	6	21.5	42	4.1	1.0	1.0	1.5	0.35	65	3.2	3.8	0.51	0.8	1.7	0.04	1806	1 1 1	0.203 0.500 1.198	82.8 83.0 89.8	12.8 12.5 9.0	4.4 4.5 1.2

as well as from pyroclastic material which was a primary source of at least part of these two elements. Uranium in the investigated sediments is probably of syngenetic origin and concentrates by sorption on planktonic organisms or organic substance during its bitumenization. The highest contents were observed in diatomites with fairly bitumen-rich organic substance. Transport of uranium associated with pyroclastic material into the basin of deposition is suggested by the increased content of this element in tuffitic sediments of the Menilite Formation of the Silesian as well as Ždánice units.

Ti, Y and rare earth (REE) contents (Tab. 3) in the Subcherty and Cherty beds of the Menilite Formation are relatively low, the sediments being characterized by the highest values of La/Th ratio (Tab. 3) and lowest ones of Th/U ratio. The same character was observed in the tuffitic material (increased La/Th and low Th/U values indicate presence of a material of volcanogene origin – Bhatia and Taylor 1981; Mc Lennan et al. 1981). High contents of organic matter, pyrite, generally low contents of total Fe dominated by FeO, similar concentrations of B and B equivalent values suggest clearly reducing character of the sedimentary environment of the Subcherty beds and Menilite Formation (particularly of the Cherty beds) only slightly communicating with the open sea and with normal to slightly increased salinity. Low Ti, Rb, Zr, Cr and Fe contents indicate minimum transport of clastic material.

Geochemical correlation between the Krosno beds of the Silesian unit and Ždánice-Hustopeče Formation of the Ždánice unit

Petrographic, mineralogical characteristics

The Krosno beds, gray variable-sandy calcareous claystones and marlstones are mineralogically characterized by quartz contents ranging from 25 to 30 % and higher proportion of feldspars amounting up to 15 %. Mica minerals (illite group and fine mica) which amount to 22 to 35 % are always accompanied by chlorite (up to 9 %), kaolinite occurs only sporadically and in small amounts, minerals of montmorillonite group were not found. Carbonates are dominated by calcite (up to 30 %), dolomite is abundant but variably distributed (up to 16 %). Overwhelming majority of samples contain pyrite (traces to 1 %). Heavy-mineral fraction comprises significant amounts of garnet, andalusite, cyanite and topaz.

The Ždánice-Hustopeče Formation. The pelitic facies is represented by gray variable-sandy yellow-green-weathering claystones. Intercalations and layers of brown-gray variable--calcareous claystones occur in places. The claystones contain laminae and rarely also thin benches of gray calcareous light-mica siltstones and fine-grained sandstones. Carbonate proportion in the studied claystones is very variable, ranging from several per cent to a maximum of 30 %. In addition to calcite the formation contains significant quantities of dolomite. Contents of quartz most frequently vary from 20 to 25 %, those of feldspar amount to approximately 9 %, only rarely exceeding 10 %. Clay fraction is dominated by mica minerals (about 25 %), chlorite is present in all samples in small to moderate quantities and so do montmorillonite--group minerals. Kaolinite occurs only exceptionally in very small amounts. Claystones often contain pyrite, locally also organic substance (predominantly in the basal part of the formation). The psammitic-pelitic facies (flysch development) is characterized by rhytmically alternating claystones and sandstones of the same petrographic character as those in the pelitic facies. From the mineralogical point of view, claystones of the psammitic-pelitic facies are almost identical with claystones of the pelitic one. Some differences can be observed only in the quantitative presence of some minerals – slightly increased contents of quartz, feldspars and chlorite, with kaolinite and pyrite being present only in trace amounts in claystones of flysch development. Heavy-mineral fraction is dominated by garnet.

Geochemical evaluation

Sediments of the Krosno beds of the Silesian unit and those of the Ždánice-Hustopeče Formation of the Ždánice unit were compared on the basic of all data available. We may state that the sediments of both compared lithostratigraphic members are very similar in their mineral composition – higher contents of feldspars, dominant assemblages of mica minerals and chlorite-group minerals, significant share of dolomite in the carbonate admixture, heavy mineral fraction dominated by garnet. The sediments are characterized by their chemical immaturity. From the chemical point of view, they have very similar contents of SiO_2, Al_2O_3, iron oxides, MgO, CaO, Na_2O, K_2O, P_2O_5, H_2O^+, vast majority of trace elements (As, Co, Cu, Mo, Ni, S and U concentrations are slightly higher in the Silesian unit), similar average values of ratios of selected pairs of trace elements and absolute B contents. Rare-earth concentrations in the Krosno beds are only slightly higher, with the ratios of light and heavy rare-earth elements being identical. Th/U, La/Th, La/Ce, Th/Yb and K/Th ratios are also very similar (Tabs. 1, 2, 3). It results from this comparison that the source areas of sediments of the Ždánice-Hustopeče Formation and Krosno beds were similar or that they both originated in the same significant source area.

Conclusions

Very similar mineralogic-geochemical character of sediments of the Subcherty beds and Menilite Formation (mainly of the Cherty beds) of the Silesian and Ždánice units, i. e. identical mineral assemblages, clearly increased contents of organic matter, pyrite and similar concentrations of a number of major and trace elements, similar ratios of selected pairs of trace elements and La/Th, Th/U, Th/Yb, K/Th ratios, highest values of SiO_2/Al_2O_3 ratios, considerably similar correlations and distribution types of numerous elements make it possible to state that the sediments of the Subcherty beds, which were in the past assigned to the Submenilite Formation, should in fact belong into the Menilite Formation.

Results of the mineralogic-geochemical study of the Krosno beds of the Silesian unit and Ždánice-Hustopeče Formation of the Ždánice unit (very similar mineral composition, very similar contents of oxides of major elements and of overwhelming majority of trace elements, absolute boron contents, similar ratios of selected pairs of trace elements, SiO_2/Al_2O_3, Al_2O_3/Na_2O, Th/U, La/Ce, Th/Yb and K/Th ratios) suggest that the source areas of the investigated sediments were similar or that the sediments originated from a single important source area. Significant presence of garnet (sometimes also andalusite, cyanite and topaz) in the heavy-mineral fraction as well as lower Zr and Ti contents indicate that these sediments included also material from metamorphic rocks. During the deposition of the Krosno beds and Ždánice-Hustopeče Formation, clastic material (in contrast to older underlying sediments) was not transported from the deeply eroded Bohemian Massif but is likely to have come from the east, from the Magura zone area.

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