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Geochemistry of Clastic Sediments of the Andělská Hora Formation (Jeseníky Mountains, Culm Facies, Bohemian Massif): Implications for the Source Area Nature

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10 Text-Figures and 3 Tables

Czech Republic
Bohemian Massif
Moravo-Silesian Zone
Culm Facies
Greywackes
Major Element Analyses
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Zusammenfassung

Grauwacken der Andělská Hora-Schichten (Teil der variszischen Flyschentwicklung des Böhmischen Massivs, wahrscheinliches Alter Oberdevon bis Unterkarbon) zeigen durch geochemische Charakteristika und Schwermineralspektren, daß diese Sedimente aus einem Liefergebiet stammen, das hauptsächlich von (Meta-)Vulkaniten aufgebaut war, die intermediären bis saueren kalk-alkalischen Magmatiten entsprachen. Der Anteil an alten (rezyklierten) Sedimenten und ihren metamorphen Äquivalenten war weniger bedeutend. Das Liefergebiet der Grauwacken wurde wahrscheinlich aus Gesteinen (meistens kadomischen Metavulkaniten) aufgebaut, die eine den metamorphen Gesteinen der benachbarten Deckengruppe von Orlík ähnliche Zusammensetzung hatten. Die chemische Zusammensetzung der Grauwacken der Andělská-Schichten nähert sich auch der Geochemie von Grauwacken aus SW-England (Mittel- bis Oberdevon) und aus W-Deutschland (Oberdevon bis wahrscheinlich Unterkarbon) und deutet auf einen ähnlichen Charakter der Liefergebiete. Dadurch wird die Annahme einer Kontinuität zwischen der Normannischen Höhe, der Mitteldeutschen Schwelle und dem vordevonischen Kristallin der Mährisch-Silesischen Zone unterstützt.

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Abstract

The greywackes of the Andělská Hora Fm. (part of the Variscan flysch sequence of the Bohemian Massif, possibly of the latest Devonian to Early Carboniferous age) show geochemical features and the transparent heavy mineral assemblage composition indicating that these sediments were derived from the source area comprising mainly (meta)igneous rocks corresponding to intermediate to acid calc-alkaline magmatites; the contribution of old (recycled) sediments and/or their metamorphic counterparts was less significant. The rock types analogous to metamorphics exposed in the nearby Orlík nappe Group (for the most part metaigneous rocks of Cadomian magmatic origin) probably formed the source area of the greywackes. The chemical composition of the Andělská Hora Fm. greywackes – similar to geochemistry of greywackes of SW England (Middle to Late Devonian) and W Germany (Late Devonian to possibly Early Carboniferous) – suggest also a similar nature of provenance of these Variscan flysch clastics. Following that, it seems to support also the idea of presumed continuity between the Mid-German Crystalline Rise/Normannian High and the pre-Devonian crystalline of the Moravo-Silesian Zone.

1. Introduction

Five samples of phyllitic greywackes and greywacke phyllites were taken from the Andělská Hora Formation of the Moravo-Silesian Culm facies (Variscan flysch sequence). Nevertheless, even such a small set of samples reflects some features of the sediment provenance since the clastic sediments represent a statistical mixture of the source rocks (cf. TAYLOR & MCLENNAN, 1985; MCLENNAN & TAYLOR, 1991).

The main investigation methods based on major and trace element geochemistry of the greywackes are completed by petrographic description of the rocks and by a comparison with the results of the regional study on the transparent heavy mineral assemblages of the Andělská Hora Formation greywackes.

2. Geological Setting

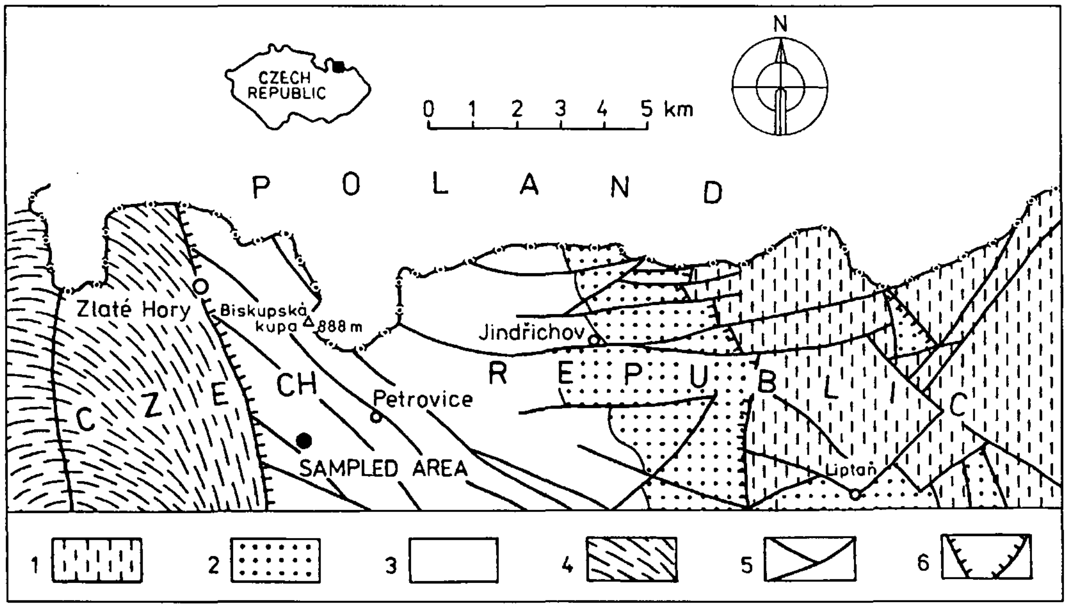
The sampled greywackes belong to the oldest formation of the Moravo-Silesian Variscan flysch sequence (the Moravo-Silesian Culm facies), called Andělská Hora Formation (Text-Fig. 1). It is underlain both in structural and in stratigraphic sense by a Devonian volcano-sedimentary complex known as the Vrbno Group (e.g. CHÁB et al., 1984; CHLUPÁČ, 1987; ZAPLETAL et al., 1989). The nearest outcrops of rocks of the Vrbno Group are situated less than 2 km westwards from the sampled area of the investigated greywackes. The overlying Horní Benešov Formation is exposed about 6-7 km to the E from there. The estimated total thickness of the Andělská Hora Fm. is over 1,000 m (ZAPLETAL et al., 1989).

The main lithological types of the Andělská Hora Fm. are phyllitic shales, siltstones and fine-grained greywackes, developed mostly as rhythmics and/or laminites. Generally the rocks are intensively deformed, nevertheless, they display some preserved relics of sedimentary structures – graded bedding, convolute deformation of laminae etc. (OTAVA, 1991). The rocks of the Andělská Hora Fm. did not yield any fossils in the sampled area and the Lower Carboniferous age has been defined indirectly (OTAVA et al., 1991); however, Famennian age is suggested for the lowest part of the Andělská Hora Fm. by CHLUPÁČ (1984).

In the area studied a general N–S direction of the regional fold system and rock bands – V_1 system in the sense of OREL (1975) – is locally influenced by a strongly developed fold system V_3 (characterized by steep dip of the b-axes to NE–ENE [OREL., l.c.]) and by the regional transversal fault Zlaté Hory – Krnov. The angle of dip of the strata, varying between 25° and 55° to the E, i.e. strong westwards vergency, seems to be a specific feature of the Andělská Hora Fm. in the investigated region (OTAVA, 1991).

In the rocks of the studied area a prominent axial cleavage is often well developed. This phenomenon is more distinct in rhythmites, laminites and, generally speaking, in pelitic and aleuritic rocks. The cleavage for the most part is dipping eastwards; it is considered to be an important criterion for identification of either normal or overturned position of strata (OTAVA, 1991).

The regional metamorphic grade of the Andělská Hora Fm., as reconstructed from petrography (KUKAL, 1980; MAŠTERA in OTAVA et al., 1991), IC values (ROBERTS, 1990; DRBAL in OTAVA et al., 1991) and $R_{max.}$ values, could be considered as epizone, close to the anchizone. The intensity of metamorphism and axial cleavage



Text-Fig. 1.
Geological sketch of the sampled area surroundings (position in the Czech Republic is included).
Moravo-Silesian Culm facies: 1 = Moravice Fm.; 2 = Horní Benešov Fm.; 3 = Andělská Hora Fm..
Hrubý Jeseník Mts. Devonian: 4 = the Vrbno and Rejvíz Groups.
Tectonic elements: 5 = faults; 6 = vergency of the tectonised contact.

gradually decreases eastwards and less distinctly southwards. In the Devonian Vrbno Group the metamorphic grade increases to NNW from the sampled area – from biotite to garnet zone (SOUČEK, 1978).

3. Petrography

Except the sample No. 1 (greywacke phyllite) all other rocks (Nos 2 to 5 – Table 1) could be defined as middle- to coarse-grained greywackes and phyllitic greywackes. The textural maturity of greywackes is low and the sampled rocks are rather epizonally metamorphosed. The texture of greywackes could be described as blastopsammitic, irregularly-grained and distinctly cleaved.

The substantial part of the psammitic fraction is represented by clasts of siltstones and/or clayey siltstones composed of very fine-grained and silty quartz with admixture of plagioclases and sometimes with a small amount of calcite cement. Less frequently the psammitic fraction is composed of clear fine-grained quartzites and granitoids, exceptionally also of felsitic volcanics. The unsorted fine-grained psammitic and aleuritic matrix with variable amount of clay is distinctly recrystallized. The recrystallization striked not only the clayey component but the quartz grains and some plagioclases, too. A part of the plagioclases is of authigenic origin. Chlorites prevail over muscovite among the sheet-silicates in matrix. In some samples (Nos 4 and 5) biotite is also present.

Because of strong recrystallization it is difficult to distinguish the psammitic fraction (clasts) from matrix, except the most stable coarse quartz grains and some plagioclases. That was the main reason why a reliable comparison of the U/F an S/U values with greywackes exposed southward was not possible.

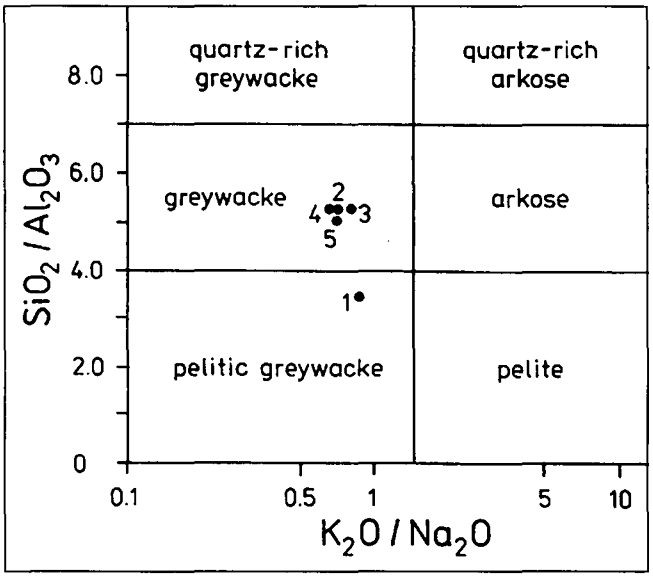
The sample No. 1 was omitted in the Table 1, because the parameters of greywacke phyllite were not compatible (due to different fractions and metamorphic grade) with the rest greywacke samples.

Table 1.
The modal composition of the Andělská Hora Fm. greywackes s.s. – greywackes and phyllitic greywackes – as derived from semiplanimetric analyses.
M_{max} = maximal size of the clast.
Components: 1 = monocrystalline quartz; 2 = monocrystalline quartz with granulated rims; 3 = aggregate of irregularly grained quartz; 4 = very fine-grained crystalline aggregate of quartz; sometimes fine-grained quartzite; 5 = very fine-grained crystalline aggregate of quartz; sometimes fine-grained quartzite + unarranged flakes of chlorite and muscovite; 6 = very fine-grained crystalline aggregate of quartz; sometimes fine-grained quartzite + arranged flakes of micas and plagioclases; 7 = very fine grained crystalline aggregate of quartz; sometimes fine-grained quartzite + unarranged flakes of chlorite and muscovite + plagioclases + porous calcite; 8 = plagioclase; 9 = hypautomorphic plagioclase with xenomorphic quartz; 10 = accumulations of prevailing sheet-silicates in the matrix; 11 = clasts of organic matter; 12 = ore grains; 13 = accessories; 14 = felsic volcanics. Matrix represents basic mass of the rock plus disintegrated psammitic fraction comprising especially sediments (components 4–7).
Sample No. 1 is omitted here – for explanation see the text of "Petrography".

sample	2		3		4		5	
component	[vol. %]	M_{max} [mm]	[vol. %]	M_{max} [mm]	[vol. %]	M_{max} [mm]	[vol. %]	M_{max} [mm]
1	4.6	0.6	5.4	0.67	4.8	-	1.1	1.2
2	3.5	0.87	6.1	-	5.0	0.4	0.2	3.2
3	6.9	0.9	9.8	2.5	13.1	1.4	14.3	1.65
Σ	15.0		21.3		22.9		15.6	
4	9.0	1.5	15.4	0.75	15.9	1.5	23.3	-
5	12.7	1.1	9.0	-	9.0	3.0	16.8	1.5
6	9.3	2.5	19.4	3.75	6.7	1.65	15.2	1.5
7	20.6	1.5	5.4	6.0	11.3	2.2	18.6	1.5
Σ	51.6		49.2		42.9		73.9	
8	1.8	0.6	4.8	0.3	4.0	0.6	1.1	0.37
9	4.6	0.9	3.1	0.9	10.8	1.4	1.0	1.35
Σ	6.4		7.9		14.8		2.1	
10	24.3	-	7.8	-	14.7	-	8.0	-
11	2.5	-	1.0	-	1.4	-	0.4	-
12	-	-	2.3	-	-	-	-	-
13	0.2	-	1.9	-	2.1	-	-	-
14	-	-	9.2	-	1.2	-	-	-
Σsand fraction	100.0		100.0		100.0		100.0	
vol. % of sand	24.9		19.6		29.5		39.5	
vol. % of matrix	75.1		80.4		70.5		60.5	

4. Analytical Methods

The Andělská Hora Fm. greywacke samples (as well as the representative rock types, described in the following text) were analyzed for major and trace element abundances (Tables 2 and 3). Major element concentrations were determined in the laboratories of the Czech Geological Survey, Prague (analysts J. HUKA and co-workers) using wet chemical analysis. Trace element abundances were established by X-ray fluorescence analysis in the laboratories of the Unigeo, Ostrava (analysts L. JANÁČKOVÁ and co-workers). Analyses of rare earth elements were prepared by instrument neutron activation in the Central laboratories of the Geoindustria, Praha (analysts Ing. J. MOUČKA and co-workers).



Text-Fig. 2.
Greywackes of the Andělská Hora Fm. in the K_2O/Na_2O versus SiO_2/Al_2O_3 ratios plot for clastic sediments after WIMMENAUER (1984).
The sample numbers from Table 2 are given with the symbols.

5. Geochemistry

5.1. Major Elements

On the basis of the K_2O/Na_2O versus SiO_2/Al_2O_3 ratios relation (WIMMENAUER, 1984) (Text-Fig. 2) the most part of the studied greywacke samples corresponds to greywackes s.s. (in greywacke field four samples are tightly clustered); a single sample – No. 1 – is situated nearby, in the field of pelitic greywackes. This classification seems to be relevant to the results of petrographic investigations on the studied samples.

The Andělská Hora Fm. greywackes display similar overall distribution pattern of volatile-free major element abundances as the post-Archean average shale (TAYLOR & MCLENNAN, 1985) when normalized to upper continental crust composition after the same authors (Text-Fig. 3a). With regard to SiO_2, TiO_2, Al_2O_3, $FeO_{tot.}$ and MgO the relative abundances are approximately identical; on the other hand, the greywackes are substantially depleted in CaO and slightly depleted in K_2O as well as significantly enriched in Na_2O relative to the post-Archean average shale.

Table 2.
Major and trace element composition of the Andělská Hora Fm. greywackes s.l..
1 = greywacke phyllite; 2 to 5 = greywackes and phyllitic greywackes.
Concentrations are given in wt.-% (major oxides) and ppm (trace elements).

	1	2	3	4	5
SiO_2	60.29	67.33	69.98	69.78	68.05
TiO_2	1.02	0.95	0.91	0.94	0.94
Al_2O_3	17.52	13.03	13.27	12.92	13.35
Fe_2O_3	1.81	1.38	1.12	1.24	1.13
FeO	5.84	3.76	4.07	3.93	4.30
MnO	0.14	0.10	0.08	0.08	0.10
MgO	3.04	2.19	2.13	2.16	2.26
CaO	0.31	2.11	0.58	0.79	1.54
Na_2O	3.06	2.83	2.59	2.98	2.90
K_2O	2.65	1.90	2.04	1.95	2.04
P_2O_5	0.16	0.16	0.13	0.14	0.15
CO_2	0.01	1.34	0.01	0.01	0.57
H_2O+	3.79	2.60	2.68	2.53	2.53
H_2O-	0.19	0.17	0.15	0.16	0.12
total	99.83	99.85	99.74	99.55	99.98
Sr	105	169	89	153	150
Rb	81	55	60	59	56
Ba	563	514	463	533	599
Th	10.5	8.78	8.36	10.4	9.74
Ta	<1	<1	<1	<1	<1
Nb	13	12	12	8	11
Zr	210	191	182	210	228
Hf	4.92	6.22	4.07	6.38	7.81
La	42.0	33.4	17.6	21.0	41.3
Ce	66.9	57.2	38.3	55.1	59.6
Sm	5.36	4.52	3.36	3.37	4.88
Eu	1.36	1.33	1.15	1.02	1.33
Tb	<1	<1	<1	<1	<1
Yb	4.05	3.33	3.10	2.75	1.60
Lu	0.43	0.41	0.24	0.40	0.40
Y	33	14	25	25	25
Sc	21.2	15.5	14.9	15.0	16.1
Cr	129	90	94	91	85
Ce/Yb	16.5	17.2	12.4	20.0	37.3
$\mathrm{Eu/Eu^*_{CH}}$	0.76	0.84	0.88	0.78	0.79
$\mathrm{Eu/Eu^*_{PAAS}}$	1.15	1.25	1.26	1.11	1.19

Table 3.
Major and trace element composition of the representative rocks of the Orlík nappe Group (1 = metagranitic blastomylonite [FIŠERA & PATOČKA; 1989]; 2 = biotite-garnet mica schist; 3 = biotite-muscovite mica schist) and the Devonian Vrbno and Rejvíz Groups (4 = porphyroid; 5 = greenschist). Concentrations are given in wt.-% (major oxides) and ppm (trace elements). Trace elements are arranged according to PEARCE (1982).

	1	2	3	4	5
SiO_2	65.37	65.05	67.47	71.45	47.11
TiO_2	0.63	0.76	0.52	0.35	0.36
Al_2O_3	15.64	15.68	15.57	16.10	15.34
Fe_2O_3	1.61	0.83	0.50	0.40	3.73
FeO	3.11	3.55	3.82	0.68	9.09
MnO	0.13	0.15	0.07	0.25	0.15
MgO	1.94	2.64	1.95	0.23	6.31
CaO	2.79	2.07	2.28	1.53	8.65
Na_2O	2.98	3.15	3.71	6.09	4.34
K_2O	3.08	3.09	2.32	1.24	0.07
P_2O_5	0.15	0.14	0.12	0.10	0.27
CO_2	0.35	0.32	0.01	0.04	0.23
H_2O+	0.80	1.92	1.45	0.98	1.40
H_2O-	0.61	0.10	0.09	0.11	0.05
total	99.19	99.45	99.88	99.56	98.70
Sr	-	124	129	169	<5
Rb	83	82	78	30	27
Ba	614	686	-	-	56
Th	9.67	6.64	6.07	16.5	7.00
Ta	1.01	<1	<1	1.58	1.03
Nb	-	7	8	22	16
Zr	-	192	204	395	110
Hf	5.48	5.81	5.83	10.5	6.82
Ce	55.9	51.3	49.6	84.2	34.7
Sm	4.87	4.57	3.14	4.93	4.55
Yb	2.58	3.18	<1	7.51	2.76
Y	-	28	24	96	30
Sc	-	17.3	13.4	6.7	35.8
Cr	-	104	70	<7	59

5.2. Trace Elements

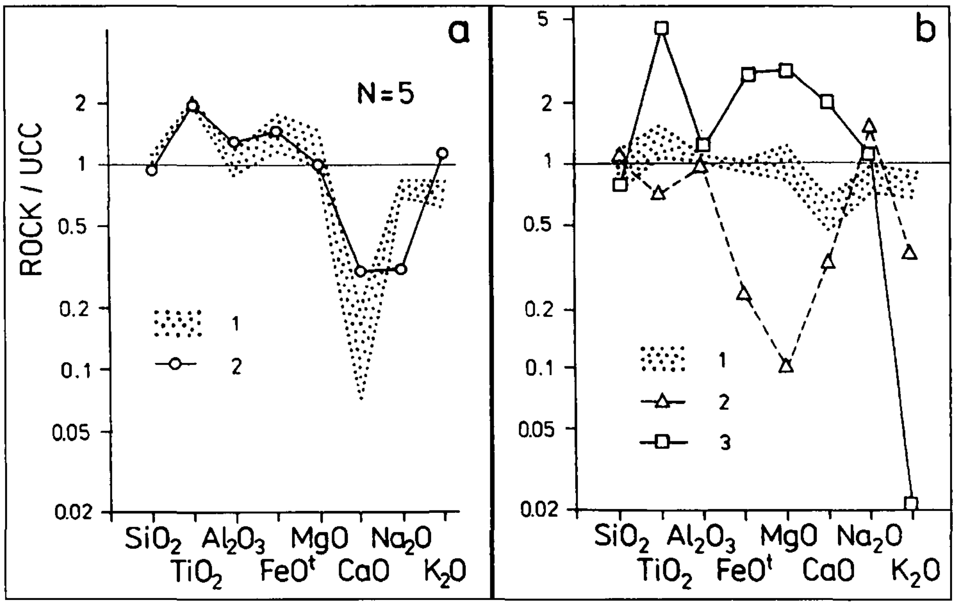
The distribution pattern of concentrations of trace elements in the Andělská Hora Fm. greywackes, normalized to upper continental crust values (TAYLOR & MCLENNAN, 1985), is also generally similar to post-Archean average shale pattern (Text-Fig. 4a). However, all LIL and some HFS elements (Sr, K, Rb, Ba, Th, Nb and Ta [for the last element see Table 2]) show lower abundances in the greywackes than in the post-Archean average shale; also Ce is present in lower concentrations in four of the five greywacke samples.

The LREE abundances in the studied rocks are rather lower relative to the common post-Archean shale standard values (PAAS after NANCE & TAYLOR [1976]); on the other hand, the concentrations of HREE vary equally below and above the PAAS distribution pattern (Text-Fig. 5a). This feature of the Andělská Hora Fm. greywackes can be seen also from relatively low Ce/Yb rations (Table 2). The significant characteristics of the greywackes is also almost negligible negative Eu-anomaly displayed by chondrite-normalized REE distribution patterns and, complementarily, a prominent positive anomaly of this lanthanide in the PAAS-normalized patterns (Text-Fig. 5b; Table 2).

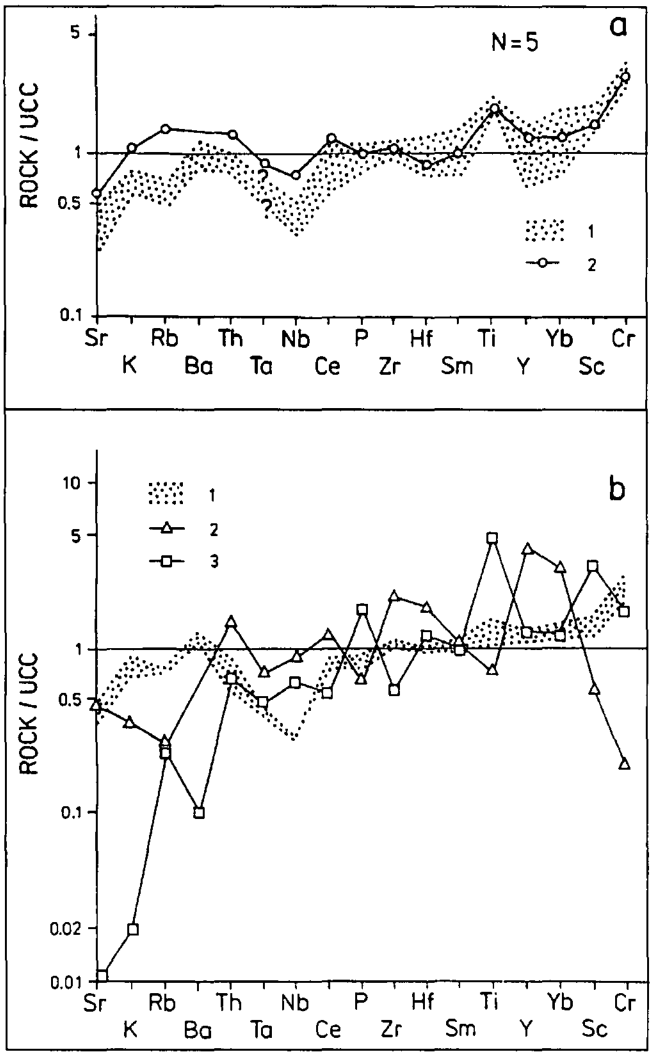
6. Transparent Heavy Mineral Assemblage

The sampling of greywackes of the Andělská Hora Fm. for heavy mineral assemblages yielded – beside a valuable lithostratigraphic tool in almost sterile clastic sequence – also important informations on the source rocks.

More than 200 samples were analysed till the present time (OTAVA, 1988). Most of them have been used in the following evaluation.



Text-Fig. 3.
a) Major element distribution in the Andělská Hora Fm. greywackes relative to upper continental crust composition after TAYLOR & MCLENNAN (1985) (1); for comparison the post-Archean average shale major element abundances (identically normalized) (TAYLOR & MCLENNAN; l.c.) are presented (2).
b) Major element distribution in the Orlík nappe Group metamorphics (one metagranite blastomylonite and two mica schists) (1); the Devonian Rejvíz Group porphyroid (2) and the Devonian Vrbno Group greenschist (3) relative to upper continental crust composition after TAYLOR & MCLENNAN (1985).



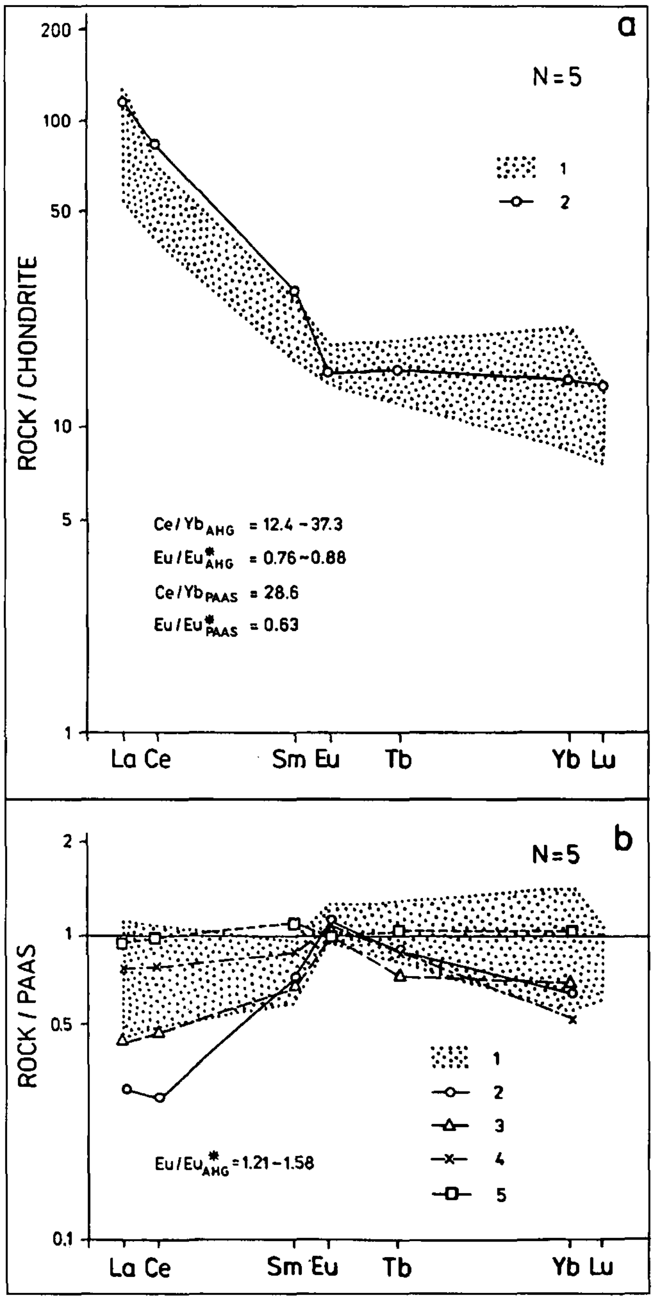
Text-Fig. 4.

a) Trace element distribution in the Andělská Hora Fm. greywackes relative to upper continental crust composition after TAYLOR & MCLENNAN (1985) (1); for comparison the post-Archean average shale trace element abundances (identically normalized) (TAYLOR & MCLENNAN; l.c.) are presented (2). The elements are arranged according to PEARCE (1982).

b) Trace element distribution in potential source rocks of Andělská Hora Fm. greywackes – Orlík nappe Group metamorphics (one metagranite blastomylonite and two mica schists) (1); Devonian Rejvíz Group porphyroid (2) and Devonian Vrbno Group greenschist (3) – relative to upper continental crust composition after TAYLOR & MCLENNAN (1985). The elements are arranged as in (a).

The Andělská Hora Fm. is the only one among the Culm facies units completely lacking a dependence between the grain size and the THMA composition. This is probably due to poor sorting of the clastic material (BOSWELL, 1933). Also, a higher stage of the chemical maturity of the material cannot be considered because of the high amount of apatite and the presence of some other mesostable minerals. The assemblage (Text-Fig. 6) could be generally defined as zircon – apatite – sphene – tourmaline with rare or even very rare presence of some other minerals as epidote, monazite, alterites (weathered minerals with changed optical properties), rutile, andalusite, spinel, anatase, brookite, hornblende, pyroxene, garnet and sillimanite.

It is worth to note the accessoric presence of purple zircons in 69 % of the samples. This variety has been referred by many authors (e.g. ZIMMERLE, 1972; KODYMOVÁ, 1977) to the Precambrian metamorphic rocks.



Text-Fig. 5.

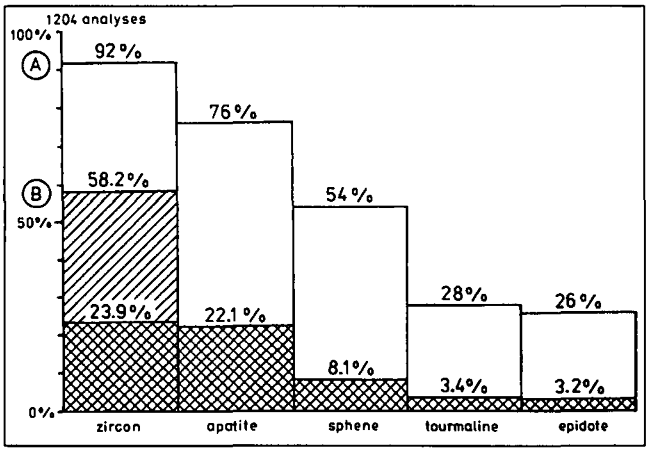
a) REE distribution in the Andělská Hora Fm. greywackes (AHG) normalized to average chondrite REE abundances (HERRMANN, 1970) (1); for the comparison chondrite-normalized post-Archean Australian average shale (PAAS) REE concentrations after TAYLOR & MCLENNAN (1985) are shown (2).

b) REE distribution in the Andělská Hora Fm. greywackes (AHG) normalized to the PAAS lanthanide abundances (TAYLOR & MCLENNAN, 1985) (1); for comparison the PAAS-normalized REE distribution curves for greywackes of various tectonic settings – oceanic island arc (2); continental island arc (3); Andean-type continental margin (4) and passive continental margin (5) = are presented (BHATIA, 1985).

7. Discussion

7.1. Secondary Changes in the Chemical Composition of Rocks

The Andělská Hora Fm. greywackes probably have not suffered any significant hydrothermal alteration after they underwent low-grade Variscan metamorphism, as their volatile components (i.e. H_2O and CO_2) contents are quite



Text-Fig. 6.
Comparison of mean contents of principal members of transparent heavy mineral assemblage (including epidote) in the Andělská Hora Fm. greywackes (B) with presence frequency of the same minerals in granitic rocks (HOPPE, 1951) (A).
In the column of zircon the higher value represents idiomorphic and oval grains together while the lower one corresponds to the abundance of idiomorphic grains only.

low (Table 2). The greywackes described in this study also display relatively uniform major element composition (Text-Fig. 3a and Table 2). That is why the major element abundances in the greywackes can be considered as largely unchanged by secondary processes (regional metamorphism and/or hydrothermal alteration). Nevertheless, mobility of alkalis and alkaline earth elements has to be expected in low-grade metamorphic conditions (e.g. WEDEPOHL, 1991) – especially CaO, Na_2O and K_2O concentrations could be disturbed in the Andělská Hora Fm. greywackes, metamorphosed in epizone in general.

The mutual consistence as well as the overall similarity of the trace element abundances relative to the post-Archean average shale composition, shown by the Andělská Hora Fm. greywackes (Text-Fig. 4a, Table 2), seems to point on probable preservation of pre-metamorphic concentrations of trace elements in the studied rocks. Only LILE group contents has to be taken with certain reservation due to the known high mobility of these elements (LUDDEN et al., 1982; WEDEPOHL, 1991 etc.). On the other hand, HFS elements remain almost immobile during regional metamorphism of sediments (e.g. MCLENNAN et al., 1983). The refractory behaviour during low- to medium-grade metamorphism is considered also with regard to REE (CULLERS et al., 1974; ELDERFIELD and SHOLKOVITZ, 1987; CAMIRÉ et al., 1993 etc.).

7.2. Source Rocks

The rock characteristics of the source area can be estimated on the basis of the clastic sediment composition (TAYLOR & MCLENNAN, 1985; MCLENNAN & TAYLOR, 1991; CAMIRÉ et al., 1993 etc.). However, the mobility of elements in the course of weathering, transport, sedimentation and diagenesis has to be taken in account when such an estimation is made.

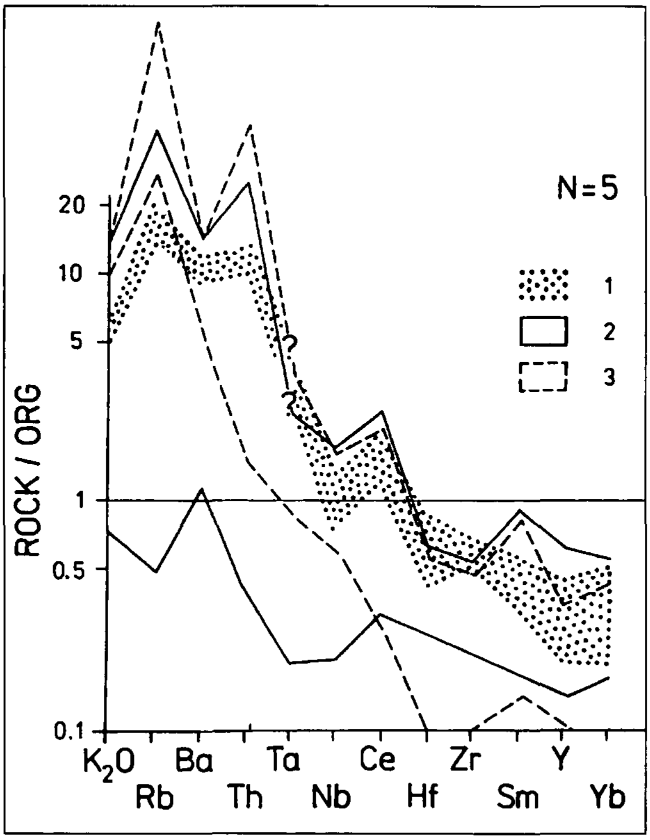
Major element concentrations (Text-Fig. 3a) – especially those of alkalis and alkaline earth elements – can be a subject of significant changes during the origin of sedimentary rocks (NESBITT et al., 1980; GROMET et al., 1984; WEDEPOHL, 1991).

Among the trace elements, utilized in diagrams on Text-Figs. 4a and 5, the REE group (and Y) is regarded to be the most resistent through the process of sedimentary rock origin (e.g. MCLENNAN, 1982; WRONKIEWICZ & CONDIE, 1987; MCLENNAN & TAYLOR, 1991). Selective absorption of LREE in clay minerals (FLEET, 1984) cannot substantially influence REE distribution pattern inhered from the source material (WRONKIEWICZ & CONDIE, 1987). Hydraulic sorting of zircon, usually leading to HREE enrichment in sediments (CULLERS et al., 1987) probably did not take place in the process of the Andělská Hora Fm. greywacke sedimentation since the greywacke Zr and Hf abundances are not significantly enriched relative to the post-Archean average shale (Text-Fig. 4a). Also diagenetic Eu enrichment (alternatively resulting in the negligible negative Eu anomaly of the greywacke chondrite-normalized REE paterns – Text-Fig. 5a) seems to be improbable: the necessary highly reducing conditions (MACRAE et al., 1992) are not presumed during the Moravo-Silesian Culm flysch greywacke sedimentation (cf. DVOŘÁK, 1989).

Refractory nature similar to that of REE during origin of sediments is also shown by HFS elements (e.g. Ta, Nb, P, Zr, Hf and Ti) and by Sc, as an example of mantle-compatible elements (MCLENNAN et al., 1983; BHATIA, 1985; WRONKIEWICZ & CONDIE, 1987; MCLENNAN & TAYLOR, 1991). As to LIL elements, only Th is considered to be rather stable (MCLENNAN & TAYLOR, 1980; MCLENNAN & TAYLOR, 1991). Abundances of the other LILE group members can be greatly and selectively altered by sedimentation process (e.g. NESBITT et al., 1980). Concentration of Cr in sediments can grow due to element absorption in clay minerals (BHATIA, 1985 etc.).

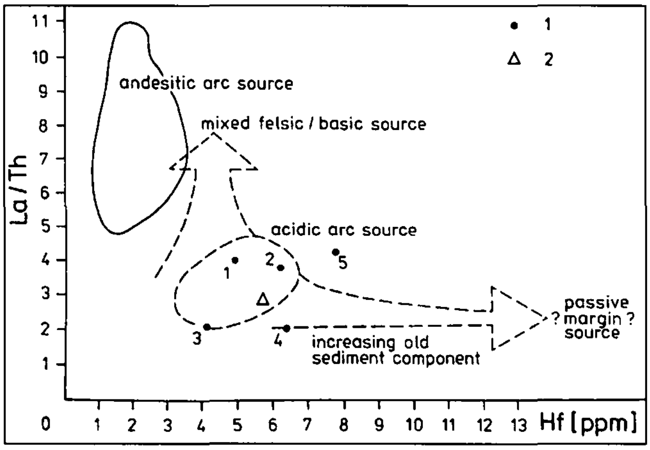
Considering the above described features of elements plotted in Text-Figs. 4a and 5, the following characteristics can be deduced to describe hypothetic source rocks prevailing in the material of the Andělská Hora Fm. greywackes:

1) For the most part relatively lower degree of REE fractionation (compared with the PAAS) as well as almost negligible negative anomaly of Eu relative to chondritic composition (and salient positive Eu anomaly relative to the PAAS value) (Text-Fig. 5); lower Ce (as a LREE representative) abundances – relative to post-Archean average shale – shown in Text-Fig. 4a has to be mentioned, too. These are features of rather into medium degree differentiated intermediate to acid calc-alkaline igneous rocks (or their metamorphic equivalents) (HASKIN et al., 1968; GILL, 1981; TAYLOR & MCLENNAN, 1985); any really substantial basic rock admixture is not probable as the PAAS-like HREE values suggest.
2) With regard to less mobile trace elements, lower contents of Ta and Nb and equal abundances of the other HFS and mantle-compatible elements relative to post-Archean average shale (Text-Fig. 4a and Table 2). As well as in the previous case these are characteristics of intermediate to acid magmatic-arc igneous rocks. However, Hf and Zr concentrations in the greywackes are usually slightly higher compared with these in the magmatites (Text-Fig. 7) and can be interpreted as an indicator of progressive erosion of the hypothetic source region dissecting both arc (?) magmatic bodies and ancient (meta)sedimentary rocks of continental basement, releasing greater amounts of zircon (Text-Fig. 8). The low and not substantially different La/Th ratios, shown by this diagram, seem to point on acidic arc nature of the provenance area (cf. FLOYD & LEVERIDGE, 1987). Again, the concentrations of compatible elements equal to post-Archean average shale do not indicate any significant contribution of basic component (Text-Fig. 4a).



Text-Fig. 7.
Trace element distribution in the Andělská Hora Fm. greywackes relative to ocean-ridge granite composition (PEARCE et al.; 1984) (1); for the comparison the envelopes of volcano-plutonic arc granites (2) and collision-related granites (3) after the same authors are shown, too.

3) The depletion in Th compared to post-Archean average shale (Text-Fig. 4a). This feature points on less significant contribution of material of recycled sediments and/or their metamorphic equivalents; in comparison to concentrations of readily mobile elements the relative Th content in sedimentary rocks increases with repeated cycles of weathering and resedimentation since Th^{4+} does not change oxidation state during weathering and remains relatively very insoluble (MCLENNAN & TAYLOR, 1980).



Text-Fig. 8.
The Andělská Hora Fm. greywackes in the Hf versus La/Th diagram for source and compositional discrimination of clastic sediments (FLOYD & LEVERIDGE, 1987).
1 = studied rocks (the sample numbers from the Table 2 are given with the symbols); 2 = upper continental crust.

The described characteristics seem to suggest that in the source material of the Andělská Hora Fm. greywackes the rocks resembling in chemical composition intermediate to acid calc-alkaline magmatites possibly dominated. Rocks of such a composition are spatially found rather close to the Andělská Hora Fm. – e.g. among the metamorphics of the Orlík nappe Group in the Hrubý Heseník Mts. (FIŠERA & PATOČKA, 1989 etc.).

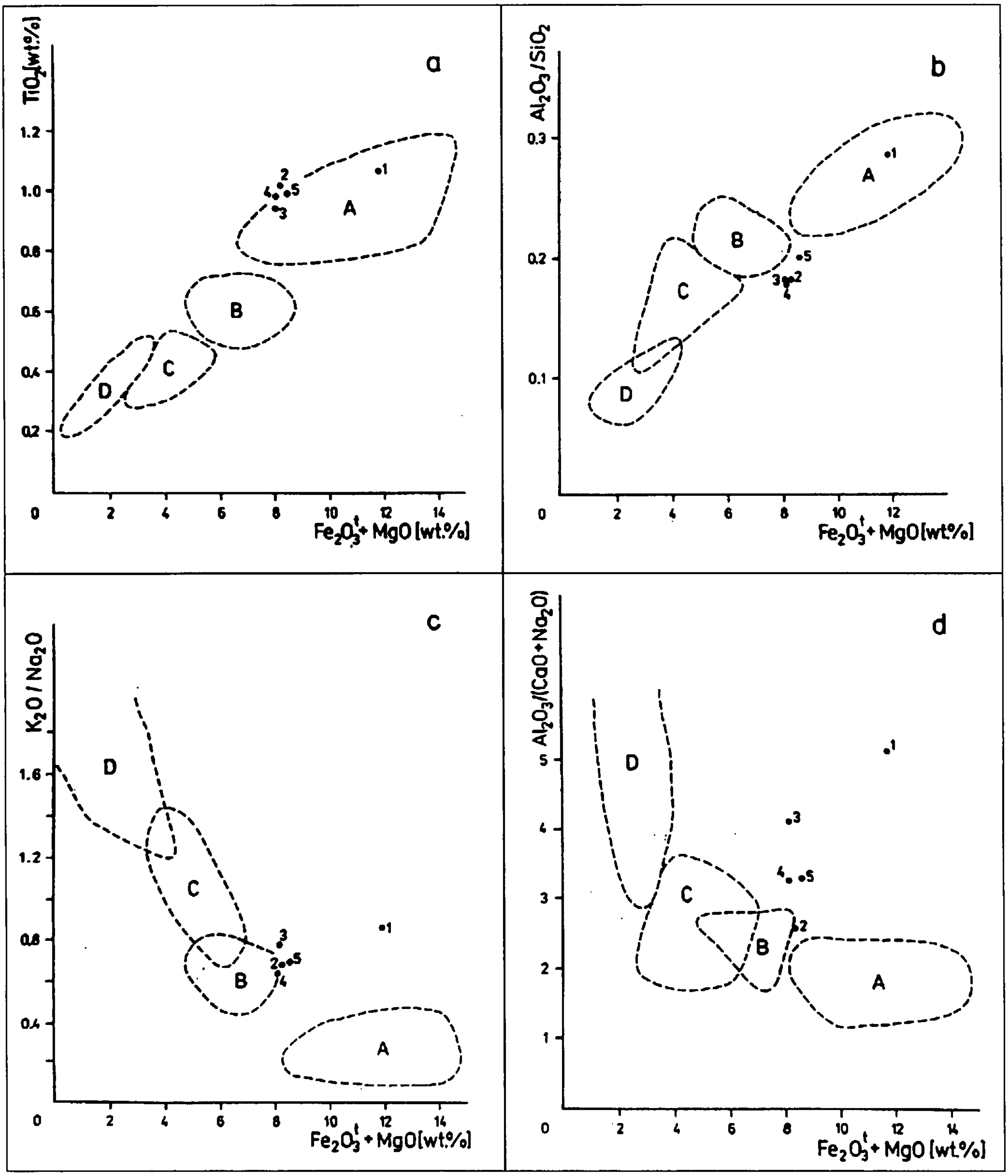
For detailed comparison the representative sample of blastomylonite, considered to have granitic intrusive protolith (e.g. FIŠERA & PATOČKA, 1989), and two samples of mica schist (biotite-muscovite mica schist and biotite-garnet mica schist), displaying the SiO_2 values closely similar to the blastomylonite silica content, were chosen from the Orlík nappe Group rocks; also two chemically contrasting Devonian metavolcanics exposed in close vicinity to the Andělská Hora Fm. were involved – the Vrbno Group greenschist and the Rejvíz Group porphyroid samples (except the blastomylonite the rock analyses are from the authors' files – Table 3). Both major and trace element compositions relative to upper continental crust values (TAYLOR & MCLENNAN, 1985) of these rocks are shown in Text-Figs. 3b and 4b. In the diagrams the blastomylonite and the mica-schists (indeed mutually almost identical in chemical composition) display overall distribution patterns of both major and trace elements rather similar to these of the Andělská Hora Fm. greywackes; on the other hand, the Vrbno Group acid and basic volcanic rock samples differ substantially (nevertheless, the greenschist shows some similarity in some HFS and compatible element abundances; Text-Figs. 3 and 4).

According to this comparison in the provenance of the Andělská Hora Fm. greywackes very probably prevailed intermediate to acid calc-alkaline magmatites and/or their metamorphic equivalents and possibly also (meta)sediments of related chemical composition; beside these principal components also basic (meta)igneous rocks were exposed in lesser amount.

Also the composition of transparent heavy mineral assemblage (i.e. the contents of the five main accessories) in the Andělská Hora Fm. greywackes shows a general relationship to the statistic evaluation of abundances of the same accessories in 1204 samples of intermediate and acid magmatites (HOPPE, 1951) (Text-Fig. 6). This feature seems to suggest a dominance of granitic rocks in the source area of the greywackes. Nevertheless, the Andělská Hora Fm. THMA composition histogram does not reflect exactly that of intermediate to acid igneous rocks and/or their metamorphosed equivalents – namely, the abundance of round zircons (34.3 %) indicate presence of (meta)sediments (possibly recycled) in the provenance of the greywacke material. Frequent occurrence of the purple zircon variety (in more then 2/3 of studied samples) suggests the significant abundance of Precambrian rocks in the source area.

7.3. Tectonic Setting of the Source Region

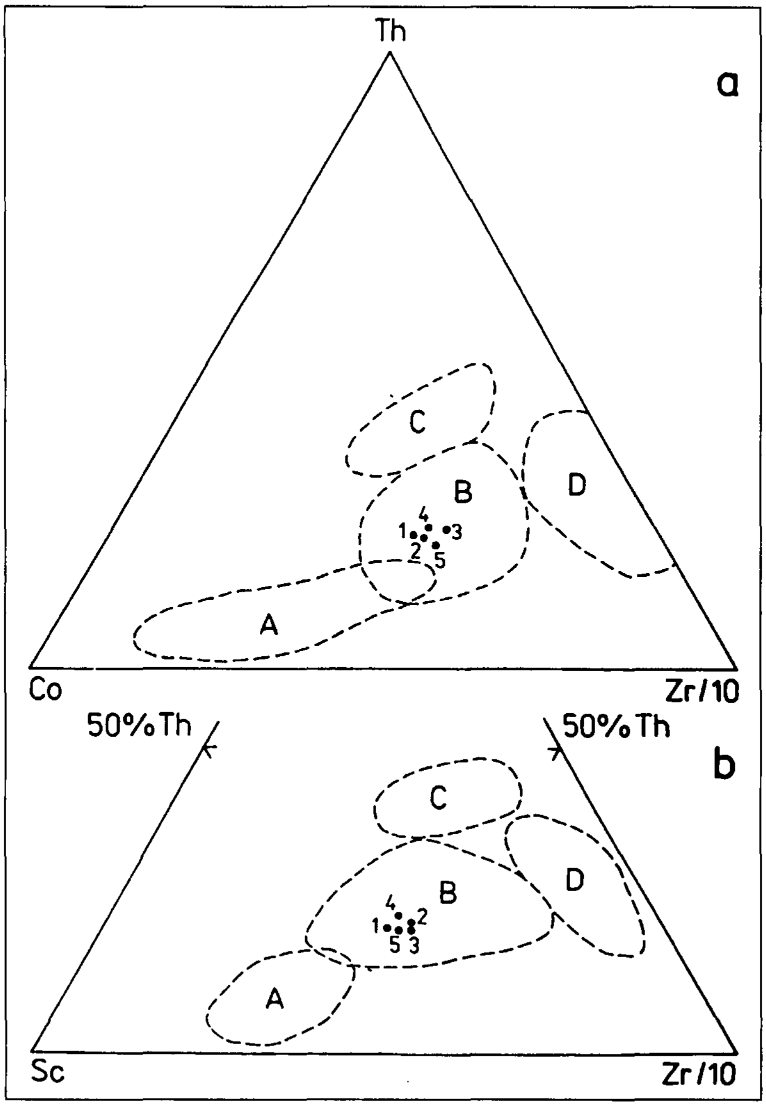
In the major element composition of clastic sediments there were identified systematic variations (in major oxide abundances as well as in abundance ratios) depending on the tectonic setting changes (BHATIA, 1983). In major element dicrimination plots the Andělská Hora Fm. greywackes seem to be similar to sediments of continental island arc and/or active continental margin (Text-Fig. 9b,c). The relatively high concentrations of TiO_2 (possibly given by mafic rock admixture – Text-



Text-Fig. 9.
The Andělská Hora Fm. greywackes in the major element composition plots of clastic sediments for tectonic setting discrimination after BHATIA (1983).
A = oceanic island arc; B = continental island arc; C = active continental margin; D = passive continental margin; Fe_2O_3 represents total iron as $Fe_2O_3^t$. The sample numbers from Table 2 are given with the symbols.

Fig. 3a) shifted the greywackes to the field of oceanic island-arc sediments in Text-Fig. 9a; the depletion of CaO (Text-Fig. 3a), probably taking place during the sedimentary process, caused the scatter of the samples in Text-Fig. 9d.

The position of the continental island arc sediments is occupied by the Andělská Hora Fm. greywackes also in triangular plots utilizing trace element concentrations (Th – Co – Zr and Th – Sc – Zr) after BHATIA & CROOK (1986) (Text-Fig. 10). In the LREE abundances the studied samples resemble the active continental margin greywackes; in the HREE concentrations they resemble passive margin clastics (Text-Fig. 5b). However, there it has to be pointed out that – according to BHATIA (1985) – the greywackes of



Text-Fig. 10.
The Andělská Hora Fm. greywackes in the trace element composition triangular plots of clastic sediments for tectonic setting discrimination after BHATIA & CROOK (1986).
A = oceanic island arc; B = continental island arc; C = active continental margin; D = passive continental margin.
The sample numbers from Table 2 are given with the symbols.

Andean-type continental margins are hardly discernible from these of passive margins on the basis of lanthanide patterns only.

Summarizing the above described characteristics of the Andělská Hora Fm. greywackes and taking into account the dominance of intermediate to acid calc-alkaline igneous rocks in their source area, indicated by the greywacke chemical composition and transparent heavy mineral assemblages, the deposition of the studied sediments in continental island arc tectonic setting could be presumed.

Nevertheless, prior to Late Devonian to Carboniferous shortening event an extensional tectonic setting existed in the Rhenohercynian Zone during Early to Late Devonian (e.g. ANDERTON et al., 1979; FLOYD, 1982; LEEDER, 1982; FRANKE, 1989). The Devonian sequence of the Jeseníky Mts., considered to be an eastern representative of the Rhenohercynian Zone (STILLE, 1951; ENGEL et al., 1983), was possibly formed in rift-related and/or back-arc extensional tectonic setting, too (CHÁB et al., 1980; PŘICHYSTAL, 1990; PATOČKA & VALENTA, in prep.); only immature island-arc setting is indicated by volcanic-arc tholeiitic to low-K calc-alkaline basalts to basaltic andesites metamorphosed to greenschists, known from the Devonian Vrbno Group northernmost part (PATOČKA, 1987). It therefore seems improbable that the depositional basin of the Andělská Hora Fm. greywackes could be adjacent to the relatively mature continental island arc of Devonian age.

The composition of the studied greywackes was controlled by the nature of the pre-existing crust– these clastics were likely derived mainly from (meta)igneous and (meta)sedimentary rocks resembling the metamorphics of the Orlík nappe Group, considered to be of pre-Devonian age (cf. MALKOVSKÝ et al., 1984). Both major and trace element geochemistry revealed the Orlík nappe Group metaigneous rocks as equivalents of volcano-plutonic arc and/or collision belt related calc-alkaline granitoids (FIŠERA & PATOČKA, 1989). Rocks showing similar composition probably dominated in the source area of the Vrbno Group Devonian metapelites, too (PATOČKA, 1992).

The purple zircons common in the Andělská Hora Fm. greywacke samples suggest the Precambrian age of a part of the source rocks; also the U-Pb zircon ages date the emplacement of the metaigneous rocks, exposed in the pre-Devonian crystalline sequences of the Moravo-Silesian Zone, close to Precambrian/Cambrian boundary, i.e. these rocks can be probably interpreted as Cadomian intrusives (VAN BREEMEN et al., 1982).

The relative enrichment of Zr and Hf in the studied greywackes (Text-Figs. 7 and 8) as well as distribution and composition of the greywacke transparent heavy mineral assemblage (Text-Fig. 6) probably reflects a significant rapid uplift of the source region and transport of relatively weakly weathered material into a differentiated basin with relatively poor sorting and mixing; a possible result is the dominance of pre-Devonian clastic material in the greywackes.

The above mentioned features of the Andělská Hora Fm. greywackes are counterparts of compositional characteristics of greywackes of the Gramscatho (SW England) and Giessen (W Germany) sequences (Middle to Late Devonian and Late Devonian to possibly Early Carboniferous in age respectively) described by FLOYD & LEVERIDGE (1987) and FLOYD et al. (1991). This relation probably indicates a similar nature of source area of all mentioned sequences of Variscan flysch clastics. Consequently, it seems to support the idea of continuity between the Mid-German Crystalline Rise/Normannian High, since Late Devonian becoming a major source area uplifted along the southern margin of the Rhenoherynian Zone (ENGEL & FRANKE, 1983; HOLDER & LEVERIDGE, 1986), and the pre-Devonian crystalline complexes of the Moravo-Silesian Zone (e.g. HAVLENA, 1976; DUDEK, 1980; ENGEL et al., 1983).

8. Conclusion

The phyllitic greywackes and greywacke phyllites, abundant in the Andělská Hora Fm. (part of the Moravo-

Silesian Culm – the Variscan flysch sequence possibly Late Devonian to Early Carboniferous in age), were investigated with regard to major and trace element geochemistry; the results were compared with the data on transparent heavy mineral assemblage of these rocks.

The major and trace element composition of the Andělská Hora Fm. greywackes probably was not substantially changed during a very low-grade regional metamorphism of Variscan age. The principal geochemical features of the greywackes – apparently lower degree of REE fractionation (compared to the PAAS), very small negative anomaly of Eu relative to chondritic composition and lower contents of Ta and Nb and equal abundances of the other HFS and mantle-compatible elements relative to post-Archean average shale – indicate the dominance of (meta)igneous rocks corresponding to intermediate to acid calc-alkaline magmatites in the source area; mafic rocks were there in minority. The depletion of the greywackes in Th (compared to post-Archean average shale) signifies a lesser contribution of old (recycled) sediments and/or their metamorphic equivalents.

Also the composition of transparent heavy mineral assemblage in the Andělská Hora Fm. greywackes – generally defined as zircon-apatite-sphene-tourmaline one – suggests a dominance of granitic rocks in the source area of the sediments. Nevertheless, the abundance of round zircons (34.3 % of all zircon grains) indicates the presence of (meta)sediments (possibly recycled ?) in the provenance of the greywacke material. Frequent occurrence of the purple zircon variety (in more then 2/3 of studied samples) points on the Precambrian age of a part of the source rocks.

In the close vicinity to the Andělská Hora Fm., the crystalline Orlík nappe Group is exposed; its meta-igneous rocks – according to major and trace element geochemistry – can be considered as counterparts of magmatic arc and/or collision belt related calc-alkaline granitoids. Also, the age of igneous origin of these rocks was probably Cadomian. The rocks closely resembling these metamorphics probably formed the source area of the studied greywackes. The dominance of pre-Devonian clastic material in the Andělská Hora Fm. greywackes is possibly a result of rapid uplift of the source region, indicated both by relative enrichment of Zr and Hf in the greywackes and by the nature of their transparent heavy mineral assemblage.

The described features of the Andělská Hora Fm. greywackes – similar to composition of greywackes of SW England (Middle to Late Devonian) and W Germany (Late Devonian to possibly Early Carboniferous) – suggest a similar type of provenance of these Variscan flysch clastics. Thus, the idea of continuity between the Mid-German Crystalline Rise/Normannian High, since Late Devonian becoming a source area of the Rhenohercynian Zone clastic sediments, and the pre-Devonian crystalline of the Moravo-Silesian Zone seems to be supported.

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