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GEOCHEMISTRY AND PROVENANCE OF THE UPPER CARBONIFEROUS SANDSTONES FROM BOREHOLE DIÓSVISZLÓ-3 (TÉSENY SANDSTONE FORMATION, SW HUNGARY)

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ABSTRACT

This paper presents the bulk geochemical data measured on core samples collected from borehole Diósviszló Dv-3 (Upper Carboniferous Téseny Sandstone Formation, Slavonian–Drava Unit, Tisza Megaunit, SW Hungary).

On average, analysed samples are slightly enriched in SiO_2 and they have similar K_2O, Rb, Ba, Th and U abundances to the Upper Continental Crust (UCC). Samples are strongly depleted in MnO, CaO, Na_2O, Sr and Pb, and they are slightly depleted in TiO_2, Al_2O_3, Fe_2O_3, MgO and P_2O_5 relative to the UCC. In general, the concentrations of both the high field strength elements and the transition trace elements are lower in Téseny sandstones from borehole Dv-3 compared with those of UCC. Total REE concentrations are lower than in the UCC, but chondrite-normalized patterns display the typical LREE-enriched pattern of UCC. These trends can be explained by a sedimentary system dominated by detritus derived from recycled upper crustal material. In addition, chondrite-normalized REE patterns, high Th/Sc, La/Sc and La/Yb ratios, low Cr, V and Ni contents and result of the TiO_2-Ni diagram indicate that these rocks were sourced dominantly from felsic magmatic rocks.

The La-Sc-Th and Th-Sc-Zr/10 ternary diagrams of the Upper Carboniferous sandstone samples are typical of continental island arc/active continental margin tectonic settings.

Key words: sandstone, geochemistry, source area, tectonic setting, Upper Carboniferous, Tisza Megaunit, SW Hungary

INTRODUCTION

Geochemical and provenance studies of clastic sedimentary rocks aim to decipher the composition and geological evolution of the sediment source areas and to constrain the tectonic setting of the depositional basin. The bulk geochemical analysis of sandstones is a powerful tool for provenance studies (Götze, 1998; Dinelli et al., 1999; Cullers, 2000; R. Varga et al., 2003; Zimmermann and Bahlburg, 2003). Due to their relatively immobile nature, the distribution of selected trace elements, such as the high field strength elements Th, Sc and Zr and REE (rare earth elements), are particularly useful indicators of geological processes. Additionally, some key trace element ratios (La/Sc, La/Th, Co/Th, Th/Sc, Cr/Th, Cr/Zr) are widely used to discriminate the provenance and tectonic setting of sandstones (Taylor and McLennan, 1985; Bhatia and Crook, 1986; McLennan and Taylor, 1991; Bauluz et al., 2000).

In this paper, results of a geochemical study of the Upper Carboniferous (Westphalian) clastic Téseny Sandstone Formation (Slavonian–Drava Unit, Tisza Megaunit, SW Hungary) are presented. Rocks of this coal-bearing fluvial facies are not exposed in Hungary and are known from numerous boreholes in southern Transdanubia, for example in boreholes Téseny T-2, T-7, Siklósbodony Sb-1, Bogádmindszent Bm-1 and Diósviszló Dv-3 (Fig. 1). Reworked material of this formation also occurs in the western part of the Mecsek Mountains in the Miocene conglomerate sequence called Szászvár Formation, where plant-bearing Carboniferous sandstone pebbles were first mentioned by Soós and Jámbor (1960).

The petrology of the clastic sedimentary rocks of Téseny Formation from above mentioned boreholes has been studied and summarized by Jámbor (1969, 1998), Hetényi and Ravasz-Baranyai (1976), Kassai (1980), Hámos (1984), Barabás-Stuhl (1986-88), Fülöp (1994) and Varga et al. (2001). A brief summary of provenance and geochemistry of Upper Carboniferous sediments was made by R. Varga et al. (2003).

This work concentrates on the investigation of a representative borehole of Carboniferous rocks near the village of Diósviszló. Upper Carboniferous sediments of borehole Diósviszló Dv-3 are composed primarily of coarse-pebble conglomerates alternating with medium to very coarse-grained sandstones (Hámos, 1984). These sandstones are composed mainly of quartz, feldspar (more K-feldspar than plagioclase), detrital grains of muscovite and biotite, and lithic clasts such as quartz-rich metamorphic rocks, acidic and intermediate volcanic clasts, granitoid fragments and siliciclastic sedimentary rocks (Fig. 2), in addition, accessory minerals (zircon, tourmaline, rutile and apatite), chlorite, kaolinite and pyrite are present in minor amounts (Barabás-Stuhl 1986-88; R. Varga et al., 2003).

Here, the major and trace element chemical composition of sandstones from borehole Dv-3 has been investigated to determine the provenance area and tectonic setting of these rocks.

SAMPLING AND ANALYTICAL METHODS

Eleven representative rock samples from borehole Dv-3 were used for geochemical study. Fine to very coarse-grained sandstones have been chemically analysed for major elements and a variety of trace elements, including some REE.

Major and trace element (Rb, Sr, Ba, Pb, Y, V, Cu, Ni and Zn) abundances of sandstone samples were established by X-ray fluorescence analysis of a powdered rock specimen using a Philips PW 2404 instrument in the laboratory of the University of Veszprém (Department of Earth and Environmental Sciences). In addition, Zr, Nb and Co were analysed by X-ray fluorescence in the XRAL Laboratories (Division of SGS Canada Inc.). The identification of the elements Th, U, Hf, La, Ce, Sm, Eu, Yb, Lu, Sc and Cr were also performed by neutron activation analysis at the same XRAL Laboratories. These results were then used to provide the basis for geochemical analysis of the sediments.

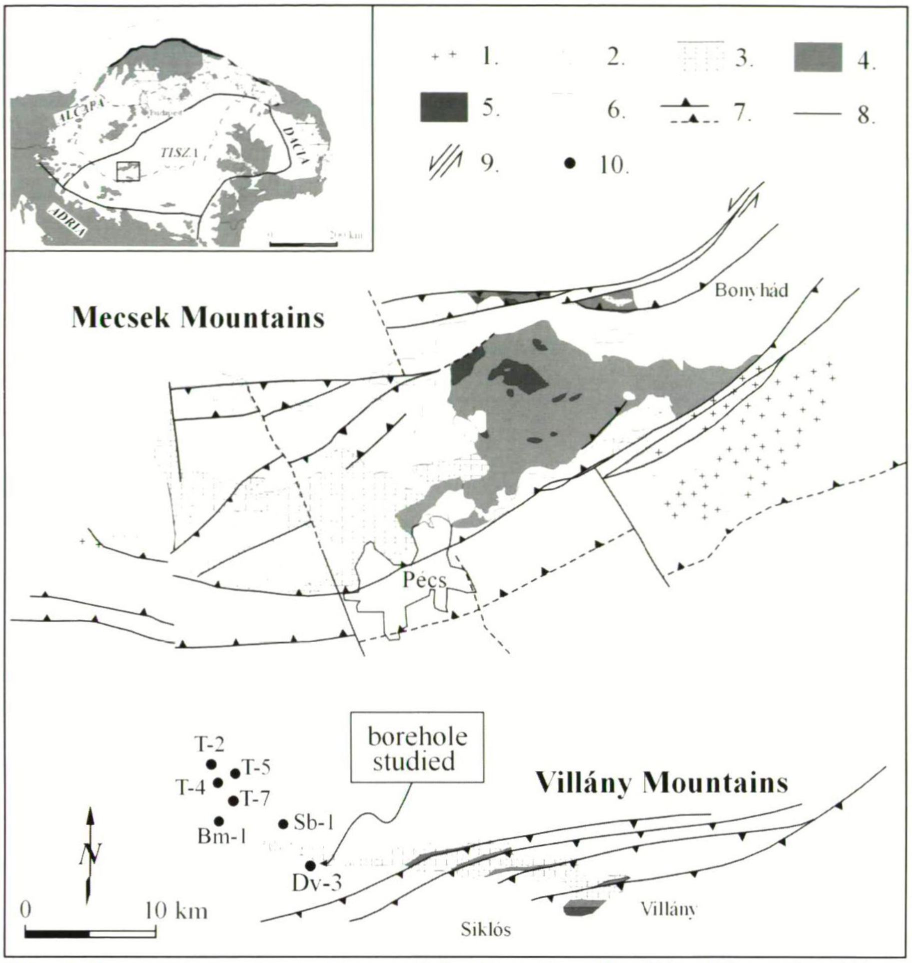

Fig. 1. Generalized geological map of the Mecsek and Villány Mountains (Tisza Megaunit, SW Hungary) and sample locality (modified after Nagy, 1968 with structural geological data of Csontos et al., 2002). Legend: 1: Carboniferous granite; 2: Permian; 3: Triassic; 4: Jurassic; 5: Cretaceous; 6: Neogene; 7: thrust mapped/supposed; 8: transfer fault; 9: strike slip fault; 10: locality of boreholes.

RESULTS AND DISCUSSION

The chemical composition of analysed sandstone samples (N=11) with the mean values and standard deviations are reported in Table 1. Likewise, average data of Upper Continental Crust (UCC) after McLennan (2001) are included as a reference. Values of some elemental ratios are listed in Table 2.

Using the chemical classification scheme of Pettijohn et al. (1972) the analysed sandstone samples are classified mainly as arkose. Only one sample is classified as litharenite (Fig. 3). Additionally, a clear shift of the chemical composition of four arkosic samples towards lower log(Na_2O/K_2O) ratios suggests that their behavior is mainly controlled by the high mobility of Na_2O, especially during chemical weathering, diagenesis and secondary alteration processes (McLennan, 2001; Zimmermann and Bahlburg, 2003).

Major element geochemistry

Whole-rock XRF analyses of the sediments collected for this study show moderate variations (in wt%) for SiO_2 (75.32±3.74) and Al_2O_3 (12.56±1.93). In comparison with the UCC (McLennan, 2001), all the samples are slightly enriched in SiO_2 (Table 1). On average, analysed sandstones have similar K_2O abundance (3.55±0.69) to the UCC (3.40). As can be seen in Fig. 4A, the samples are greatly depleted in MnO, CaO and Na_2O, and they are slightly depleted in TiO_2, Al_2O_3, Fe_2O_3, MgO and P_2O_5 relative to the UCC. These differences are probably due to the quartz dilution effect. In addition, low values of CaO and Na_2O would also reflect the differential effects of chemical weathering of source area and the absence of neutral and basic plagioclases (R. Varga et al., 2003). On the other hand, sample 4/Dv-3, has slightly higher percentages of TiO_2 and Al_2O_3, probably because of its finer grain-size and higher contents in phyllosilicates and heavy minerals relative to the other sandstones. Samples 5/Dv-3, 6/Dv-3, 7/Dv-3 and 8/Dv-3 are noticeable by their extremely low contents of mobile elements, such as Mn, Ca and Na. This chemical composition might have a post-depositional origin in the depth interval of 1235.0-1301.2 m of borehole Dv-3. Petrographic features of these samples reflect extensive hydrothermal alteration with concomitant pyritization. As the result of the secondary processes, the mobile elements have been partially removed from these sediments.

Trace element geochemistry

Compared to average upper continental crust (McLennan, 2001), analysed sandstones have similar contents in large ion lithophile elements (LILE), such as Rb and Ba, although variations are broad (Fig. 4B). They are clearly depleted in Sr and Pb. In general, the concentrations of both the high field strength elements (HFSE: Zr, Hf, Nb and Y) and the transition trace elements (TTE: Sc, V, Cr, Cu, Co, Ni and Zn) are lower in Téseny sandstones from borehole Dv-3 compared with those of the UCC. Samples are slightly depleted in Zr, Hf, Nb, Sc, V and Cr. They have a similar Y, Th and U content and they are highly depleted in Cu, Co, Ni and Zn.

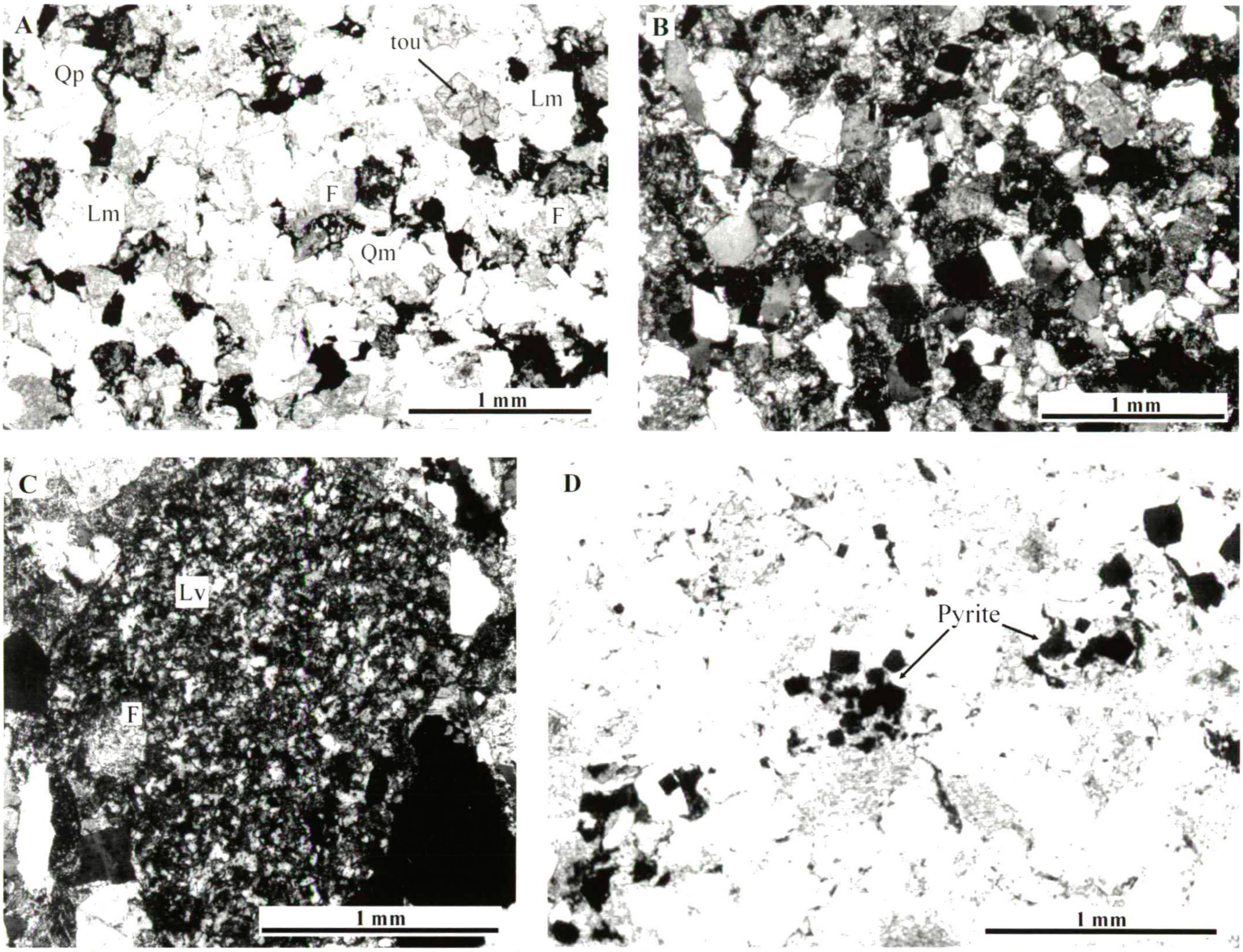

Fig. 2. Photomicrographs of sandstone samples from borehole Dv-3: ***(A)*** medium-grained sandstone, sample 3/Dv-3, 1N. Legend: Qp=polycrystalline quartz, Qm=monocrystalline quartz, F=feldspar, Lm=metamorphic rock fragment, tou=tourmaline. ***(B)*** medium-grained sandstone, sample 3/Dv-3, +N. ***(C)*** strongly sericitized feldspar (F) in fine-grained felsitic groundmass of volcanic rock fragment (Lv), sample 11/Dv-3, +N. ***(D)*** petrographic evidence for pyritization, sample 11/Dv-3, 1N.

This depletion, as with the major elements, is most likely to be a result of dilution of the elemental concentration by quartz. On the other hand, sample 4/Dv-3 contains greater amounts of Th, U, Zr, Hf, Nb, Y and Cr relative to the UCC (Fig. 4B). These concentrations are most likely to be controlled by the distribution of clay minerals and detrital accessories such as zircon, rutile and monazite.

In the Upper Carboniferous sandstones, the Zr/Hf values range from 30 to 56 (38.7⊕7.7). This suggests that these elements are controlled by zircons (Bauluz et al., 2000), since these values of the Zr/Hf elemental ratio are nearly identical to those reported by Murali et al. (1983) from the analysis of zircon crystals (39⊕2).

With respect to the REE, concentrations of La, Ce, Sm, Eu, Yb and Lu are significantly lower in Téseny sandstones (except for sample 4/Dv-3) compared with those of the UCC (Table 1). Previous studies (McLennan, 1990; Cullers, 1995) have shown that the sand fraction has mostly low REE contents, suggesting that the major control is a dilution effect caused by quartz, a mineral with very low REE abundances.

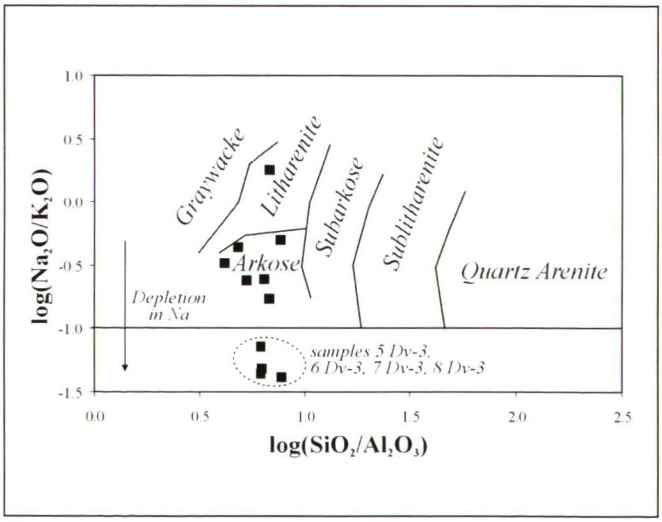

Fig. 3. Chemical classification scheme of sandstones based on major elements: log(Na_2O/K_2O) vs. log(SiO_2/Al_2O_3) diagram (after Pettijohn et al., 1972). Samples in dotted ellipse suffered diagenetic/hydrothermal alteration.

The REE chemical data acquired from Upper Carboniferous sediments of borehole Dv-3 are normalized to chondrite composition (Fig. 4C). Chondrite normalization factors are those listed by Taylor and McLennan (1985). REE patterns of the studied samples show similar general trends. Their REE fractionation, expressed by La_N/Yb_N ratio, is higher (12.6⊕4.1) compared with that of the UCC (9.2). The La_N/Sm_N values in the sandstones range from 4 to 5 (4.4⊕0.3). This suggests that the light REE (LREE) fractionation is similar to that of the UCC (4.2). These ratios show relatively depleted concentrations of the heavy REE (HREE) compared to the average composition of the UCC.

Provenance and tectonic setting

Due to their relatively immobile nature, the distribution of selected trace elements, such as the Th, Zr, Hf, Sc, V, Cr, Co, Ni and REE, are particularly useful indicators of provenance of clastic sedimentary rocks (Bhatia, 1985; Taylor and McLennan, 1985; Dinelli et al., 1999; Bauluz et al., 2000; Lee, 2002; Zimmermann and Bahlburg, 2003). The REE, Th and Sc are the most useful for inferring source rock composition because their distribution is not seriously affected by secondary processes such as diagenesis and metamorphism and are less affected by heavy mineral fractionation than are elements such as Zr and Hf (Bhatia and Crook, 1986; Floyd et al., 1991; McLennan and Taylor, 1991; Cullers, 1995).

Trace elements such as Cr are useful in identifying accessory detrital components such as chromite, commonly derived from mafic to ultramafic sources. Input from mafic source areas would also result in an enrichment of V and Ni. Another good tracer of mafic rock components is the compatible element Sc, especially when compared with Th, which is incompatible and thus enriched in felsic rocks. Both elements are generally immobile under surface conditions and therefore inherit the characteristic features of their source (Floyd et al., 1991; Dinelli et al., 1999; Amorosi et al., 2002; Zimmermann and Bahlburg, 2003).

Previous geochemical studies (Cullers, 1995; Cullers and Berendsen, 1998; Lee, 2002) have shown that the Th, Zr and La are enriched in felsic rather than in mafic rocks, because they are highly incompatible during most igneous melting and fractination processes. Sc, Cr and Co are typically much

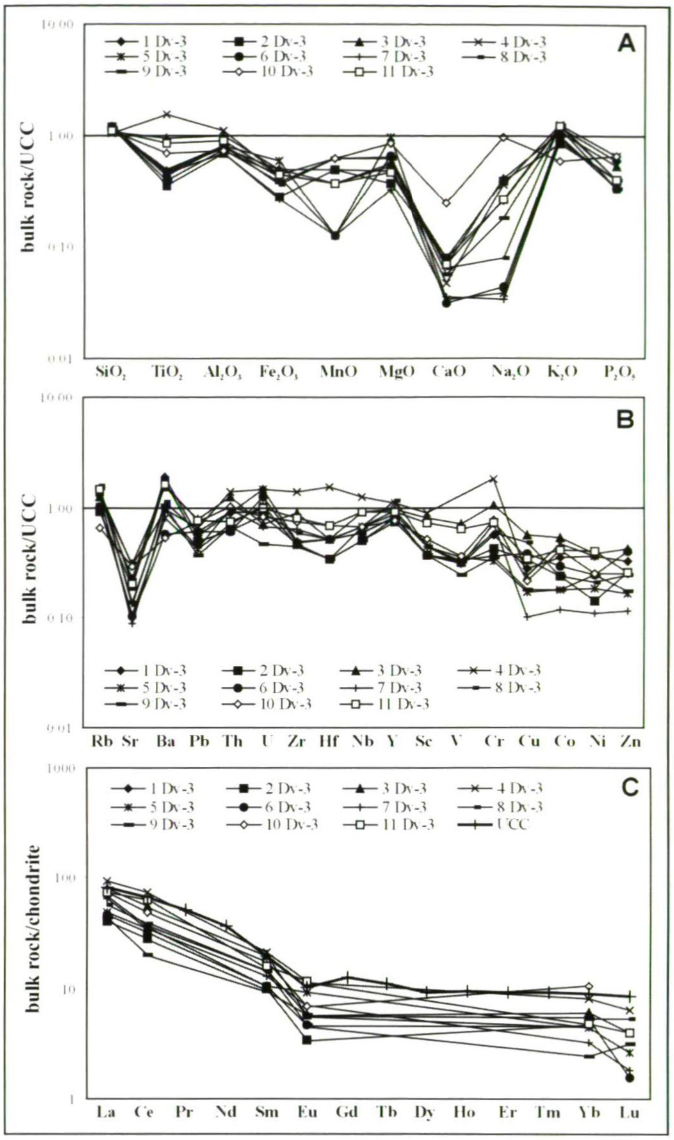

Fig. 4. Upper Continental Crust (UCC)-normalized (McLennan, 2001) major ***(A)*** and trace element ***(B)*** composition of Téseny Sandstone samples from borehole Dv-3. ***(C)*** Chondrite-normalized (Taylor and McLennan, 1985) rare earth element (REE) patterns for Téseny sandstones. UCC composition plotted for reference.

Table 1. Chemical composition (major element concentrations in weight percent and trace element concentrations in ppm) of sandstone samples from borehole Diósviszló Dv-3. Legend: LOI - loss on ignition; sd. dev. - standard deviation; UCC - Upper Continental Crust after McLennan (2001).

sample depth (m)	1/Dv-3 1199.0	2/Dv-3 1218.4	3/Dv-3 1219.5	4/Dv-3 1220.6	5/Dv-3 1235.0	6/Dv-3 1240.0	7/Dv-3 1289.0	8/Dv-3 1301.2	9/Dv-3 1301.7	10/Dv-3 1316.4	11/Dv-3 1343.9	mean value	sd. dev.	UCC
SiO_2	74.84	79.69	71.00	68.77	75.70	77.52	81.82	75.65	76.86	74.12	72.57	75.32	3.74	66.00
TiO_2	0.33	0.24	0.64	1.05	0.31	0.30	0.31	0.34	0.27	0.47	0.58	0.44	0.24	0.68
Al_2O_3	11.82	10.50	15.05	16.72	12.30	12.50	10.65	12.32	11.41	11.07	13.84	12.56	1.93	15.20
Fe_2O_3	2.53	1.41	2.53	2.24	3.00	2.12	1.33	1.82	1.92	2.25	2.26	2.13	0.49	5.03
MnO	0.04	0.04	0.03	0.03	0.01	0.01	0.01	0.05	0.05	0.05	0.03	0.03	0.02	0.08
MgO	1.08	0.82	1.26	1.17	2.14	1.44	0.72	1.41	1.39	1.86	1.05	1.30	0.42	2.20
CaO	0.33	0.33	0.29	0.20	0.14	0.13	0.15	0.27	0.24	1.03	0.29	0.31	0.25	4.20
Na_2O	1.01	1.52	1.62	1.42	0.15	0.17	0.13	0.31	0.70	3.79	1.03	1.08	1.06	3.90
K_2O	4.04	2.93	3.64	4.25	3.30	3.43	3.07	4.24	3.94	2.05	4.20	3.55	0.69	3.40
P_2O_5	0.09	0.06	0.08	0.10	0.05	0.05	0.06	0.06	0.05	0.10	0.06	0.07	0.02	0.15
LOI	3.89	2.71	4.07	3.56	2.66	2.51	1.70	3.50	3.44	3.13	3.85	3.18	0.72	
Total	100.00	100.25	100.21	99.51	99.76	100.18	99.95	99.97	100.27	99.92	99.76			

Table 1. continued

sample depth (m)	1/Dv-3 1199.0	2/Dv-3 1218.4	3/Dv-3 1219.5	4/Dv-3 1220.6	5/Dv-3 1235.0	6/Dv-3 1240.0	7/Dv-3 1289.0	8/Dv-3 1301.2	9/Dv-3 1301.7	10/Dv-3 1316.4	11/Dv-3 1343.9	mean value	sd. dev.	UCC
Rb	143	103	139	155	114	114	147	178	168	73	165	136	32	112
Sr	79	68	109	104	37	37	31	46	48	103	70	67	29	350
Ba	1038	957	844	534	447	315	517	613	575	296	896	639	257	550
Pb	9.5	8.4	13.3	11.0	7.1	10.4	7.3	10.2	6.3	12.6	13.1	9.9	2.5	17
Th	9.6	6.7	13.5	15.0	7.5	6.5	10.4	9.7	7.1	11.0	8.0	9.5	2.8	10.7
U	4.1	2.4	2.0	4.1	2.9	3.5	1.9	2.5	1.3	2.3	2.8	2.7	0.9	2.8
Zr	94	88	168	267	87	90	120	111	84	140	153	127	55	190
Hf	3	2	3	9	2	3	3	3	2	4	4	3.5	2.0	5.8
Nb	7	6	11	15	8	7	8	8	6	8	11	8.6	2.7	12
Y	18.0	16.4	21.0	24.0	19.2	18.1	20.6	25.8	17.8	17.0	20.4	19.8	2.9	22
La	25	15	29	34	18	17	24	21	16	27	27	23	6.1	30
Ce	35	27	53	70	33	31	33	37	19	47	61	40	15	64
Sm	3.4	2.3	4.6	4.9	2.4	2.4	3.0	3.3	2.2	4.1	3.7	3.3	0.9	4.5
Eu	0.5	0.3	0.5	1.0	0.8	0.4	0.6	0.4	0.5	0.6	1.0	0.6	0.2	0.88
Yb	1.2	1.2	1.5	2.0	1.1	1.3	0.8	1.3	0.6	2.6	1.2	1.3	0.5	2.2
Lu	-	-	0.15	0.24	0.10	0.06	0.07	0.20	0.12	-	0.15	0.1	0.06	0.32
Sc	5	5	11	12	6	5	6	6	5	7	10	7.1	2.6	13.6
V	32.7	33.5	75.0	-	37.8	35.7	33.1	34.8	26.2	38.8	68.0	41.6	16.2	107
Cr	47	35	87	150	27	30	58	49	29	63	61	58	36	83
Cu	6.9	8.3	14.0	6.0	4.2	9.6	2.5	11.9	4.5	5.4	8.6	7.4	3.5	25
Co	6	4	9	8	3	5	2	4	3	7	7	3.5	2.3	17
Ni	15.8	6.3	16.9	16.0	8.1	10.8	4.8	9.3	10.7	11.0	17.5	11.6	4.4	44
Zn	23.3	18.3	29.7	-	11.6	28.5	8.1	17.5	12.4	17.8	19.1	18.5	7.0	71

more compatible than the REE, Th and Zr. Correspondingly, the La/Sc, La/Co,Th/Sc, Co/Th, Cr/Th and Cr/Zr ratios of detrital rocks are very sensitive indicators of igneous differentiation processes and source rock composition (Bhatia and Crook 1986; Bauluz et al., 1995; Cullers and Berendsen, 1998). In addition, the REE patterns may differ in different sources and have been used as provenance indicators (Bhatia, 1985; McLennan, 1990; Floyd et al., 1991; Cullers 1995; Lee, 2002; Zimmermann and Bahlburg, 2003).

On the basis of the chemical data, average Cr content of the Upper Carboniferous Téseny sandstones from borehole Dv-3 is 58 ppm. The respective Cr content of the UCC is 83 ppm (McLennan, 2001). In addition, the V and Ni values are much lower than in the UCC (Table 1). These low concentrations from sandstones provide no support for significant amounts of mafic or ultramafic rocks in the source area. With respect to the other transition trace elements, Co, Cu and Zn are highly depleted relative to the UCC, whereas other compatible elements such as Sc show less depletion (Fig. 4B). The general depletion of compatible elements is suggesting a relatively felsic source (Floyd et al., 1991; Cullers and Berendsen, 1998; Bauluz et al., 1995; Zimmermann and Bahlburg, 2003). This result is consistent with the petrographic composition and underlines the insignificance of a mafic or ultramafic contribution to the Carboniferous deposits.

Table 2. Values of key major and trace element ratios of sandstone samples from borehole Diósviszló Dv-3. Legend: sd. dev. - standard deviation; UCC - Upper Continental Crust after McLennan (2001).

sample depth (m)	1/Dv-3 1199.0	2/Dv-3 1218.4	3/Dv-3 1219.5	4/Dv-3 1220.6	5/Dv-3 1235.0	6/Dv-3 1240.0	7/Dv-3 1289.0	8/Dv-3 1301.2	9/Dv-3 1301.7	10/Dv-3 1316.4	11/Dv-3 1343.9	mean value	sd. dev.	UCC
SiO_2/Al_2O_3	6.33	7.59	4.72	4.11	6.15	6.20	7.68	6.14	6.74	6.70	5.24	6.15	1.1	4.34
K_2O/Na_2O	4.00	1.93	2.25	2.99	22.00	20.18	23.62	13.68	5.63	0.54	4.08	9.17	8.9	0.87
Na_2O/K_2O	0.25	0.52	0.45	0.33	0.05	0.05	0.04	0.07	0.18	1.85	0.25	0.37	0.52	1.15
Zr/Hf	31	44	56	30	43	30	40	37	42	35	38	38.7	7.7	32.8
Th/Sc	1.9	1.3	1.2	1.2	1.2	1.3	1.7	1.6	1.4	1.6	0.8	1.4	0.3	0.8
La/Sc	5.0	3.0	2.6	2.8	3.0	3.4	4.0	3.5	3.2	3.9	2.7	3.4	0.7	2.2
Co/Th	0.6	0.6	0.7	0.5	0.4	0.8	0.2	0.4	0.4	0.6	0.9	0.5	0.2	1.6
Cr/Th	4.9	5.2	6.4	10.0	3.6	4.6	5.6	5.0	4.1	5.7	7.6	5.7	1.8	7.8
Cr/Zr	0.5	0.4	0.5	0.6	0.3	0.3	0.5	0.4	0.3	0.5	0.4	0.4	0.1	0.4
La/Co	4.2	3.7	3.2	4.2	6.0	3.4	12.0	5.2	5.3	3.9	3.9	5.0	2.5	1.8
La/Yb	20.8	12.5	19.3	17.0	16.4	13.1	30.0	16.1	26.7	10.4	22.5	18.6	6.0	13.6
La/Sm	7.3	6.5	6.3	6.9	7.5	7.1	8.0	6.4	7.3	6.6	7.3	7.0	0.5	6.7
La_N/Yb_N	14.2	8.5	13.2	11.4	11.1	8.9	20.4	11.0	18.2	7.0	15.3	12.6	4.1	9.2
La_N/Sm_N	4.6	4.1	4.0	4.4	4.7	4.4	5.0	4.0	4.6	4.2	4.6	4.4	0.3	4.2

In general, certain trace element ratios also support a silicic source area of Téseny sandstones. The Cr/Zr, La/Sm and La_N/Sm_N values in analysed sandstones are similar to those of the UCC (Table 2). Additionally, values of the Co/Th (0.5±0.2) and Cr/Th (5.7±1.8) ratios are lower in the samples than in the UCC (1.6, 7.8, respectively). On the other hand, mean values of the Zr/Hf (38.7), Th/Sc (1.4), La/Sc (3.4) and La/Co (5.0) ratios are significantly higher in the studied sandstones, than in the UCC (32.8, 0.8, 2.2, 1.8, respectively). On average, the samples from borehole Dv-3 have fractionated REE patterns with La/Yb=18.6±6 and La_N/Yb_N=12.6±4.1, in addition, the LREE are also fractionated, La/Sm= 7.0±0.5 and La_N/Sm_N=4.4±0.3 (Table 2). These characteristics indicate that the clastic sedimentary rocks were sourced mainly from exposed upper crustal material and the source area of these Carboniferous sediments was felsic.

Major and trace elements in sandstones have also been used in binary diagrams of source rock composition. According to the TiO_2-Ni diagram after Floyd et al. (1989), the source areas of the Upper Carboniferous samples from borehole Dv-3 are predominantly of acidic magmatic nature (Fig. 5). This is consistent with the petrographic data (Hámos, 1984; R. Varga et al., 2003) and the result of the La/Th-Hf diagram published by R. Varga et al. (2003) and indicates that sediments were derived mainly from felsic magmatic rocks.

Many types of discrimination diagrams of tectonic settings that use major element chemistry have been proposed for clastic sediments (Bhatia, 1983; Roser and Korsch, 1986). The K_2O/Na_2O vs. SiO_2 binary diagram (Roser and Korsch, 1986) discriminates between passive continental margin, active continental margin and oceanic island arc tectonic settings (Fig. 6). This provenance classification diagram shows a wide spread for the Téseny sandstones and cannot be used to interpret the tectonic setting successfully because of the high mobility of Na, particularly during chemical weathering of feldspar and post-depositional processes.

Immobile trace elements in detrital sediments have also been used successfully in discrimination diagrams of paleotectonic settings. The La-Sc-Th and Th-Sc-Zr/10 ternary diagrams (Bhatia and Crook, 1986) have been used to differentiate between island arc (oceanic or continental) and continental margin (active or passive) settings. La-Sc-Th and Th-Sc-Zr/10 ratios of the Upper Carboniferous sandstone samples after R. Varga et al. (2003) are typical of continental island arc/active continental margin tectonic environments (Fig. 7).

Petrographic and geochemical features of Carboniferous sandstone samples from borehole Dv-3 are very similar to those of rocks from boreholes Bogádmindszent Bm-1 and Téseny T-2 - T-7 and to those of the reworked Upper Carboniferous clastic sediments of the Miocene conglomerate sequence in southern Transdanubia. However

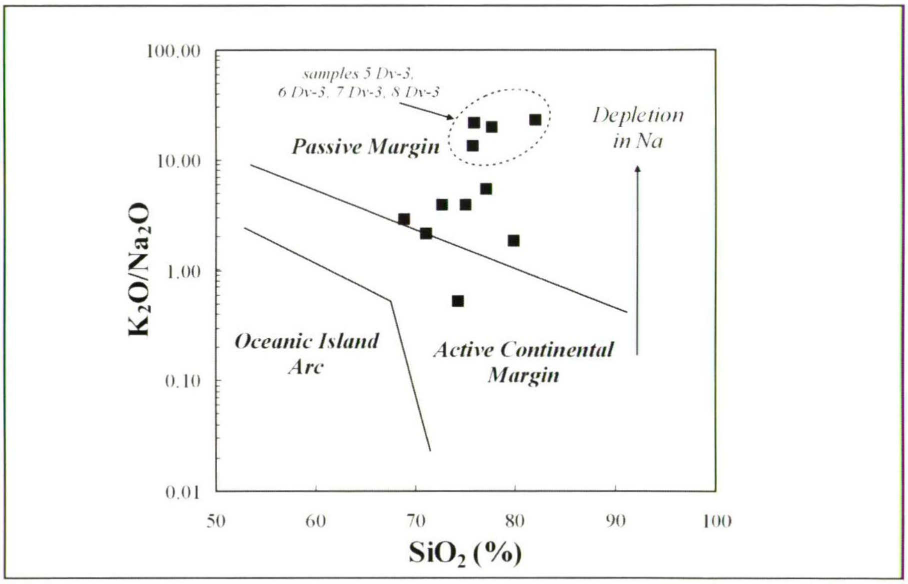

Fig. 6. Tectonic discrimination diagram for sandstones after Roser and Korsch (1986). Samples in dotted ellipse suffered diagenetic/hydrothermal alteration.

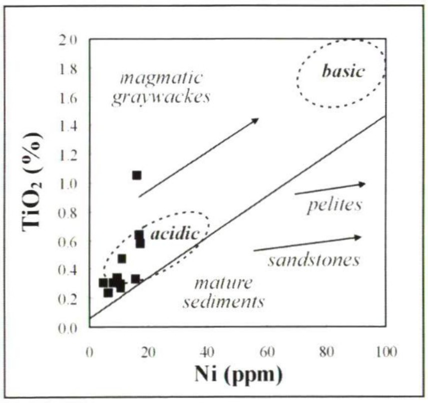

Fig. 5. Characterisation of the source rock composition based on Ni-TiO_2 diagram (Floyd et al., 1989).

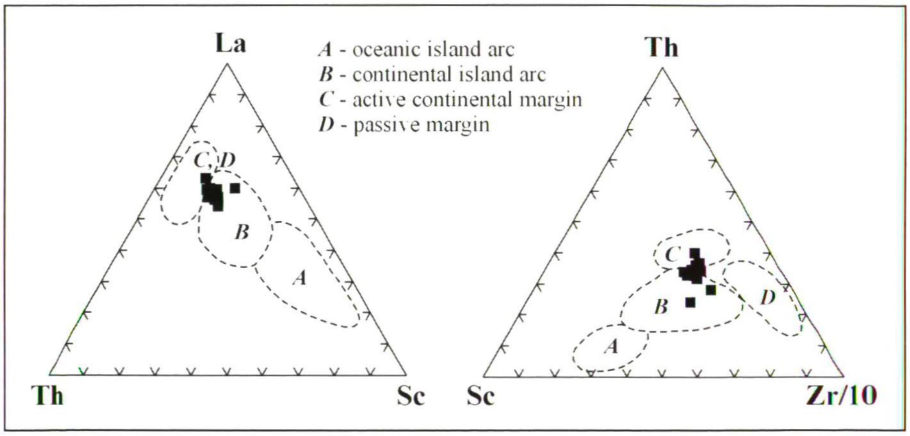

Fig. 7. Tectonic discrimination diagrams for clastic sedimentary rocks after Bhatia and Crook (1986).

there are small differences compared to sandstones from borehole Siklósbodony Sb-1 (Varga et al., 2001; R. Varga et al., 2003). On the basis of petrography and bulk rock geochemistry, the provenance of sandstone samples from borehole Dv-3 is the same as that of the clastic sediments from the above mentioned boreholes.

CONCLUSIONS

Geochemical signatures of the Upper Carboniferous sandstonesamples from borehole Dv-3 are typical of continentally-derived sediments. On average, analysed samples are slightly enriched in SiO_2 and they have similar K_2O and Rb, Ba, Th and U abundances to the UCC. Téseny sandstones are strongly depleted in MnO, CaO, Na_2O, Sr and Pb, and they are slightly depleted in TiO_2, Al_2O_3, Fe_2O_3, MgO and P_2O_5 relative to the UCC. The concentrations of both the high field strength elements and the transition trace elements are lower in Téseny sandstones from borehole Dv-3 compared with those of the UCC. These low HFSE and TTE concentrations from sandstones provide no support for significant amounts of mafic or ultramafic lithologies in the source area.

Chondrite-normalized REE patterns, high Th/Sc, La/Sc and La/Yb ratios and low Cr, V and Ni contents indicate that the Upper Carboniferous detrital rocks were sourced dominantly from exposed upper crustal material. These characteristics also reflect higher proportion of felsic magmatic rocks in the source area relative to the UCC composition.

According to the TiO_2-Ni diagram after Floyd et al. (1989), the source areas of the Upper Carboniferous samples from borehole Dv-3 are predominantly of acidic magmatic nature. The La-Sc-Th and Th-Sc-Zr/10 ternary diagrams (Bhatia and Crook, 1986) of the Upper Carboniferous sandstone samples are typical of continental island arc/active continental margin tectonic settings.

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REFERENCES

AMOROSI, A., CENTINEO, M. C., DINELLI, E., LUCCHINI, F., TATEO, F. (2002): Geochemical and mineralogical variations as indicators of provenance changes in Late Quaternary deposits of SE Po Plain. Sedimentary Geology, **151**, 273-292.

BARABÁS-STUHL, Á. (1986-88): Permian clastic sedimentary successions form southern Baranya Hills and Villány Mountains – Summarized results, III. Manuscript, Mecsek Ore Environment Company, Pécs, Hungary, 54-81. (In Hungarian)

BAULUZ LAZARO, B., MAYAYO BURILLO, M. J., FERNANDEZ-NIETO, C., GONZALEZ LOPEZ, J. M. (1995): Mineralogy and geochemistry of Devonian detrital rocks from the Iberian Range (Spain). Clay Minerals, **30**, 381-394.

BAULUZ, B., MAYAYO, M. J., FERNANDEZ-NIETO, C., GONZALEZ LOPEZ, J. M. (2000): Geochemistry of Precambrian and Paleozoic siliciclastic rocks from the Iberian Range (NE Spain): implications for source-area weathering, sorting, provenance, and tectonic setting. Chemical Geology, **168**, 135-150.

BHATIA, M. R. (1983): Plate tectonics and geochemical composition of sandstones. Journal of Geology, **91/ 6**, 611-627.

BHATIA, M. R. (1985): Rare earth element geochemistry of Australian Paleozoic graywackes and mudrocks: provenance and tectonic control. Sedimentary Geology, **45**, 97-113.

BHATIA, M. R., CROOK, K. A. W. (1986): Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins. Contributions to Mineralogy and Petrology, **92**, 181-193.

CSONTOS, L., BENKOVICS, L., BERGERAT, F., MANSY, J., WÓRUM, G. (2002): Tertiary deformation history from seismic section study and fault analysis in a former European Tethyan margin (the Mecsek–Villány area, SW Hungary). Tectonophysics, **357**, 81-102.

CULLERS, R. L. (1995): The controls on the major- and trace-element evolution of shales, siltstones and sandstones of Ordovician to Tertiary age in the Wet Mountains region, Colorado, U.S.A. Chemical Geology, **123**, 107-131.

CULLERS, R. L., BERENDSEN, P. (1998): The provenance and chemical variation of sandstones associated with the Mid-continent Rift System, U.S.A. Eur. J. Mineral., **10**, 987-1002.

CULLERS, R. L. (2000): The geochemistry of shales, siltstones and sandstones of Pennsylvanian-Permian age, Colorado, USA: implications for provenance and metamorphic studies. Lithos, **51**, 181-203.

DINELLI, E., LUCCHINI, F., MORDENTI, A., PAGANELLI, L. (1999): Geochemistry of Oligocene-Miocene sandstones of the northern Apennines (Italy) and evolution of chemical features in relation to provenance changes. Sedimentary Geology, **127**, 193-207.

FLOYD, P. A., WINCHESTER, J. A., PARK, R. G. (1989): Geochemistry and tectonic setting of Lewisian clastic metasediments from the early Proterozoic Loch Maree Group of Gairloch, N. W. Scotland. Precambrian Research, **45**, 203-214.

FLOYD, P. A., SHAIL, R., LEVERIDGE, B. E., FRANKE, W. (1991): Geochemistry and provenance of Rhenohercynian synorogenic sandstones: implications for tectonic environment discrimination. In A. C. Morton, S. P.Todd, P. D. W. Haughton (eds): Developments in Sedimentary Provenance Studies, Geological Sociaty Special Publication, **57**, 173-188.

FÜLÖP, J. (1994): Téseny Sandstone Formation. In J. Fülöp: Geology of Hungary. Paleozoic, II. Akadémiai Kiadó, Budapest, 322-332. (In Hungarian)

GÖTZE, J. (1998): Geochemistry and provenance of the Altendorf feldspathic sandstone in the Middle Bunter of the Thuringian basin (Germany). Chemical Geology, **150**, 43-61.

HÁMOS, G (1984): Mineralogy and petrology of the Upper Carboniferous conglomerate beds from the borehole Diósviszló-3 (Téseny Sandstone Formation, Villány Mountains). MSc. thesis, Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary (In Hungarian)

HETÉNYI, R., RAVASZ-BARANYAI, L. (1976): The anthracitiferous Upper Carboniferous sequence of Baranya, South Hungary, in the light of boreholes Siklósbodony-1 and Bogádmindszent-1. Ann. Report Hung. Geol. Inst. for 1973, 323-361. (In Hungarian with English abstract)

JÁMBOR, Á. (1969): Carboniferous deposits in the area between the Mecsek and Villány Mountains. Ann. Report Hung. Geol. Inst. for 1967, 215-221. (In Hungarian with English abstract)

JÁMBOR, Á. (1998): Stratigraphy of the Carboniferous sedimentary rocks from the Tisza Megaunit. In I. Bérczi, Á., Jámbor (eds): Stratigraphy of formations of Hungary. MOL Rt. and Hung. Geol. Inst. publ., 173-185. (In Hungarian)

KASSAI, M. (1980): Distribution of the Upper Carboniferous formations as outlined upon seismic and telluric measurements in SE Transdanubia. Ann. Report Hung. Geol. Inst. for 1978, 301-307. (In Hungarian with English abstract)LEE, Y. I. (2002): Provenance derived from the geochemistry of late Paleozoic–early Mesozoic mudrocks of the Pyeongan Supergroup, Korea. Sedimentary Geology, **149**, 219-235.

MCLENNAN, S. M. (1990): Rare Earth Elements in Sedimentary Rocks: Influence of Provenance and Sedimentary Processes. In B. R. Lipin, G. A. McKay (eds.): Geochemistry and Mineralogy of Rare Earth Elements, Reviews in Mineralogy, **21**, 169-200.

MCLENNAN, S. M. (2001): Relationships between the trace element composition of sedimentary rocks and upper continental crust. Geochemistry, Geophysics, Geosystems, **2**, 2000GC000109 (electronic publication)

MCLENNAN, S. M., TAYLOR, S. R. (1991): Sedimentary rocks and crustal evolution: tectonic setting and secular trends. Journal of Geology, **99/1**, 1-21.

MURALI, A. V., PARTHASARATHY, R., MAHADEVAN, T. M., SANKAR DAS, M. (1983): Trace element characteristics, REE patterns and partition coefficients of zircons from different geological environments – a case study on Indian zircons. Geochimica et Cosmochimica Acta, **47**, 2047-2052.

NAGY, E. (1968): Triassic formation of the Mecsek Mountains. MÁFI Évkönyv (Annals of Hung. Geol. Inst.), **51**, 1, 1-198. (in Hungarian)

PETTIJOHN, F. J., POTTER, P. E., SIEVER, R. (1972): Sand and Sandstone. Springer-Verlag, New York.

ROSER, B. P., KORSCH, R. J. (1986): Determination of tectonic setting of sandstone-mudstone suites using SiO_2 content and K_2O/Na_2O ratio. Journal of Geology, **94**, 635-650.

R. VARGA, A., SZAKMÁNY, GY., JÓZSA, S., MÁTHÉ, Z. (2003): Petrology and geochemistry of Upper Carboniferous siliciclastic rocks (Téseny Sandstone Formation) from the Slavonian–Drava Unit (Tisza Megaunit, S Hungary) – summarized results. Acta Geologica Hungarica, **46/1**, 95-113.

SOÓS, I., JÁMBOR, Á. (1960): Fossil plant-bearing Upper Carboniferous pebbles from the Helvetian conglomerate of the Mecsek Mountains. Földtani Közlöny, **90/4**, 456-458. (In Hungarian with German abstract)

TAYLOR, S. R., MCLENNAN, S. M. (1985): The Continental Crust: its Composition and Evolution. Blackwell, Oxford.

VARGA, A., SZAKMÁNY, GY., JÓZSA, S., MÁTHÉ, Z. (2001): Petrographical and geochemical comparison between the Carboniferous sandstone pebbles of the Lower Miocene conglomerate from western Mecsek Mts. and Téseny Sandstone Formation. Földtani Közlöny, **131/1-2**, 11-36. (In Hungarian with English abstract)

ZIMMERMANN, U., BAHLBURG, H. (2003): Provenance analysis and tectonic setting of the Ordovician clastic deposits in the southern Puna Basin, NW Argentina. Sedimentology, **50/6**, 1079-1104.

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