Carpathian Journal of Earth and Environmental Sciences, November 2012, Vol. 7, No. 4, p. 219 - 230

PETROLOGY AND GEOCHEMISTRY OF THE UPPER PERMIAN - MIDDLE TRIASSIC SILICICLASTIC FORMATIONS OF THE IBAFA-4 BOREHOLE (NW-MECSEK MTS., HUNGARY)

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Abstract: In this paper, we present the results of the petrological and geochemical study of the Upper Permian-Middle Triassic Kővágószőlős Sandstone, Jakabhegy Sandstone and Patacs Siltstone Formations sampled by borehole Ibafa-4. Granitoids, metamorphites and acidic volcanites were the dominating rock types in the provenance of Bakonya and Kővágótöttös Sandstone Members of the Kővágószőlős Sandstone Formation, although in the provenance of Bakonya Member granitoids and metamorphites were typical. The provenance of Cserkút Sandstone Member of the Kővágószőlős Sandstone Formation was less variegated: the granitoids and metamorphites had been already eroded, therefore the acidic volcanic clasts became dominant. The provenance of Jakabhegy Sandstone Formation resembles to Cserkút Member, but the Jakabhegy Sandstone is more mature that reinforces the earlier supposition that it had redeposited. The provenance of Patacs Siltstone was very similar to that of Jakabhegy Sandstone Formation. The geochemical data well reflect the mineralogical and petrological qualities, the effect of grain size and the post-sedimentary effects. The results indicate significant, subsequent Na depletion and a slight K enrichment in Kővágótöttös and Cserkút Member (Kővágószőlős Sandstone) and in the Jakabhegy Sandstone as well. The Na depletion is characteristic especially for the same members in Ibafa-4 borehole thus for the Gorica environs. The partial fading exhibited by the Jakabhegy Sandstone is due to the diagenetic effect. Cu enrichment in Bakonya Member of Kővágőszőlős Sandstone Formation which is known in W-Mecsek was also recognised in the Ibafa-4 borehole.

Keywords: petrology, geochemistry, siliciclastic rocks, provenance, copper enrichment, Tisza Megaunit, SW Hungary

1. INTRODUCTION

The Permian-Lower Triassic siliciclastic series is well known for many years in large thickness from the surface and boreholes in Western-Mecsek Mountains in South Hungary. Further to the west from this territory, on the so called Gorica district these siliciclastic formations exist under Miocene sediments and only few informations were available until now.

The aim of the evaluation of the Upper Permian-Middle Triassic formations of the Ibafa-4 borehole was to discover the petrological and geochemical properties of these formations in the less known Gorica area.

The examination of the Permian-Triassic siliciclastic rocks of Western-Mecsek Mts. is an exceptionally topical issue, because on the one hand uranium ore occurs in these rocks, and on the other hand high-level radioactive waste repository is going to be formed in the Upper Permian Boda Siltstone Formation which belongs to this series. The aim of drilling the Ibafa-4 borehole is connected with this latter mentioned research. The Ibafa-4 borehole was drilled in 2004-2005 by Mecsek Ore Enviroment Company in the Gorica area, located in the northwestern part of the Mecsek Mountains, southern Transdanubia, Hungary (Fig. 1).

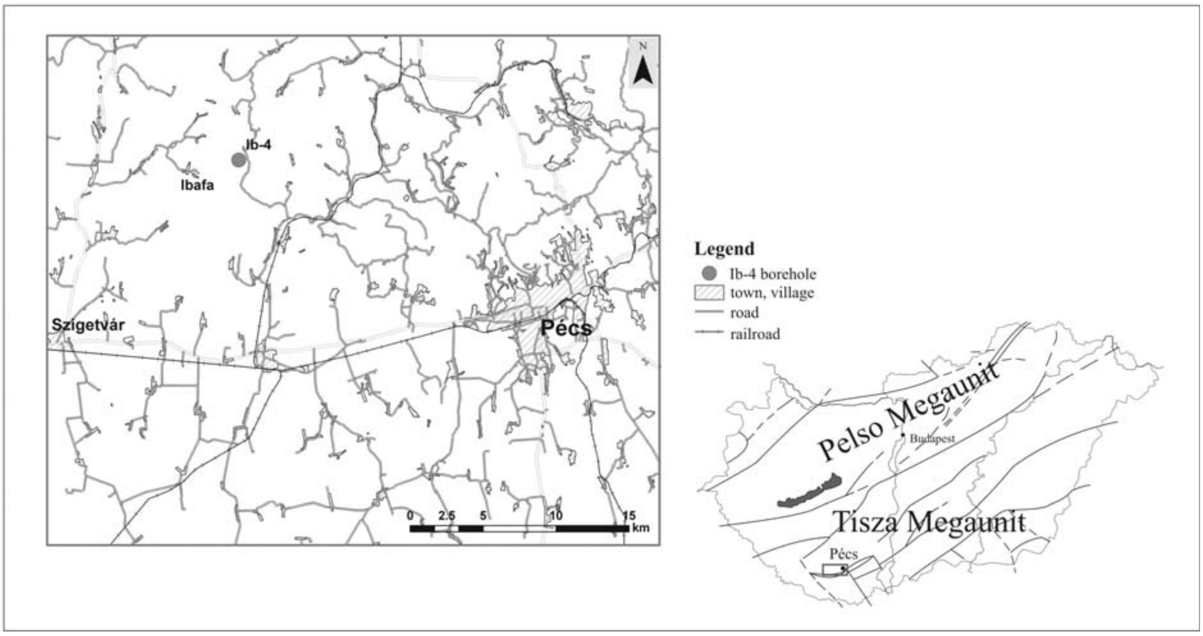

Figure 1. Major structural units of the Pannonian Basin (after Kovács, S. et al., 2000 and Császár, 2005) and the location of the Ibafa-4 borehole

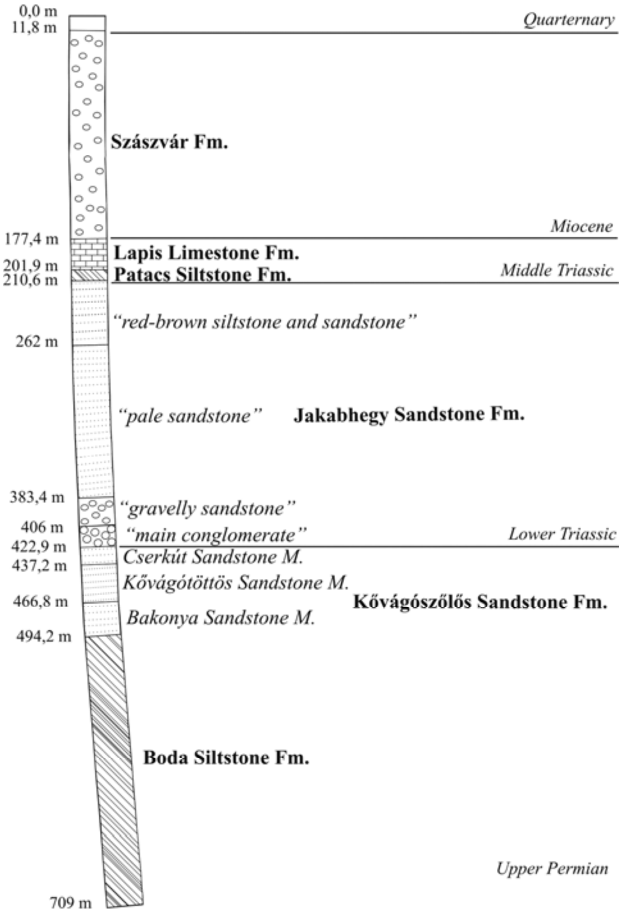

Figure 2. The succession of Ibafa-4 borehole

The aim of our study was the petrological and geochemical examination of the Upper Permian–Middle Triassic Kővágószőlős Sandstone, Jakabhegy Sandstone and Patacs Siltstone Formations in the Ibafa-4 borehole, together with the comparison of our results with the „classical" environments of the W-Mecsek Mts. of the same formations.

The geology of Gorica Block is less known than that of anticline of the W-Mecsek Mts., because the working up and the examination of drillcores of the drillings which were made in the 1960-1970's in Gorica area did not happen. The Ibafa-4 borehole has provided new facilities to discover this area, so thus with our study we could get preciser idea from the paleoenviroment, and we were able to compare the studied formations with the same „classical" formations in W-Mecsek Mts.

Unfortunately the Ibafa-4 borehole did not reach the footwall of Boda Siltstone, it stopped in it. The cover of Boda Siltstone is the Upper Permian Kővágószőlős Sandstone Formation, which is almost complete in this borehole except its topmost Lower Triassic Tótvár Member, which is missing here. Above Kővágószőlős Sandstone the Lower Triassic Jakabhegy Sandstone Formation follows, and the Middle Triassic Patacs Siltstone Formation closes the siliciclastic succession. The siliciclastic series is covered by limestone breccia, which was pending identified as Lapis Limestone Formation. After a long hiatus the Miocene Szászvár Formation and thin clay beds of Quarternary had been deposited representing the youngest period (Fig. 2).

2. HISTORY

From the middle of the 1950's after the detection of the urainium ores the exploration of the Permian formations in southern Transdanubia has been resumed. In that period of time lots of boreholes were drilled in the Mecsek and Villány Mts. and in those environments. At the end of the 1980's the exploitation of the ore became uneconomic and in 1997 the mining was closed down.

The uranium-bearing Kővágószőlős Sandstone Formation was given much attention, hence numerous examinations, manuscripts were made and several articles were published (Barabás, 1979; Barabásné, 1981; Fazekas, 1987; Fülöp, 1994; Barabás & Barabásné, 1998). The Jakabhegy Sandstone Formation was studied by Kassai (1973), Fazekas (1987), Török (1998), Bércziné et al. (2004), and Barabás & Barabásné (2005). Török (1998) and Bércziné et al. (2004) summarized the results about Patacs Siltstone Formation.

The examination of the Permian–Lower Triassic formations of southern Transdanubia at the end of the 1980's became topical again because the Boda Siltstone considered as a possible rock for high level radioactive waste disposal in Hungary (Árkai et al., 2000, Demény et al., 1996, Kovács, L. et al., 2000). A modern detailed petrological and geochemical investigations started at the end of the 1990's aimed to Carboniferous–Middle Triassic siliciclastic series of the Mecsek and Villány Mts. to make clear their paleogeography and their geological and tectonic development (Varga et al., 2003, 2005; Varga et al., 2006, 2007; Bodor & Szakmány, 2009, Parti, 1989, Csicsák & Szakmány, 1998). Recently the sedimentology of the Boda Formation in this series is under study (Konrád et al., 2010).

3. GEOLOGICAL SETTING

The Mecsek Mts. and its environs are the SW part of the Tisza Megaunit. The Permian formations of Mecsek Mts. developed through Variscian orogenesis, settled in half-graben structured, inner basins, and they are part of the thick molasse sequence. The older sequence consists of the Upper Carboniferous Téseny Sandstone – Lower Permian Korpád Sandstone and the acidic-intermediate Gyűrűfű Rhyolite Formation, the younger sequence is the Cserdi Formation, Boda Siltstone and Kővágószőlős Sandstone (Barabás & Barabásné, 1998). The youngest part of the Upper Paleozoic molasse is the 150-1400 m thick Kővágószőlős Sandstone Formation. Its footwall is the partly heteropic Boda Siltstone, its cover is Jakabhegy Sandstone Formation. The Kővágószőlős Sandstone is an alluvial succession consists of various colored conglomerate, pebbly and arkosic sandstone, siltstone and claystone beds. The formation was divided to four members in practice by the grounds of the dominant rock colours, and lithological and sedimentological characters, these members are partly heteropic with each other. The oldest member is the Bakonya Sandstone ("variegated succession") which shows river basin, floodplain, and periodic river facies too. The Kővágótöttös Sandstone Member ("grey succession") is continously superimposed on the Bakonya Sandstone. It shows marsh, abandoned meander facies, rarely has got floodplain and lacustric interbeddings. The Cserkút Sandstone Member ("cover red succession") which shows river basin facies is continously superimposed on the Kővágótöttös Sandstone. The Tótvár Member is the uppermost member of the formation ("purple pebbly sandstone") which was produced by periodic rivers. The Permian/Triassic boundary was defined by microflore assemblage and it runs in Kővágószőlős Sandstone (at the contact of Cserkút Sandstone and Tótvár Member) (Barabás & Barabásné, 1998, Bércziné et al., 2004). The formation can be regarded as one huge oxidation-reduction megacycle containing in its core grey sandstones of intensively reduced state with coalified plant remains, whereas heavily oxidized red sandstone constitute the external part of the grey sandstone core (Vincze & Somogyi, 1984; Vincze, 1987). The grey core (Kővágótöttös Member) and red mantle (Cserkút Member) are interfingered. The predominant green-coloured transitional redox facies (the lower and upper boundary facies) developed along the boundary of the oxidized and reduced rocks. The U-ore mineralization developed on the geochemical barriers of the boundary facies (along oxidation-reduction fronts).

The thickness of the semi-aridic, fluvial, Buntsandstein type Jakabhegy Sandstone Formation is strongly variable: 60-380 m in the area of Mecsek-Villány Mts. Its footwall spread from crystalline rocks to Kővágószőlős Sandstone Formation (Császár, 2005). It has got four lithostratigraphic members. These units usually superimposed on each other, but rarely occur in heteropic way. The maturity of sandstones is high which implies several redepositions. The lowest member is the "jakabhegy main conglomerate", which has fluvial channel line facies showing the increased relief energy. The "pebbly sandstone" member developed continously from the "jakabhegy main conglomerate" (Török, 1998, Bércziné et al., 2004). According to Bércziné et al., (2004) this succession is fluvial bar formation and the direction of transportation was from NNW. Barabás & Barabásné (2005) consider that it is an alluvial plain sediment of a meandering river. The "pale sandstone" member developed continously from the previous one (Fazekas, 1987). The lower part of the „pale sandstone” implies wave-dominated delta according to Török (1998), its upper part shows transition to intertidal plain, however according to (Bércziné et al., 2004) fluvial facies is also possible, furthermore Barabás & Barabásné (2005) implies wave-dominated delta. The „reddish-brown siltstone and sandstone” member which developed gradually from „pale sandstone” according to Török (1998), is already an intertidal plain, flat coast sediment, but Parti (1989) established for the „lacustric layers” shallow marine-coastal origin, and Csicsák & Szakmány (1998) consider that the „transitional layers” generated in tidal channels and on tidal flats. The lower-middle parts of the „member” according to Barabás & Barabásné (2005) formed on tidal delta, and the „grey layers” shows marsch facies.

At the early period of the slow Triassic transgression in the Mecsek and Villány Mts. the 10-150 m thick Patacs Siltstone Formation deposited. It developed from Jakabhegy Sandstone Formation by continous variation of layers. Red siltstone, fine grained red and greenish-grey sandstone and green sandstone are typical. The rocks became increasingly carbonated tending to the upper parts of the formation. The material of the sediment is terrigenous, deposited near by the coast in a ramp which evolved in the Lower Anisian by relative increasing of sealevel. The fossils indicate shallow marine, the clay minerals euhaline, tidal flat enviroment (Bércziné et al., 2004).

4. ANALYTICAL METHODS

After the review of the Ibafa-4 drillcores, we selected 52 representative samples from Kővágószőlős, Jakabhegy and Patacs Formations (26, 23 and 3 pc) to make detailed macroscopic and microscopic petrographic invetigation. We measured 300-400 clasts per sample by linear counting (Dickinson & Suczek 1979) in 18 representative sandstone samples. X-ray diffraction analyses on 11 samples (9 sandstones, 2 siltstones) to determine the matrix and the cement was made at the Department of Mineralogy of Eötvös Loránd University (Budapest, Hungary) (Bruker D5000 instrument, X-ray source: CuKα, graphite crystal monocromator, stintillation detector). Chemical analyses (major, trace and rare earth element) was made on the same 11 samples with ICP-MS and ICP-AES method (ACME Analytical Laboratories Ltd., Vancouver). We compared our petrological, mineralogical and geochemical results with the typical, equal formations from the W-Mecsek Mts. (unpublished data).

5. RESULTS

5.1. Petrology

Macroscopically the samples of Bakonya Sandstone Member are reddish green, grain-supported, poorly or moderately sorted, polymict, variable grain sized arkosic sandstones and orthoconglomerates, with subangular grains. The samples of Kővágótöttös Sandstone Member are greenish grey, grain-supported, poorly, moderately or moderately well sorted polymict siltstones-fine to coarse-grained subarkoses - medium-grained orthoconglomerates, the grains are mainly angular-subangular. The samples of Cserkút Sandstone Member are brownish red, grain-supported, moderately well sorted, polymict, variable grain sized litharenites and sublitharenites, together with fine-grained orthoconglomerate and matrix-supported, poorly sorted, oligomict siltstone. The grains are angular.

The samples of Jakabhegy Sandstone Formation are reddish purple, grain-supported, poorly-moderately sorted, oligo-polymict, variable grainsized orthoconglomerate and variable grained subarkoses and litharenites. Some sections of Jakabhegy Sandstone are not reddish purple, but pale (particularly the „pale sandstone member”). However in Ibafa-4 borehole other sections of the Jakabhegy Sandstone are also pale, their colour had bleached (into light yellow or white), and it do not match to the „pale sandstone”.

The samples of Patacs Siltstone Formation are matrix-supported, well, moderately well, moderately sorted, oligomict claystones-siltstones and grain-supported, well sorted, polymict, fine-grained subarkose.

In Kővágószőlős Sandstone quartz is the most abundant constituent. In Bakonya Sandstone Member the number of monocrystalline quartz (Qm) slightly exceeds the amount of polycrystalline quartz (Qp), and in Kővágótöttös and Cserkút Sandstone Member the monocrystalline quartz is also dominating. The amount of K-feldspar (orthoclase, sanidine > microcline) is almost the same as polycrystalline quartz in Bakonya Member and the amount of plagioclase is far less than K-feldspar, while the amount of feldspar in Kővágótöttös Member slightly decreased compared with the underlying member, mainly in the fine grainsize fraction. The amount of K-feldspar (orthoclase, microcline, sanidine) far exceeds the plagioclase, the amount of plagioclase decreases upwards. In Cserkút Member the amount of K-feldspars is much less than in the underlying members (orthoclase+sanidine > microcline), and their amount decreases upwards, while the amount of plagioclase is very low, and it is absent at the top of the member.

In Bakonya and Kővágótöttös Member some muscovite of clastic origin and partly or completely chloritised biotite are also present rarely. Accessories of the 3 members are mainly zircon and tourmaline, while in Kővágótöttös Member apatite, and in Bakonya Member rutile and garnet are present also, together with opaque minerals (bornite, calcosine, pyrite). Rarely small remnants of plant stems also occur in Bakonya Member.

Among rock fragments of the 3 members acidic volcanic fragments dominate: they originally have vitrophyric, felsitic and rarer spherolitic texture, more or less silicified, together with less amount of pyroclastic rock fragments. In latters we could separate pumice fragments. The pyroclastic rock types also occur as pebbles. The amount of volcanic origin fragments slightly exceeds the number of polycrystalline quartz in Cserkút Sandstone. In Bakonya Member several intersertal, rarely subophitic mafic magmatic fragments are also present, while in Kővágótöttös and Cserkút Sandtone basic volcanites are only in very few amount.

In Bakonya Sandstone there are numerous granitoid and (granitic)aplite fragments but in less amount than volcanogene fragments in sandstone (these rock types occur also as pebbles), however in Kővágótöttös Member the amount of granitoids and aplite fragments are in less quantity compared with the underlying member and with the volcanic fragments in this member.

In Kővágótöttös Member there are only few metamorphic fragments (sand and pebble) originated from micaschist, sericitized micaschist, sericitized or chloritized schist, mylonite, chloritized mylonite and gneiss, which are present in the underlying Bakonya Member also but in higher amount. In Bakonya Member there are quartz-phyllite, siliceous schist, mylonite, foliated sericitized or opacitized metamorphites, and also other rock types in minor quantity: strongly deformated quartzite, gneiss, protomylonite, augen mylonite, sericitized micaschist, quartz-sericite schist, chlorite-quartz-sericite schist, knotted schist, metasandstone and metasiltstone. The granitoid and metamorphic fragments of Cserkút Member (micaschist, chloritized micaschist, mylonite, augen mylonite, gneiss) occur in low amount. There are no granitoid and gneiss fragments in the fine grainsize, however, both mono- and polycrystalline quartz types dominate in this fraction.

There are few sedimentary fragments in the 3 members, which are finegrained sandstone, subarkose, wacke, quartz arenite, fresh or carbonatized/chloritized siltstone.

Rarely finegrained sandstone, wacke, siltstone and claystone also as pebbles are present in Bakonya Sandstone. In Kővágótöttös Member quartzite is more common among the pebbles, but siliceous shale, pyroclastite and metavolcanite are rarely present. The size and diversity of pebbles are less in the Cserkút Sandstone than in the other members. The most common pebble types are quartzite (mostly deformated and banded) and gneiss. There are felsitic rhyolite, pyroclastite, less metamorphite (mylonite, feldspar-quartz-sericite schist) and finegrained sandstone pebbles too. There are many siltstone and claystone intraclasts in this member.

The cement of Bakonya Sandstone is sericite, chlorite or dolomite (Table 1). Carbonate also presents as pseudomorph, mainly after feldspar. In Kővágótöttös Member the cement is mainly chlorite and dolomite, but sericite occurs too. The cement in Cserkút Sandstone is mainly hematite, less chlorite, sericite and carbonate also occur. Carbonate in some places occurs in very great amount, but it become minimal near the uppermost part of the member.

The Kővágótöttös Member is very strongly carbonatized in the Ibafa-4 borehole, in some cases great amount of the grains (mainly feldspar) are replaced by carbonate. This alteration does not attach to a section and its presence and ratio changes unregularly.

The predominant mineral of the sandstones of Jakabhegy Sandstone Formation is quartz (Qm > Qp, Qm >> Qp). K-feldspar is much less than quartz, and from the middle to the top of the formation their number become similar to volcanic fragments (from the footwall to the middle of the formation the volcanic fragments's number is less). Latters enrich in the finer grainsize fraction, and both mono- and polycrystalline quartz types rather in the coarser grainsize fraction are common.

The amount of orthoclase and sanidine is higher than that of microcline. Plagioclase is absent from the bottom to the middle of the formation, but close to the cover occurs rarely. The appearance of acidic volcanic fragments is usually similar to the volcanic fragments of Kővágószőlős Formation (disregarding small textural differences of several samples), however in this formation the amount of pyroclastic clasts, which are partly different from the earlier ones is notable (similarly in pebbles). Basic volcanic fragments are totally absent. The amount of granitoide and metamorphic fragments (gneiss, sericitized schist and rarely micaschist) is very low. Sedimentary fragments (metasandstone) occur rarely, however siltstone-claystone intraclasts are common. Compared to the underlying formation there are higher amount of clastic origin micas, represented by mainly muscovite fresh and bleached biotite and chlorite.

Table 1. Semi-quantitative results of the X-ray diffraction analysis

Formation	***Kővágószőlős Sandstone***				***Jakabhegy Sandstone***				***Patacs Siltstone***	
Sample/ Minerals	***Ib-4 M4***	***Ib-4 M5***	***Ib-4 M17***	***Ib-4 M20***	***Ib-4 M36a***	***Ib-4 M36b***	***Ib-4 M42***	***Ib-4 M48***	***Ib-4 M51***	***Ib-4 M52***
Quartz	+++	+++	+++	+++	+++	++++	++++	++	+++	++
Plagioclase (Na)	++	++	tr	tr	tr	tr	tr	tr	tr	tr
K-feldspar	++	++	++	++	++	++	+	++	++	++
Muscovite	++	+	++	++	++	+	+	+	+	++
Biotite	tr		++	++	++	+	+	++	++	+++
Dolomite	tr	+	++	tr	+	+	+	+	+	+
Clinochlore	tr	tr		tr		tr			tr	tr
illite/smectite	+		++	+	+	+		+	+	

++++ > 50%, +++ 31-50%, ++ 11-30%, + 5-10%, tr < 5%

(Components were identified by Search/Match based on ICDD PDF-2 (2005) database after smoothing and background removal. Semi-quantitative results were obtained by FPM (Full Pattern Matching, LeBaile-fitting) method in EVA module of Diffrac*Plus* (Bruker), without instrumental profile correction. Expected error of results is +/-5% on absolute scale.)

Accessories are mainly zircone and tourmaline, less garnet, apatite and rutile are also present. Pebbles are mainly acidic volcanites and quartzite, there are few metamorphites (gneiss, mylonite, micaschist, quartzose metasandstone) among them. Siltstone and claystone intraclasts are very common. Cement is mainly hematite, finegrained opaque minerals, silica and less sericite (Table 1).

Monocrystalline quartz is the most dominant component in Patacs Siltstone Formation. The amount of strongly sericitized K-feldspar is similar to the amount of polycrystalline quartz. Plagioclase is rare. There are few felsitic volcanic and micaschist fragments in the finegrained sandstone, but those are not present in siltstones. Muscovite, biotite and chlorite are the typical micas, zircone, tourmaline and garnet occur as accessories. We notice that the dominance of monocrystalline quartz, against the amount of the polycrystalline quartz and other lithic fragments is due to the fine grainsize of the formation.

The Patacs Formation does not contain any pebbles. Cement is mainly hematite, chlorite, and less sericite (Table 1).

5.2. Geochemistry

Bulk rock chemical analyses were made on 1-2 representative samples of each formations and members of Ib-4 borehole (Table 2). Beside of the evaluation of formations and members of the Ib-4 borehole we compared our results with the chemical composition of the same formations (Kővágószőlős and Jakabhegy Formations) from the W-Mecsek areas (unpublished data).

The multielement diagrams of the major elements (Fig. 3) of Cserkút Sandstone Member and Jakabhegy Sandstone Formation samples are quite similar to each other, the only difference is the less Na_2O content of Jakabhegy Sandstone. The major element distribution of Kővágótöttös Member slightly differs from others, as there is strong negative Na_2O anomaly, but there is positive anomaly of K_2O. The Bakonya Member differs remarkably from others, although its SiO_2, TiO_2, Al_2O_3 and Fe_2O_3 content is very similar to that of other members of Kővágószőlős Sandstone Formation and Jakabhegy Formation, however there is no negative Na_2O anomaly and the value of K_2O is nearly similar to that of Upper Continental Crust (UCC).

The difference between the two Bakonya Member samples in the case of MnO, CaO and P_2O_5 is notable, but in the case of Na_2O and K_2O it is minor. The major element distribution of Patacs Siltstone Formation is similar to that of other samples, however the anomalies of Na_2O and K_2O are not present. Its high negative MnO anomaly is similar to Cserkút Sandstone and Jakabhegy Formation.

There is positive K_2O anomaly in the Kővágótöttös Member, Cserkút Member and Jakabhegy Formation both in Ibafa-4 borehole and in W-Mecsek Mts. (unpublished data). The K_2O content of Bakonya Member in W-Mecsek Mts. like in Ibafa-4 borehole is almost the same as that of UCC.

The depletion of highly compatible trace elements compared to UCC is typical for every members and formations in borehole Ib-4 (Fig. 4). The amount of immobile trace elements are similar to that in UCC, or rather show slight negative anomaly, except the sample of Kővágótöttös Member and Patacs Formation, their Zr, Hf, Nb and Y content is slightly higher. The Sr shows approximately same negative anomaly in the three formations. The values of other mobile trace elements slightly or strongly variable.

Table 2. Chemical composition of the examined formations in Ibafa-4 borehole (The analysis was made in ACME Analytical Laboratiories Ltd., Vancouver, by ICP-MS and ICP-AES method).

Formation		***Kővágószőlős Sandstone***				***Jakabhegy Sandstone***				***Patacs Siltstone***	
Sample		***Ib-4 M4***	***Ib-4 M 5***	***Ib-4 M 17***	***Ib-4 M20***	***Ib-4 M36a***	***Ib-4 M36b***	***Ib-4 M42***	***Ib-4 M48***	***Ib-4 M51***	***Ib-4 M52***
SiO_2	%	70,36	67,56	64,00	71,85	72,40	79,94	83,04	74,19	69,48	57,08
TiO_2	%	0,29	0,36	0,52	0,35	0,30	0,29	0,33	0,29	0,81	0,89
Al_2O_3	%	12,08	12,05	12,74	13,47	14,18	10,77	8,16	12,05	13,71	18,04
Fe_2O_3	%	2,62	1,91	2,82	2,51	3,23	1,51	2,85	3,39	4,23	8,66
MnO	%	0,05	0,12	0,09	0,01	0,01	0,01	0,01	0,02	0,01	0,03
MgO	%	1,90	2,24	2,96	1,32	0,63	0,43	0,31	0,75	1,05	2,06
CaO	%	1,74	3,34	3,32	0,52	0,24	0,21	0,20	0,30	0,45	0,39
Na_2O	%	2,39	3,29	0,22	0,23	0,12	0,11	0,06	0,41	0,65	0,24
K_2O	%	3,45	2,96	5,14	5,51	5,67	4,75	3,34	5,87	5,72	6,73
P_2O_5	%	0,06	0,10	0,11	0,08	0,13	0,15	0,14	0,12	0,30	0,16
LOI	%	4,90	5,50	7,90	4,00	3,00	1,80	1,50	2,40	3,40	5,50
Rb	ppm	113	85	156	165	180	146	91	175	166	244
Sr	ppm	167	174	96	104	176	137	176	166	185	163
Ba	ppm	1120	455	483	594	493	446	310	1073	640	549
Pb	ppm	24	4,6	10	5,1	16	3	20	4,9	17	12
Th	ppm	6,8	5,7	10	6,9	9,5	13	10	10	31	15
U	ppm	2,1	18	5,3	6,6	2,4	2,5	4,3	1,8	5,5	4,1
Zr	ppm	117	168	271	172	128	183	161	125	542	194
Hf	ppm	3,3	4,8	7,3	4,8	3,6	5,4	4,8	3,8	16	6,1
Nb	ppm	8,1	7,2	10	7,8	8,2	7,9	6,9	7,2	16	18
Ta	ppm	0,7	0,4	0,7	0,6	0,6	0,6	0,5	0,6	1,2	1,3
Y	ppm	15	20	23	16	16	19	15	18	43	31
La	ppm	19	19	23	14	24	26	20	22	65	35
Ce	ppm	35	40	51	29	47	54	43	43	135	73
Pr	ppm	4,3	4,9	6,4	3,6	5,8	6,6	5,1	5,5	17	9,0
Nd	ppm	16	19	25	13	21	25	20	22	65	35
Sm	ppm	3,1	3,9	4,8	2,9	4,2	4,7	3,6	4,2	12	6,5
Eu	ppm	0,5	0,8	0,9	0,6	0,8	0,7	0,6	0,8	1,5	1,4
Gd	ppm	2,7	3,2	3,9	2,5	3,3	3,7	3,1	3,4	9,5	5,7
Tb	ppm	0,5	0,6	0,7	0,4	0,5	0,6	0,5	0,6	1,4	0,9
Dy	ppm	2,4	3,2	3,6	2,6	2,8	3,3	2,6	3,1	7,7	5,3
Ho	ppm	0,5	0,7	0,7	0,6	0,6	0,6	0,5	0,6	1,5	1,0
Er	ppm	1,6	1,8	2,4	1,6	1,7	1,9	1,4	1,8	4,2	3,0
Tm	ppm	0,3	0,3	0,4	0,3	0,3	0,3	0,2	0,3	0,7	0,5
Yb	ppm	1,5	1,8	2,4	1,6	1,6	1,8	1,4	1,6	4,0	2,9
Lu	ppm	0,2	0,3	0,4	0,3	0,3	0,3	0,2	0,3	0,6	0,4
Sc	ppm	3,0	4,0	4,0	4,0	7,0	5,0	3,0	4,0	8,0	14
V	ppm	36	55	42	50	31	23	35	26	55	103
Cr	ppm	20	27	20	20	20	20	27	41	48	75
Co	ppm	4,6	3,3	4,0	3,0	2,3	1,3	1,8	3,8	13	10
Ni	ppm	20	8,1	10	6,8	8,7	3,9	15	13	33	26
Zn	ppm	52	16	25	19	20	6,0	21	13	58	51
Cu	ppm	5,2	3751	26	26	4,0	8,1	5,8	10	35	3,6
Ag	ppm	<0,1	8,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	0,2	<0,1
Au	ppb	0,8	1,7	0,7	1,0	<0,5	<0,5	1,5	0,8	1,2	1,3

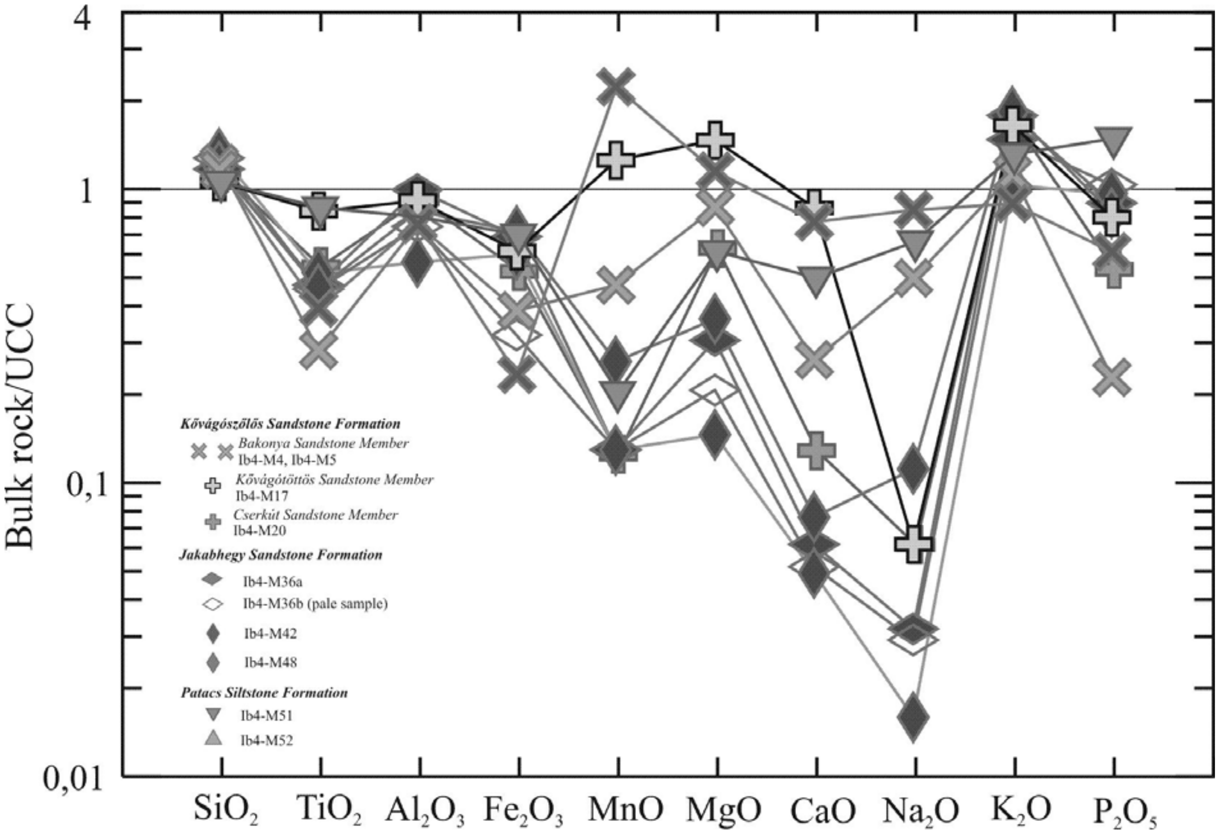

Figure 3. The multielement diagram of the major elements of the samples in Ibafa-4 borehole, normalised to the Upper continental crust (McLennan 2001)

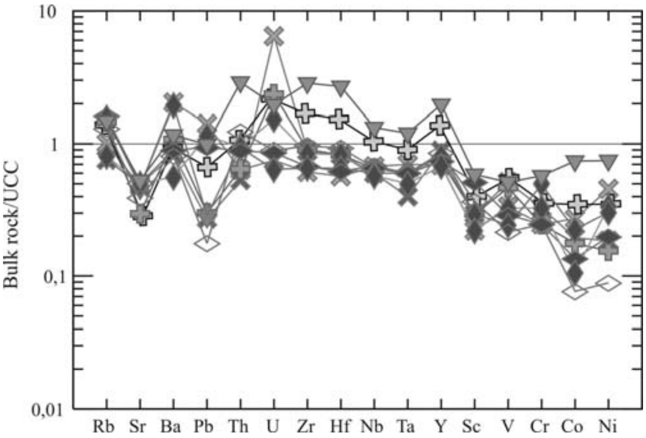

Figure 4. The multielement diagram of the trace elements of the samples in Ibafa-4 borehole, normalised to the Upper continental crust (McLennan 2001) For key see Figure 3.

Rare Earth Elements (REEs) distributions (Fig. 5) of Bakonya Sandstone, Cserkút Sandstone and Jakabhegy Sandstone are very similar to each other: compared with the UCC they are depleted in light and heavy REEs too. The REE distribution of Kővágótöttös Member is near to that in UCC, and the content of the REEs of Patacs Siltstone Formation shows the highest values compared with the values of UCC.

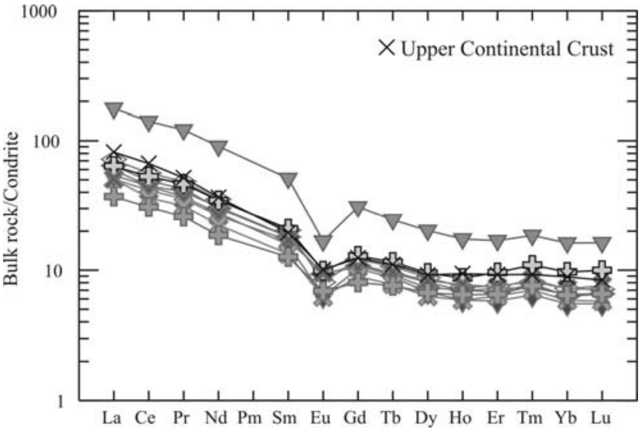

Figure 5. Rare Earth Element distribution of the samples in Ibafa-4 borehole, normalised to the chondrite (Taylor & McLennan 1985) For key see Figure 3.

5.3. The subsequent alteration of Jakabhegy Sandstone

In the Ibafa-4 borehole some parts of the Jakabhegy Sansdtone changed in their appearance compared with the fresh material: the dark red-purplish red colour of the formation changes into white-light yellow along sharp borders. This fading occurs in the coarser grain size parts of the sandstone. According to our visual inspection and optical microscopy investigation the hematite and fine grained opaque minerals are absent in the pale parts, but there is no difference between the detrital composition.

Scanning electron microscopic and electron microprobe examinations has established that the cement of the red sandstone is muscovite and/or illite which is absent in the pale parts, where the grains are slightly more compacted. In the faded parts small amount of pyrite occurs indicating reductive environment. There is positive K_2O anomaly in the Kővágótöttös Member, Cserkút Member and Jakabhegy Formation both in Ibafa-4 borehole and in W-Mecsek Mts. (unpublished data).

The difference in the mineralogy of two parts are supported by the chemical analyses (red sample: Ib-4 M36a, and the pale sample: Ib-4 M36b – chosen from next to the Ib-4 M36a sample); i.e. the pale part is significantly depleted in Al_2O_3, Fe_2O_3, K_2O, Rb, Sr, Cs, V, Ni, Zn and Pb compared to red part (Table 2) due to its lower muscovite and/or illite and hematite contents. On the other hand in the pale part the Zr, Hf, Th, Y and REE content is higher than in the unaltered, red part, due to the relative enrichment of stable heavy minerals (e.g. zircon).

According to the above mentioned observations it is assumed that the characteristic fading of the Jakabhegy Sandstone in the Ibafa-4 borehole is an altering effect of a post-depositional, reduction solution. During this process the muscovite and/or illite, which formated during weathering and diagenesis, disappeared and hematite was replaced by the pyrite. The solution could migrate easier through the sandstone which have medium-coarse grain size (larger initial pore-space). During the diagenesis the sandstone could easier compacted because of the leached cement.

This fading do not bound to the former mentioned high Na depletion and K enrichment of the Jakabhegy Formation, because in Kővágótöttös and Cserkút Sandstone Members there was no fading observed.

5.4. Copper anomaly in Bakonya Sandstone

The bulk rock chemical analyses show a ca. 55 times Cu enrichment (3750 ppm) in a sample of the Bakonya Sandstone Member of the Kővágószőlős Sandstone (Ib-4 M5) compared to the Upper Continental Crust. Moreover Ag enrichment is also present (8,1 ppm) (Table 2). Accordig to our microscopic observations and the SEM and EDAX examinations the copper minerals are present mainly between the clasts in form of cement, and mainly consist of bornite and (replacatitive) chalcocite. Beside bornite and chalcocite As-bearing spheroidal pyrite and a small amount of calcopyrite occurs also in the cement. Beside sulphides Fe- and Mn-bearing dolomite cement also appears. A smaller proportion of bornite is present in the detrital grains, for example in volcanic fragments.

In the Western Mecsek Mts. the Cu mineralization in Bakonya Member which has been known ealier, is similar to the Cu enrichment of the Ibafa-4 borehole, which occurs in the transition zone between the lower oxidated and the upper reducated parts, where the copper content is about 2000 ppm (Vincze, 1985). Typical accompanying element of copper in this redox zone is uranium („Cu-U mineralization”) (Vincze, 1985), sample from Ib-4 borehole also shows slight positive U-anomaly (18 ppm; Table 2). In this zone the copper minerals (calcopyrite, chalcocite, covelline, bornite) are generally present in the cement, but the encrustation and the partly replacement of sand grains by copper minerals are common. The ore minerals commonly replace each other and their intergrowths along the distinct planes is also frequent. Some parts of the calcopyrite – principally at the margins or the whole grain – can be replaced by chalcocite or covelline, this phenomena is peculiar for chalcocite and bornite too. The bornite is more resistant than calcopyrite. The replacement of calcopyrite by bornite also occurs. In the pyrite-calcopyrite association the calcopyrite replaces the older, minor pyrite (framboidal). According to Vincze (1985) the Cu-U accumulation (similarly the U mineralization at the boundary of Kővágótöttös/Cserkút Member) is syngenetic, and the mineralization is dia- and epigenetic, the latter took place at tele-epithermal temperatures.

6. DISCUSSION AND CONCLUSIONS

The mineralogical and petrological composition of the studied siliciclastic succession of Ibafa-4 borehole shows that a mature, continental area had eroded, and this supposition agrees with the earlier opinion about the same formations of Western Mecsek area (Barabás & Barabásné, 1998). In all the three studied formations quartz, K-feldspar and volcanic originated rock fragments are the most typical components, the amount of plagioclase, micas, accessories, plutonic, metamorphic and sedimentary rock fragments present in less amount and high variability. Among the studied formations the Bakonya Sandstone Member of Kővágószőlős Sandstone Formation shows the most complicated feature. Siliceous shale, knotted schist and carbonitized siltstone are typical in the Bakonya

Member, next to the mineral-lithic fragments which are present in the other members and formations. The amount of feldspars (K-feldspar >> plagioclase) in Kővágótöttös Sandstone Member is less, particularly the amount of plagioclase descreases from Bakonya Member to upper parts of the succession. The amount of plutonic rock fragments also decreases, compared with the underlying member. Siliceous shale, knotted schist and carbonized siltstone are also occur in this member, however in less amount. In Cserkút Sandstone Member next to the quartz grains there is higher amount of volcanic originated fragments than in the previous members, together with the notable decrease of feldspars (K-feldspar >> plagioclase) and granitoid fragments. That suggests that the volcanites had predominated over the granitoids during the time in the provenance.

The fragments and pebbles of Jakabhegy Sandstone Formation are less variegated than in the underlying formation. In the lower member, named "main conglomerate" and in the whole formation mainly acidic (rhyolitic) volcanic and quartzite pebbles are typical. Mainly in the upper part of the formation the siltstone intraclasts are relative common. Quartz variants, the volcanic originated fragments (in lower amount) and K-feldspars are dominating in sand and finer grained fraction. Plagioclase appears just from the middle of the formation, in very low quantity. Towards the middle of the formation the maturity increases gradually, and upwards from the middle it slightly decreases. Compared with the Kővágószőlős Formation, in Jakabhegy Formation more and variegated pyroclasts and metavolcanics occur, but the character of rhyolitic fragments and pebbles is very similar to that in the underlying formation. The amount of granitoid and not really variegated metamorphic fragments is low. Either the acid volcanites became dominant against older metamorphites and granitoids in the source area, or the dominance of acid volcanites was caused by redeposition, or both.

The results of geochemical examinations which determine the provenance also show dominancy of acidic rocks in the source territory, so that was a mature, continental area. On the ground of our petrological observations the provenance of Bakonya Member and Kővágótöttös Member was really similar: next to the granitoids and metamorphites, acidic volcanites were also presented. However in the provenance of Bakonya Sandstone the granitoids and metamorphites were dominating. The characteristic siliceous shale and knotted schist fragments of the Bakonya Member and Kővágótöttös Member may had derived from an outcropped (lower-Paleozoic?) series or from the redeposition of earlier (Carboniferous?) sediments. According to Fülöp (1994) the erosion of Bakonya Sandstone is from the "schist mantle", and later with the fast erosion of the area the granites had exhumated and thus became the source of the clastic material. According to Fazekas (1987) the source of carbonized siltstone pebbles is the "Silurian of Szalatnak" or the "carbonaceous Carboniferous of Villány". The source may have been that schist and conglomerate (Silurian or Carboniferous) which were penetrated under Miocene series by the borehole Horváthertelend-1, approximately 4 kilometres NW from borehole Ibafa-4. The provenance of Cserkút Sandstone Member was less variegated than the footwall formations: the much of the older granitoids and metamorphites had already eroded, and the younger acidic clasts had taken their place. The reason of this feature is not known yet.

The question is why there are any differences between the clasts of the heteropic Kővágótöttös Member and Cserkút Member (the previous represents the marsch, and the latter represents the river facies (Barabás & Barabásné, 1998)), if the two formations deposited at the same time, at close quarters. Possibly in the reductive, acidic marsch of Kővágótöttös Sandstone the clasts (which had had similar composition and amount like Cserkút Sandstone) suffered stronger or total alteration, causing the difference. Another reason may be the subsequent carbonatization which altered the clasts. The different hydraulical relations between marsch and river environments may effect diverse grain size and grain composition-distribution. Another opportunity may be that the observed minor differences of the clasts are the peculiarity of the Ibafa-4 borehole, because comparing our samples with the samples of the typical same Cserkút Member from W-Mecsek Mts., slight higher amount of the volcanic fragments can be observed.

However to answer the question additional, detailed petrological and mainly sedimentological examinations are needed.

The clasts of Jakabhegy Sandstone Formation approximately similar to clasts of Cserkút Sandstone Member, consequently the buildup of their provenance was similar, but there are much less lithic fragments, and the sediment is maturer in Jakabhegy Formation. On the ground of these we can reinforce for borehole Ibafa-4 the earlier suppose (Bérczine et al., 2004) for the whole W-Mecsek area that the Jakabhegy Sandstone contains redeposited material.

The provenance of Patacs Siltstone Formation is very similar to provenance of Jakabhegy

Formation. Small differences in the amount ratio of the clasts are probably caused by the difference between the grainsizes of the two formations. We suppose that the provenance of Cserkút Member, Jakabhegy Formation and Patacs Siltstone was similar. Fazekas (1987) considers the Kővágószőlős Sandstone Formation, Jakakbhegy Sandstone Formation and Patacs Siltstone Formation as one unit, in which the process of changing developes gradually, without sharp borders, so the provenance did not change with the deposition of "main conglomerate", and the only difference between Kővágószőlős Formation and Jakabhegy Formation is shown by the maturity.

The petrographic difference between the Ibafa-4 samples and the samples of the W-Mecsek Mts. is represented by a bit higher amount of volcanic fragments in Cserkút Sandstone Member in the Ibafa-4 samples. The geochemical examinations indicate acidic source for W-Mecsek samples as well.

The results of geochemical examinations well reflect the minerological-petrological qualities (dominant acidic magmatic and metamorphic clast composition, presence of heavy minerals), the effect of grain size and the post-sedimentary effects. The results indicate that there was a significant posterior Na depletion and a slight K enrichment in Kővágótöttös and Cserkút Member of Kővágószőlős Formation, and in Jakabhegy Formation in borehole Ibafa-4, on contrary Na depletion is missing in the Kővágótöttös Sandstone and Cserkút Sandstone in the W-Mecsek area. Additional evidence of this depletion is the strong alteration and disintegration of the drillcores, which is macroscopically also well visible.

The enrichment in TiO_2 values of Kővágótöttös Member may derive from the difference in grain size (phyllosilicate and heavy mineral enrichment in fine grained fraction), and the higher value of MgO, CaO and MnO is due to the higher secondary carbonate content. The diversity of TiO_2 and P_2O_5 values of Patacs Siltstone may also be explained by the effect of fine grain size. The higher Zr, Hf, Nb and Y content of Kővágótöttös Member and Patacs Formation presumably derive from the heavy mineral enrichment. The higher REE (compared to UCC) values of Kővágótöttös Member and Patacs Formation are also due to the effect of fine grain size, as in finer grained siliciclastic sediments the heavy minerals enrich better, hence the REE values become higher.

For further interpretation of our results a detailed, modern sedimentological review is needed on the studied formations of Ibafa-4 borehole and also on the Permian – Triassic siliciclastic succession of Western Mecsek Mts.

Our results show that the studied formations in borehole Ibafa-4 drilled in Gorica district in many respect (composition, distribution, source area, etc. of the clasts) is similar to the same series of W-Mecsek, but at the same time several differences (condensated sedimentation, strong Na depletion) can be established. Partial fading is present in the Jakabhegy Sandstone of the Ibafa-4 borehole caused by a reduction solution as an evidence of an additional diagenetic effect.

The former known Cu-U anomaly in Bakonya Member of Kővágőszőlős Sandstone Formation is found also in the Ibafa-4 borehole. According to Vincze (1985) the Cu-U accumulation is syngenetic, and the ore mineralization is dia- and epigenetic, but detailed study is necessary in the future to solve the Cu enrichment problem in the territory.

7. ACKNOWLEDGEMENTS

We are thankful for the Mecsek Ore Enviroment Company (Pécs, Hungary) and the Radioactive Waste Management Office Public Limited Company (Budaörs, Hungary) to permit our work and to give us free run of the materials. We would like to thank the evaluation of the X-ray diffraction measurements to Béla Raucsik (University of Pécs, Hungary) and Ferenc Kristály (University of Miskolc, Hungary). The present work was supported by the Pro Renovanda Cultura Hungariae Foundation and by the TÁMOP-4.2.1.B-10/2/KONV-2010/0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

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Received at: 19. 06. 2012
Revised at: 14. 09.2012
Accepted for publication at: 28. 09.2012