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Abstract

The petrological and geochemical composition of Neogene lacustrine successions and basement rocks of the Belanovica basin in Central Serbia, were investigated in three exploration boreholes, drilled in the central part of the former lake. Two boreholes accessed the basement, while the third one terminated in the lowermost Neogene interval, composed of coarse-grained clastics. Formation and diversification of the lake basin was influenced by strong syndepositional volcanic activity. The vertical distribution of selected elements from basal clastics (Cr, Ni, and Mg) and from overlying lake sediments (Ba, Sr, Na, K, etc.) indicates both the southern and northern margins of the basin, as potential source areas. The elemental concentrations are consistent with petrography. Based on the derived data, a reconstruction of the basin history is presented. The lack of index fossils resulted in a less accurate stratigraphy and the need for further updating by employment of the fission-track low-temperature thermochronometers. Additionally, outcrop studies and correlation with lake sediments in the Valjevo-Mionica basin is suggested.

1. INTRODUCTION

The increasing interest in lacustrine sediments since the early 1970s arose from new proof of their scientific and economic importance. Lacustrine successions may preserve details of sedimentary processes from the earliest stage of lake genesis to its very end (BINFORD & DEEVEY, 1983; TALBOT & KELTS, 1989; ENGSTROM et al., 2000; COHEN, 2003; OBRADOVIĆ & VASIĆ, 2007). Palaeolimnological data such as shoreline features, isotopic composition of authigenic carbonates, groundwater influences and changes in sediment grain size, structure and mineralogy, are useful in the reconstruction of lake-level changes in response to regional climate change (DIGERFELDT et al., 1993; FRITZ, 1996, 2008; HICKMAN & WHITE, 1989; ALMENDIGER, 1993). The economic importance of former lakes relies on the significant accumulations of solid and liquid hydrocarbons as well as of other valuable resources, such as diatomite and diatomaceous earth, sedimentary zeolite, clay (particularly bentonite), magnesite, dolomite, borates, including the recently discovered jadarite (STANLEY et al., 2007; WHITFIELD et al., 2007).

Serbian lakes formed during the late Oligocene and Miocene in dominantly NNW–SSE trending depressions along the old reactivated faults (OBRADOVIĆ & VASIĆ, 2007). Sedimentation occurred in several tectonic, i.e. lake phases, which were related to different tectonic events, such as contraction, extension etc. (OBRADOVIĆ & VASIĆ, 2007).

The majority of Serbian lakes underwent two (e.g. Valjevo-Mionica, Slanci, Jadar, Čačak-Kraljevo, Pranjane, Mlava basin) or three (Niš, Aleksinac, Kremna, etc), but rarely only one sedimentation cycle (Kosjerić and Leskovac basins) (OBRADOVIĆ & VASIĆ, 2007; Fig. 1). The alternation of lake sediments with those formed in marsh or alluvial systems, sometimes with coal and/or oil shales resulted in highly diverse facies. The alternation of lake and marine sedimentation has been identified in the Valjevo-Mionica coastal area, at the ancient watering place of Vračević (OBRADOVIĆ & DIMITRIJEVIĆ, 1978; OBRADOVIĆ et al., 1997; OBRADOVIĆ & VASIĆ, 2007; KRSTIĆ et al., 2012; NEUBAUER et al., 2016).

The manner of presentation of the Serbian lakes is also highly diverse. Lake basins were presented either according to their age and depressions where they have been developed (ANĐELKOVIĆ et al., 1991; OBRADOVIĆ & VASIĆ, 2007) or were classified geographically, such as basins in northern, central and eastern Serbia (KRSTIĆ et al., 2003; DOLIĆ, 1986). According to KRSTIĆ et al. (2003) the lake basins are remnants of a single lake (Lake Serbia), whereas other authors recognized many Miocene lakes in mostly endemic and/or geographically isolated environments (e.g. MAROVIĆ et al., 2007; HARZHAUSER & MANDIĆ, 2008). Furthermore, the geochemistry including isotope studies of the Serbian lakes is little known. The present study fills that gap by providing geochemical data that support results obtained by classic petrographic techniques. The objective in this study was to determine the range of concentrations of selected elements, which are indicative for the source of material: ultramafic rocks, or acid igneous, and metamorphic rocks.

2. REGIONAL GEOLOGICAL SETTING

The Belanovica basin is part of the E-W trending Valjevo-Mionica-Belanovica graben (MAROVIĆ et al., 2007). This two-part graben structure (Belanovica in the east and Valjevo-Mionica segment in the west) was one of the major depressions within the Peri-Pannonian Realm. Subsequent movements along the diagonal faults led to the separation of individual basins (ANĐELKOVIĆ et al., 1991). The more intensive subsidence along the southern-border fault and asymmetrical inversion revealed a markedly asymmetrical Belanovica basin (MAROVIĆ et al., 2007). The northern margin of the Belanovica basin is formed by the Brajkovac and Bukulja Mountains, composed of ~30–20 Ma old granitoid rocks (KNEŽEVIĆ et al., 1994; CVETKOVIĆ et al., 2007) and Devonian to Carboniferous low-grade metamorphic rocks

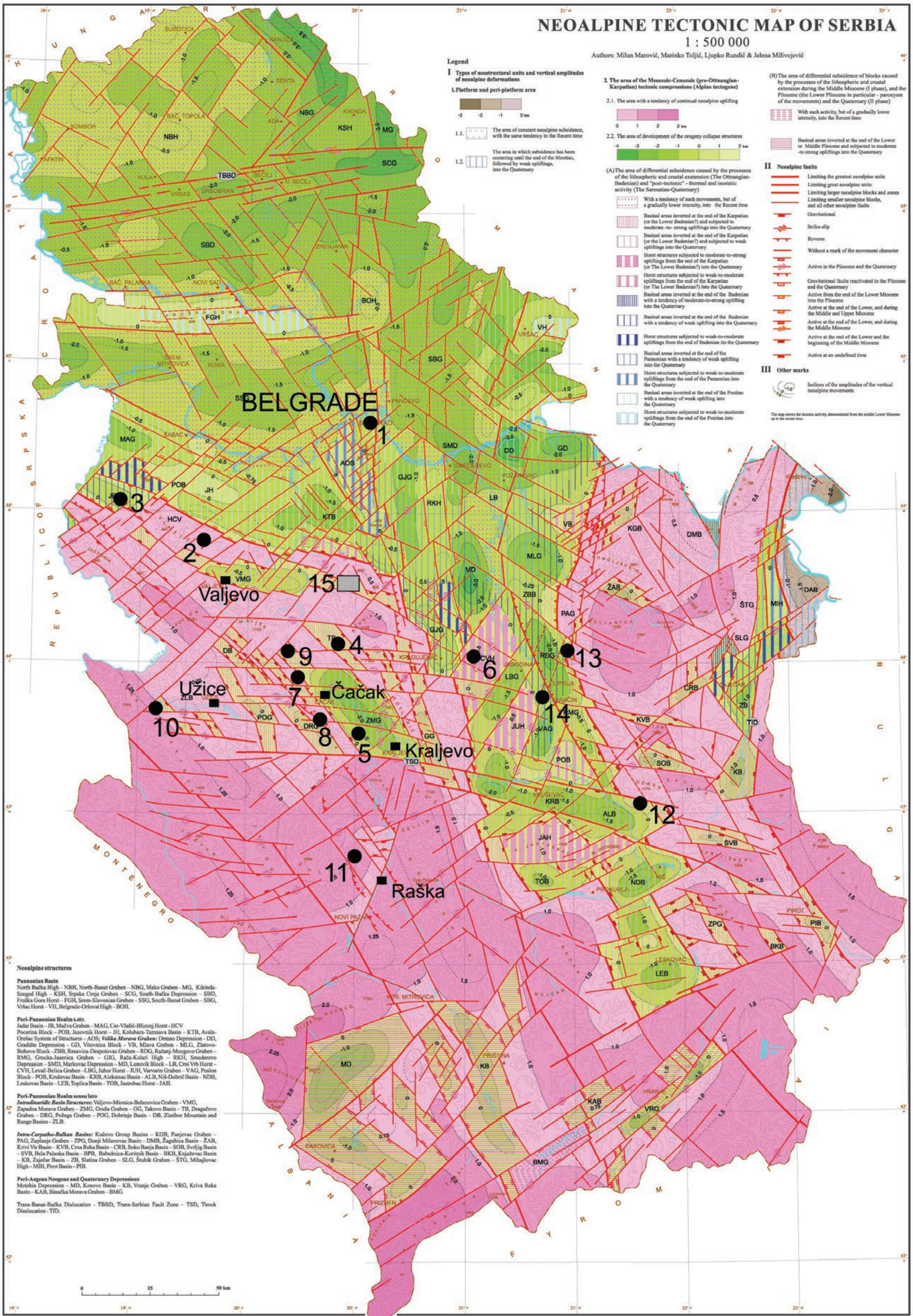

Figure 1. Neoalpine tectonic map of Serbia 1:500.000 (MAROVIĆ et al., 2007) with locations of the lacustrine basins (OBRADOVIĆ & VASIĆ, 2007).

Legend: 1. Slanci (Slanci-Grocka) basin; 2. Valjevo-Mionica basin; 3. Jadar basin; 4. Takovo-Gomji Milanovac basin; 5. Čačak-Kraljevo basin; 6. Dobrinje-Ježevac basin; 7. Kosjerić basin; 8. Dragačevo basin; 9. Pranjani basin; 10. Kremna basin; 11. Kopaonik basin and Jarandol basin; 12. Aleksinac basin; 13. Senje-Resava basin, 14. Velika Morava trough (Niš, Zaplanje, Jelašnica, Leskovac, Barbeš, Ražanj, Popovac, Braničevo and Mlava basin) and 15. The position of Figure 2 is represented by the rectangle.

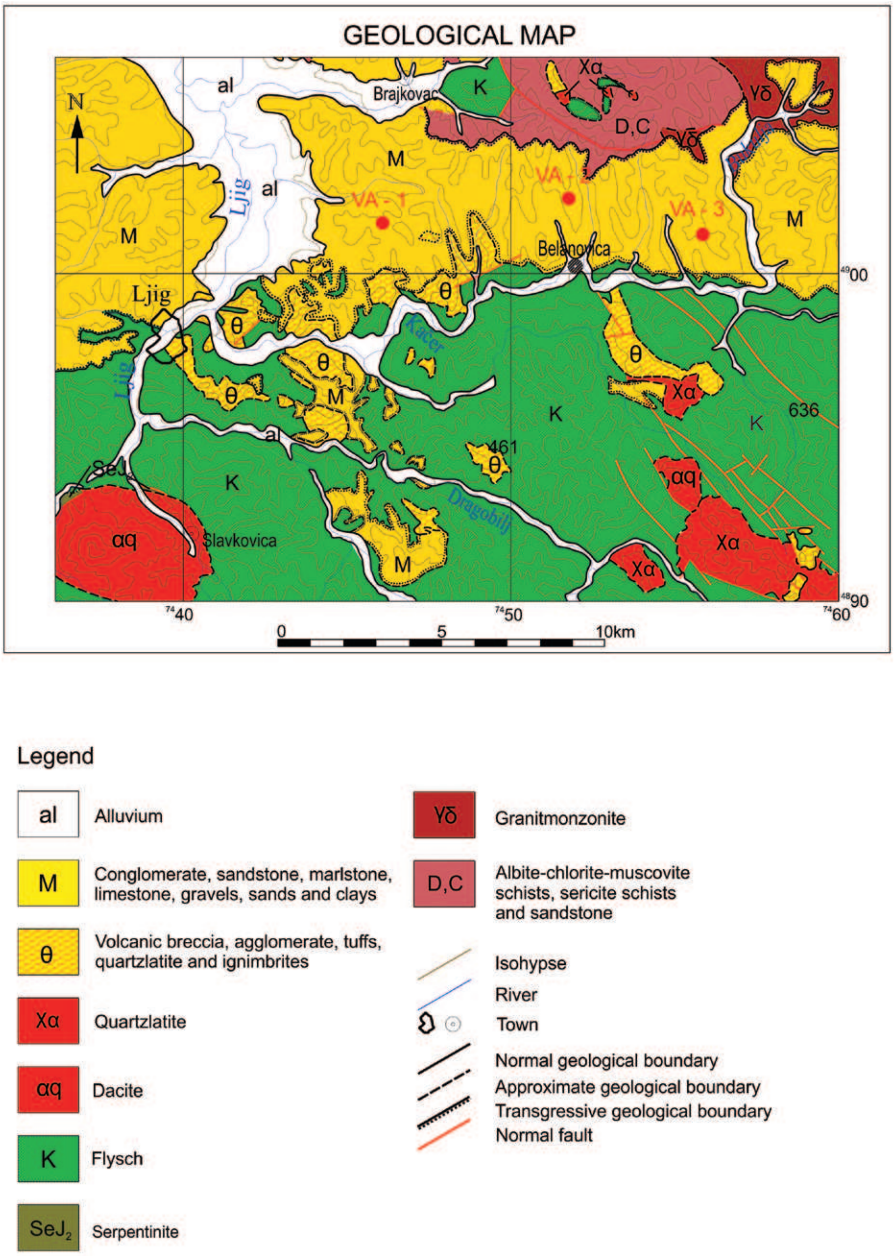

Figure 2. Geological map of the broader area of the Belanovica basin with borehole locations – detail from the Basic Geological Map 1:100.000, sheet Gornji Milanovac (FILIPOVIĆ et al., 1971). Redrawn by M. RADISAVLJEVIĆ, using AutoCad 2014 software.

(TRIVIĆ et al., 2010; MAROVIĆ et al., 2007). Its southern margin comprises Jurassic ophiolites dominated by serpentinite, Cretaceous flysch sediments and Miocene volcanic and volcaniclastic rocks (Fig. 2).

According to MAROVIĆ et al. (1999) the studied basin is included in the Serbian depositional province, which has been formed as a consequence of the Early Miocene extension and subsidence of the Pannonian basin due to Early-Middle Miocene collapse and core exhumation in the Sava zone and Tiszia (e.g. HORVATH et al., 2015). Extension of the Pannonian basin additionally increased the heat transfer that is presently still observed (MATENCO & RADIVOJEVIC, 2012).

3. MATERIALS AND METHODS

All sedimentary rock samples were optically analyzed using a petrographic polarized microscope for transmitted light (Leica DMLSP), connected to a Leica DFC290 HD camera over the application LAS V4.1. Major and trace chemical elements (including REEs) contents were determined in 158 samples (76 from the borehole VA-1, 54 from VA-2 and 28 from VA-3) in the SGS laboratory in Lakefield (Canada) using ICP-AES analysis (ICP 12B package), with samples repeated to ensure analytical consistency. Samples were cleaned of weathered surfaces and crushed to <2 cm before being ground to a <200 μm in an agate mill RETSCH PM 200. Accuracy and precision were estimated on the basis of standard rock materials and replicate analyses. Contents for 12 elements used in discussion in all 158 samples and detection limits are given in Supplementary Table. Procedures for manipulating data and drawing graphs were performed using Sigma Plot version 11.0 from SYSTAT Software Inc. San Jose, CA, USA; available at: www.systatsoftware.com.

Granulometry was determined in epiclastic and sandy-gravelly loose sediments. The amount of sample for analyses depends on the grain size, thus about 100 g was taken from the former and

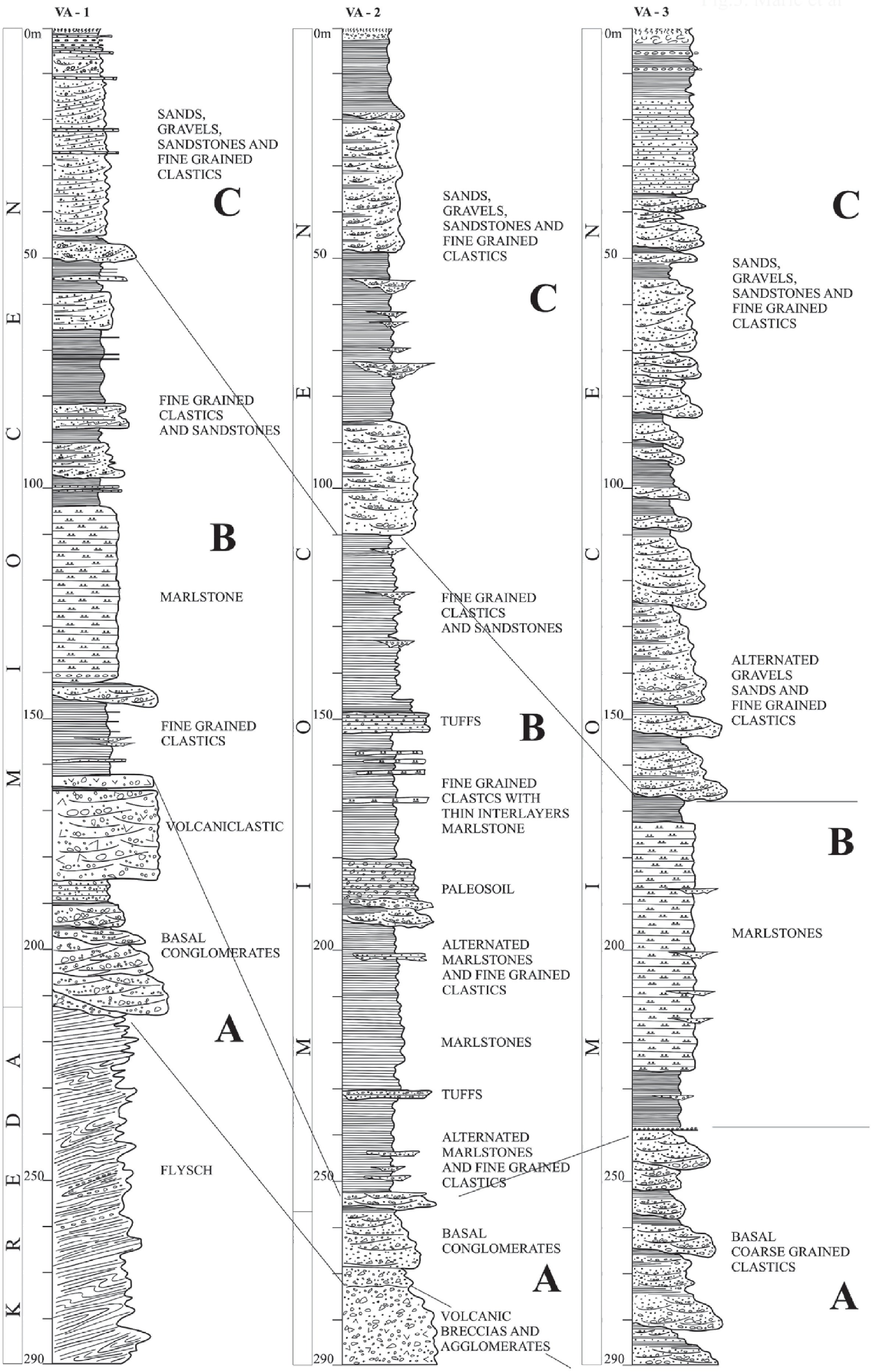

Figure 3. Lithostratigraphic columns of boreholes. Lithofacies are marked as in the text. Solid lines connect the same levels.

Table 1. Modal analyses of redeposited volcaniclastic (epiclastic) rocks and sands from borehole VA-1. Average values and standard deviation were calculated for each constituent in both rock types. The depth of samples in metres is given in brackets.

minerals in %	epiclastite					sands							
	71 (188.5)	67 (184.5)	61 (171.3)	60 (167.0)	avg. ± S.D.	5 (13.7)	11 (33.6)	17 (50.6)	23 (63.6)	26 (68.8)	32 (86.2)	35 (96.5)	avg. ± S.D.
quartz	86	40	45	48	55 ±18	63	66	64	66	59	40	57	59 ± 9
feldspar	6	30	9	7	13 ± 10	14	14	13	12	14	11	13	13 ± 1
rock fragm.	8	30	45	44	32 ±15	18	18	21	19	17	16	21	19 ± 2
calcite	tr.	tr.	tr.	tr.	–	4	1	2	2	2	2	3	2 ± 1
muscovite	–	–	–	–	–	1	1	–	1	5	15	4	4 ± 5
biotite	–	–	1	1	0.5 ± 0.5	–	–	tr.	tr.	tr.	tr.	tr.	–
chlorite	tr.	–	–	–	–	–	–	–	–	2	16	2	2 ± 6
faunal fragm.	tr.	tr.	–	tr.	–	tr.	–	–	tr.	1	tr.	tr.	–
heavy min.	–	tr.	tr.	–	–	tr.	tr.	tr.	tr.	tr.	tr.	tr.	–

avg. – average; S.D. –Standard deviations; tr. -trace; - not detected.

up to 50 g from the finer-grained sediments. The qualitative-quantitative mineralogical composition was determined for four samples of epiclastites using the > 0.063 mm fractions, and in seven sand samples using fractions 0.125–0.25 and 0.25–0.50 mm. The highest dispersion of data is noted for quartz and rock fragment abundance in epiclastites. Average values and standard deviation are presented for each constituent in Table 1. Fractions were prepared by wet-sieving techniques and analyzed afterwards under the binocular microscope (Leica EZ4D) and a polarised light microscope (Leica DMLSP). The latter analysis required thin-sections prepared with xilol as the immersion liquid.

Micropalaeontological analyses included 36 samples washed and sieved under warm water (meshes 0.6–0.125 mm); discrete details of fossil molds required additional cleaning using 6% hydrogen peroxide. Samples were analyzed by binocular microscope Leica (up to 35 x magnification) and by reflected light microscope Olympus BH2 (magnification up to 100 x). Analyses were performed by RUNDIĆ at the Department for Palaeontology of the Faculty of Mining and Geology, University of Belgrade.

The content of $CaCO_3$, as a proxy for carbonate content and precise determination of fine-grained clastites, was determined in 69 samples using a method of calcimetry and Scheibler's calcimeter. Depending on the intensity of the sample reaction with diluted HCl, 0.5 g or 1 g of sample was ground in an agate vial. All analyses were performed at the Department for Mineralogy, Crystallography, Petrology and Geochemistry of the Faculty of Mining and Geology, University of Belgrade.

4. RESULTS

Detailed mapping of cores from three exploration boreholes (VA-1, VA-2 and VA-3) enabled determination of the basin infill and basement rocks (Fig. 3). Neogene sediments in the borehole VA-1 overlie Cretaceous flysch (212–335 m) and volcanic and volcaniclastic rocks in VA-2 (268–296 m). The borehole VA-3 did not access the basement.

Basement

Weakly lithified, moderate to well-sorted sandstones prevail in flysch clastites in VA-1. Sandstones are stratified in thin to moderately thick beds and consist of rock fragments that were derived from metamorphic rocks (including serpentinites) and limestones. Flysch sediments in VA-1 containing serpentinite/ultramafite fragments have a high heavy metal content, particularly Ni (from 413 to 1429 ppm) and Cr (from 106 to 992 ppm; Supplementary Table).

Volcanic and volcaniclastic rocks (ignimbrites) in borehole VA-2 are products of volcanic activity dated to about 23 Ma or younger (CVETKOVIĆ et al., 2000). Among them, the quartz latites of hypocrystalline porphyritic texture, followed by fragments of lamprophyres, were the most abundant products originating from Rudnik mountain (Fig. 4a). Heavy metal contents in the underlying rocks in VA-2 range from 9.4–10.6 ppm (Cr) and 4.4–5.2 ppm (Ni).

Unit A

The oldest Neogene unit is the "Basal coarse-grained clastites" (BCC; A in Fig. 3). They consist of material derived from the volcanic complex and flysch, from Triassic limestones or re-deposited volcaniclastic material (interval 212–162.5 m in VA-1; 268 to 258 m in VA-2 and 240–300 m in VA-3). Volcaniclastic material mostly consists of quartz (38.3–86.1%) and rock fragments (7.7–45.0 %). Feldspar is subordinate (2.7–4.8%; Table 1). Fossil remains are lacking.

Unit B

The transition from BCC into the overlying unit (B in Fig. 3), "Marlstone and fine-grained clastites", marks the package of laminated and clayey siltstones (at 165 m depth in VA-1, and above 254 m depth in VA-2) where the lacustrine mollusc fauna occurs for the first time in the succession (remains of freshwater gastropods – *Gyraulus* sp., *Planorbarius* sp., *Theodoxus* sp.; Fig. 4b). The amount of sand and gravel in this unit increases laterally along with the thickness of the unit itself (from 110 m in VA-1 to 140 m in VA-2).

The given unit is typically represented in borehole VA-1 where three lithofacies are distinguished: (1) fine-grained clastites (sandy-clayey siltstones prevail); (2) marlstone (compositionally uniform) and (3) fine-grained clastites and sands. Horizontal lamination in lithofacies 1. and 2., determined by laminae of different granulometry, colour, composition and thickness is common. Bioturbation occurs locally.

The aforementioned lithofacies are weakly differentiated in borehole VA-2, particularly when composed of marlstone. Sands composed of well-rounded grains originating from volcanic complex and flysch sediments occur throughout the column of VA-2, either as beds or as packages. The most abundant constituents of the sands are quartz (40.3–66.1%; Table 1) and rock fragments (15.6–21.3 %). Feldspar occurs in significant amounts (10.6–14.1 %), as well as muscovite (0.5–15.3%) and chlorite (1.6–15.7 %). Fine-grained clastites of different shades of brick-red colour, as well as green silty clays with carbonate nodules within the interval 195–180 m (see Fig. 3) suggest subaerial exposure.

Unit B in column VA-3 displays an upward decrease in grain-size and thickness. Rounded pebbles in gravels were derived from clastites and altered volcanic rocks, while the finer-grained clas-

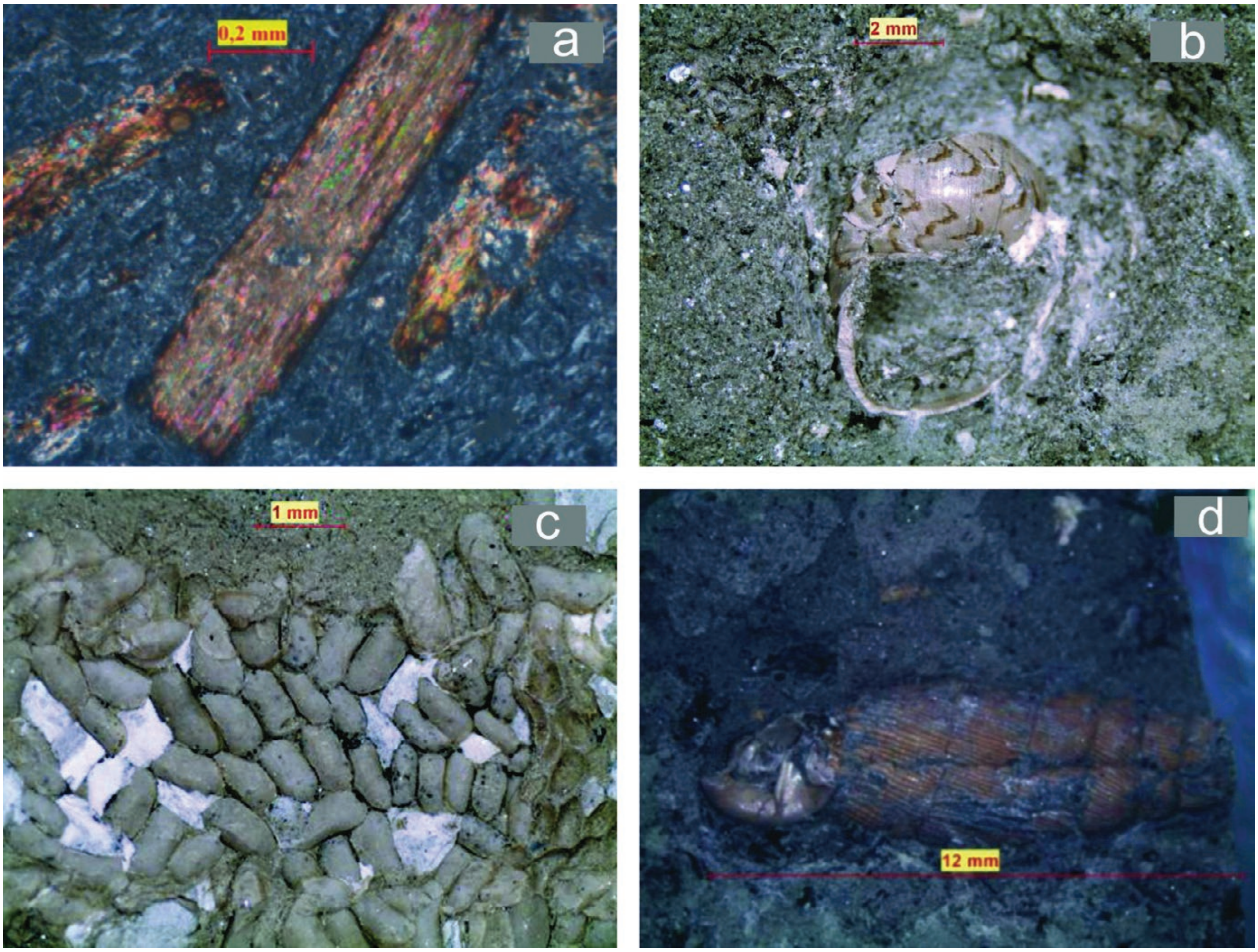

Figure 4. a.Photomicrograph of lamprophyre; b. *Theodoxus* sp.; c. Accumulated ostracods in marlstone at 195 m (VA-3); d. *Clausilia* sp.

tites are composed of fragments of metamorphic rocks. Sands display sedimentary structures of wave action (lenticular, wavy and flaser lamination). Debris of mollusc remains (molds) is common. Fine-grained clastites are calcite-clayey siltstones with 10–15% $CaCO_3$ (Table 2). Deformational structures resulted from vertical and horizontal movements – small syn-sedimentary landslides. Fresh-water organisms were identified in marlstones: carbonized flora, fish bones and scales, pyritized shell valves, ostracods (*Candona* sp., *Amplocypris* sp., *Hungarocypris*? sp.) and gastropods. Accumulated, i.e. gathered ostracods are common (Fig. 4c).

Unit C

The youngest recognized unit (C in Fig. 3) is "Sand, gravel, sandstone and fine-grained clastites". Its boundary with the previous unit is marked by basal conglomerates.

A typical succession occurs within the VA-1, from the surface to 50 m depth. Sands are composed of quartz (63.2–66.1%), rock fragments (18–21.1%) and feldspars (12.8–14.0 %). Muscovite is less abundant (up to 1 %) and chlorite and biotite are lacking (first three samples of Table 1). Sands in the deeper sections are of different granulometry and colour, and are organized in sets of trough cross or cross and horizontal lamination. Elements of wave-action, such as wavy (ripple) lamination and weakly developed small-scale flaser or lenticular lamination, occur occasionally. In the upper part, thin to moderately thick beds of sandstone occur. Intraformational fragments of sandstone, originating from a basal unit (B – marlstone and fine-grained clastites) reflects that the former sands were cemented by calcite. Sandstones are considered to represent sub-litharenite, litharenite and arkose having similar composition to the underlying exposed sands (Table 1).

Sand and gravel in VA-2 alternate with fine-grained clastites. Fine-grained clastites and marlstone display horizontal lamination. The content of freshwater bivalves (*Mytilopsis* sp. and *Pisidium* sp.), gastropods (*Melanopsis* cf. *decollata* STOLICZKA, *Melanopsis* ex gr. *lyrata* NEUMAYR, *Gyraulus* ex gr. *pulici* BRUSINA, *Prososthenia* sp., *Planorbarius* sp.) and ostracods (*Hungarocypris* sp. and *Candona* sp.) is high.

Sands and gravels also comprise this unit in the VA-3 column too. Their boundary with the previous unit marks the sequence of yellowish-red coarse-grained gravels. Variations in shades of red, yellow and grey colours through the overall unit reflect on relatively shallow, oxygen-rich environment. The lower part of the unit includes alluvial-lacustrine sequences (polymict gravels) with a notable presence of fragments from metamorphic rocks. Sands vary in grain-size and display either horizontal or cross lamination. In finer-grained clastites, i.e. siltstones with more or less sandy fraction, one palaeosol horizon with two levels of carbonate concretions was detected. Their structures reflect wave-action (wavy lamination and weakly developed flaser or even lenticular lamination). Fossil material includes mollusc molds and well preserved terrestrial gastropods (e.g. *Clausilia* sp.; Fig. 4d).

5. DISCUSSION

The natural concentration of elements in sediments is a function of the mineralogy of the source, the grain size and diagenetic processes/environment (MOURA & KROONENBERG, 1990; HAKSTEGE et al., 1993; HUISMAN & KIDEN, 1997). Sedimentary rocks derived near sources may inherit the source rock signatures, particularly the fine-grained ones due to their less variable composition in comparison with sandstones (CULLERS, 2000). These signatures may be later modified by weathering, hydraulic sorting and diagenesis (CULLERS et al, 1987). The obtained geochemical data for all the exposed rocks support the results from the common petrographic techniques and indicate the source rocks.

Basement rocks

Flysch in VA-1 contains rock fragments that were derived from metamorphic rocks (including serpentinites) and limestones. Their high Ni (413–1429 ppm) and Cr (106–992 ppm; Supplementary Table) contents reflect the southwestern part of the studied area with serpentinite as the predominant source material. In terms of sedimentology, flysch corresponds to the distal parts of the fan in the bottom of the basin. Considering the flysch sediments that outcrop about 15 km west of Belanovica (e.g. around the volcanic mass of Slavkovica) an Albian-Cenomanian age may be inferred. The presence of the brachiopod *Kingena concinna* OWEN in the coarse-grained clastites with serpentinite fragments suggests a Middle Cenomanian age, whereas the limestone fragments originate from the Upper Albian and Lower Cenomanian carbonates (RABRENOVIĆ et al., 2002; VASIĆ et al., 2001). Volcanic and volcaniclastic rocks (ignimbrites) in borehole VA-2 are products of volcanism the evolution of which involves the mixing of ultrapotassic and calc-alkaline magmas, which has been very important and led to highly diverse products (CVETKOVIĆ et al., 2007; CVETKOVIĆ et al., 2001; PRELEVIĆ et al., 2001; PRELEVIĆ et al., 2004).

The contents of Cr (9.4–10.6 ppm) and Ni (4.4.–5.2 ppm) in VA-2 are notably lower than in VA-1 (Supplementary Table). The average crustal abundance of Ni is 0.01 %, while in sedimentary rocks it ranges from 5–90 µg/g (COX, 1995). The borehole VA-3 did not access the basement but considering the data from the Basic Geological Map corresponds to flysch sediments at the southern and to Devonian-Carboniferous metamorphic rocks at its northern margin (FILIPOVIĆ et al., 1971).

Basement rocks display lithological and geochemical differences indicating petrological and stratigraphic differences of palaeorelief at the onset of lake formation. According to the depth distribution of the Neogene basement the lake bottom was probably tilted towards the east, i.e. from VA-1 to VA-3.

Basin infill (Neogene units)

Unit A (alluvial phase)

The oldest Neogene unit is **basal coarse-grained clastites** (BCC). As deposition took place during a partly developed lake basin the character of an alluvial system remained, particularly in VA-3. BCC in VA-1 and VA-2 reflect the periodically high terrigenous input into the basin, most probably by torrential flows. It is composed of material derived from the volcanic complex and flysch, from Triassic limestones or re-deposited volcaniclastic material.

Table 2. The $CaCO_3$ % content in samples (for the long core samples, several powdered samples were made for analyses. Such samples have the same number but are signed by uppercase letters, e.g. 13 A, 13 B, etc.).

VA-1					VA-2					VA-3				
No.	sample	depth	% $CaCO_3$	rock determination after FOLK et al. (1970)	No.	sample	depth	% $CaCO_3$	rock determination after FOLK et al. (1970)	No.	sample	depth	% $CaCO_3$	rock determination after FOLK et al. (1970)
1	15	45.3	7.6	sandy-clayey siltstone	32	13	241.3	22.1	calcite-clayey siltstone	49	10	241.7	10.2	calcite-clayey siltstone
2	18	52.2	44.2	marlstone	33	14	243.3	11.9	calcite-clayey siltstone	50	13A	224.5	20.4	calcite-clayey siltstone
3	19	54.0	10.2	calcite-clayey siltstone	34	17	222.7	39.9	marlstone	50	13B	219.4	35.7	marlstone
4	20	55.6	10.2	calcite-clayey siltstone	35	18	214.8	25.5	calcite-clayey siltstone	50	13C	211.1	34.8	marlstone
5	21	59.1	12.7	calcite-clayey siltstone	36	19	201.7	42.5	marlstone	50	13D	204.3	37.4	marlstone
6	25	67.7	13.6	calcite-clayey siltstone	37	20	195.3	7.6	clayey- sandy siltstone	50	13E	203.6	41.6	marlstone
7	27	70.8	16.1	calcite-clayey siltstone	38	25	160.4	11.9	calcite-clayey siltstone	50	13F	195.0	21.2	calcite-clayey siltstone
8	29	75.4	13.6	calcite-clayey siltstone	39	26	158.7	54.4	marlstone	50	13G	186.5	39.9	marlstone
9	30	79.9	17.0	calcite-clayey siltstone	40	28	140.7	16.1	calcite-clayey siltstone	50	13I	182.0	27.2	calcite-clayey siltstone
10	33	88.2	12.7	calcite-clayey siltstone	41	30C	130.2	10.2	calcite-clayey siltstone	50	13H	181.0	38.2	marlstone
11	36	99.5	14.4	calcite-clayey siltstone	41	30B	128.0	11.9	calcite-clayey siltstone	50	13J	177.6	31.4	calcite-clayey siltstone
12	37	103.4	17.0	calcite-clayey siltstone	41	30A	127.1	48.4	marlstone	50	13K	173.0	28.0	calcite-clayey siltstone
13	38	105.7	50.1	marlstone	42	33	110.5	17.0	calcite-clayey siltstone	51	14	168.2	13.6	calcite-clayey siltstone
14	39	108.8	48.4	marlstone	43	35	88.2	30.6	calcite-clayey siltstone	52	17	147.5	11.0	calcite-clayey siltstone
15	40	11.4	27.2	calcite-clayey siltstone	44	36C	84.0	43.3	marlstone	53	21	98.2	12.7	calcite-clayey siltstone
16	41	113.7	56.9	marlstone	44	36B	79.2	34.0	calcite-clayey siltstone	54	26	48.9	4.2	clayey siltstone
17	42	117.5	39.9	marlstone	44	36A	78.5	28.9	calcite-clayey siltstone	55	29	11.1	11.0	calcite-clayey siltstone
18	43	121.3	46.7.	marlstone	45	38	66.6	25.5	calcite-clayey siltstone					
19	44	123.8	39.9	marlstone	46	40	48.3	49.3	marlstone					
20	45	128.2	51.8	marlstone	47	41	43.0	9.3	clayey siltstone					
21	46	129.8	59.5	marlstone	48	43	26.1	42.5	marlstone					
22	47	131.5	51.0	marlstone										
23	48	134.5	42.5	marlstone										
24	49	136.8	51.0	marlstone										
25	50	138.8	39.9	marlstone										
26	52	146.2	52.7	marlstone										
27	53	151.5	20.4	calcite-clayey siltstone										
28	54	153.2	81.5	limestone										
29	56	157.8	16.1	calcite-clayey siltstone										
30	57	159.0	50.1	marlstone										
31	58	161.9	12.7	calcite-clayey siltstone										

The lower unit in VA-1 corresponds to an alluvial system (not completely differentiated) and the upper part is re-deposited volcaniclastic rocks. The latter displays elements of debris flow, locally likely lahars, as being suddenly brought into the basin. In terms of sedimentology, the BCC corresponds to alluvial facies. Sedimentology of BCC additionally confirms the lithological difference of lake margins and reflects to a different way of contribution (alluvial flows or lahars). Subsidence during deposition of the BCC was more rapid than authigenic processes, such as lake infilling. Although the fossil remains are lacking, their early Middle Miocene age may be supposed according to similar lithological succession in other basins, e.g. in the Lake Popovac (SANT et al., 2017) and according to data from the Basic Geological Map, sheet Gornji Milanovac (FILIPOVIĆ et al., 1971).

Unit B (lacustrine phase)

After deposition of the BCC the lake was completely formed. The transgression took place and the input of medium- and coarse-grained terrigenous material decreased, particularly in the central part of the lake (where the boreholes were drilled). Coarser particles retained close to the margins forming the alluvial-lake and marginal-lake facies. Slightly higher amounts of such material were brought into the area of boreholes VA-1 and VA-2, due to the proximity of the basin margin. Finer-grained volcaniclastic material was synchronously brought into the basin revealing the first level of vitroclastic tuffs (see Fig. 3). Localized occurrences of tuff (~ 232 m in VA-2) suggest that pyroclastic material arrived as lahars; otherwise a much broader area would be covered. According to KRSTIĆ et al. (2012) lake basins in Serbia are commonly lacking organisms with a calcium carbonate shell, as the lake water had to be acidic due to influence of volcanic activity. Lake acidification is additionally supported by the early soil development along with the role of atmospheric precipitation (RENBERG, 1990). Such a situation occurred during the period of deposition of the fine-grained clastites in shades of brick-red colour and green silty clays with carbonate concretions in alluvial sequences (interval 195–180 m in VA-2), reflecting the periodic subaerial conditions.

This unit (**marlstone and fine-grained clastites**) includes three lithofacies: (1) alluvial-lacustrine fine-grained clastites, (2) lacustrine marlstone, and (3) deltaic fine-grained clastites and sands.

(1) The upward decrease of grain-size and dimension of sand bodies in all three boreholes indicate that material was brought by muddy, turbidity flows. The sand bodies resembled the shape of channels through which sand and gravel have been distributed. The coarsening and thickening upward pattern is caused by the increasing and coeval exhumation during extension of a source area (ANDRIĆ et al., 2017). This gradually growing source area led to almost uni-directional sourcing of the basin (only from the north). The provenance ZFT (zircon fission tracks) age of 14.8 ± 0.8 Ma (Serravalian) for the coarse clastic sample from the Belanovica Basin, combined with some euhedral morphologies indicated the northern Bukulja pluton as the source area (STOJADINOVIĆ et al., 2017).

In the middle part of the basin the finest-grained, silty and clayey particles were deposited, and together with microcrystalline calcite allowed the formation of intrabasinal and lake facies, i.e. clastic-carbonate sediments. In terms of sedimentology this interval represents the alluvial-lacustrine facies. Constituents of sands, well-rounded pebbles originating from the volcanic complex and flysch sediments, together with the high content of magnesium (Mg) in VA-3 (up to 2.16%) suggests the southern margin as the source area, as well as in VA-2 (up to 8.43%; Supplementary Table). In VA-1 both margins were included (Fig. 5a). The contents of barium and strontium in fine-grained clastites is the highest in VA-1 (in given unit average Ba-115.20 ppm, Sr-809.63 ppm; Supplementary Table). This reflects either different amount of calcite-clayey siltstones, i.e. calcite where Ba2+ substitutes Ca2+ or more involvement of granitic rocks that tend to contain higher concentrations of Ba than the low-silica rocks (CULLERS, 1994). The slight increase of Ba+Sr in VA-2 can suggest an increasing amount of fragments from lamprophyres or volcanic rocks with Ba-bearing biotite at least (e.g. HENDERSON, 1982; SHAW & PENCZAK, 1996). A low to moderate Ba and Ti-bearing mica is thought to have been formed by magmas in a subduction-enriched subcontinental lithospheric mantle (JAQUES et al., 1986; THOMPSON et al., 1997). Such an interpretation is consistent with the already mentioned interaction between lamprophyric and granitoid magmas (PRELEVIĆ et al., 2004).

(2) During deposition of the **marlstone** lithofacies, which was the first truly intrabasinal facies, the basin was at least intermittently stratified. Contents of Ba+Sr (500–2000 ppm) in the marlstones in VA-2 in respect to Na+K (0.6–1.1 %) could be explained by the substitution of K+ by Ba2+ due to the presence of material from the southern margin (volcanic rocks; Fig. 5b). The increase of Ba+Sr in respect to the almost uniform contents of Na+K in marlstones in VA-1 and VA-2 is in agreement with the presence of hydrous Mn and Fe oxides, clay minerals and organic matter, which adsorb Ba2+ at higher pH (WEDEPOHL, 1978). The presence of sulfide (i.e. pyrite mineralization and carbonized flora) suggests periodically reduced conditions and an abundance of organic matter (recall the Fig. 4c).

A slight but progressive increase of Th+U with the increase of Na+K in VA-1 and VA-3 is in agreement with the increased contribution of material derived from the Bukulja and Brajkovac granites (Fig. 5c). It should be mentioned that in the Valjevo-Mionica basin there was a noted increase in the concentrations of uranium in coaly interbeds in Jelovik Village (KRSTIĆ et al., 2011).

The high concentrations of Th (3–16.7 ppm; Supplementary Table) could be due to the concentration of certain accessory minerals (e.g. zircon, monazite) in high-silica source rocks, i.e. granites (CULLERS, 1994). This element is (together with Sc) considered to be the most useful REE for inferring source rock composition as its distribution is not severely affected by secondary processes (CULLERS, 1994). In VA-2 these values do not correlate due to the variable abundance of fragments from felsic rocks and flysch clastites.

(3) The final lithofacies (**fine-grained clastites and sands**) of this unit received material from both margins. Alluvial systems from the South brought enormous amounts of coarser-grained terrigenous compounds (gravel and sand) into the basin resembling a deltaic model of deposition, i.e. alluvial-lake facies with well-evolved delta. Delta comprised a delta plain, delta front and prodelta and it was intermittently flooded by a lake (constructive and destructive phase).

Unit C (alluvial-lacustrine phase)

The youngest recognized unit is termed **sand, gravel, sandstone and fine-grained clastites**. Intraformational fragments of sandstone, originating from unit B (marlstone and fine-grained clastites) shows that the former sands were cemented by calcite, most probably mobilized internally from the same unit. Constituents of dominating sands and gravels in VA-1 and VA-2 imply almost exclusive origin from the northern margin, i.e. from metamorphic and granitoid rocks. This could be a consequence of tilting to the south and uplift of the northern area leaving the Bukulja and Brajkovac massifs exposed to erosion. The high percentage of quartz relative to other minerals suggests that all the analyzed sandstones are most likely first cycle sediments, i.e. products of intense chemical weathering (CULLERS & PODKOVYROV, 2002). Such an inference is additionally supported by the good correlation of boron (B) and lithium (Li), particularly in VA-2, where the lake depositional environment lasted the longest. In terms of sedimentology these sediments are considered to represent alluvial-lacustrine facies. Local occurrences of lenticular bodies of sand or gravel on a metre to decametre scale resemble the channel forms by which particles were distributed.

Sands and gravels comprise this unit in column VA-3, too. Their boundary with the previous unit is marked by a sequence of yellowish-red coarse-grained gravels. The colour-variations throughout the unit reflect a shallow, oxygen-rich environment and the gradual closure of the basin. The presence of a palaeosol horizon with two levels of carbonate concretions in finer-grained clastites indicates periodic subaerial conditions and supports the previous conclusion. The lower part of the unit includes alluvial-lacustrine intervals (polymict gravels) with the notable presence of fragments from metamorphic rocks.

The highest boron contents usually occur in sedimentary beds associated with volcanic activity, as in the volcaniclastic rocks in VA-1 (unit B, interval 170–199m; values 87–172 ppm; Supplementary Table). In contrast, the tuffaceous rocks in VA-2 display similar behaviour as sedimentary rocks in VA-1 and VA-3 – uniform B and slight increased Li (Fig. 5 d, e). Most of the boron content of sands and sandstones can be attributed to the pres-

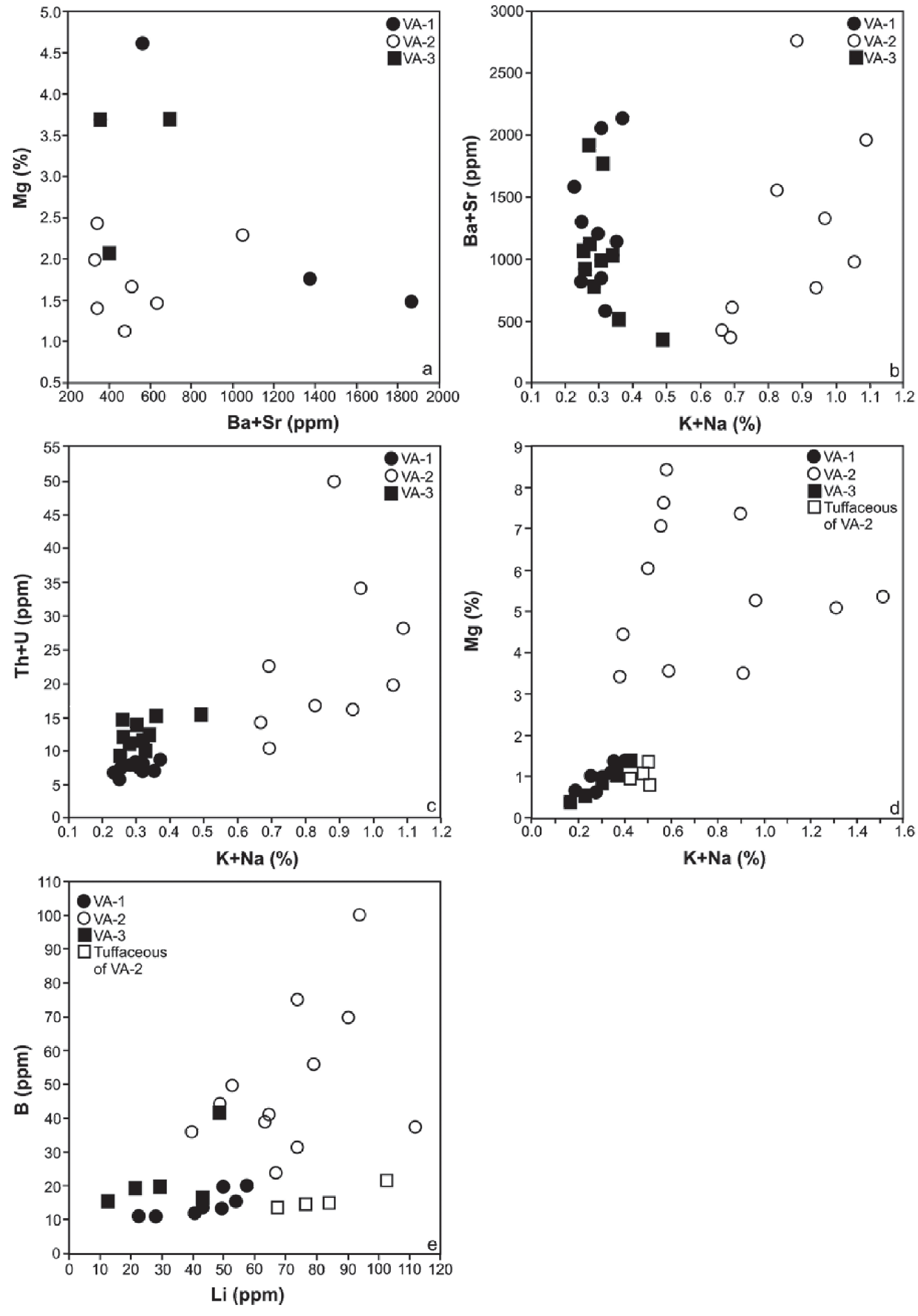

Figure 5. Distribution of selected elements in distinguished lithofacies.

ence of tourmaline or to higher proportions of clay (HARDER, 1970). In finer-grained sediments its concentration varies inversely with grain size, thus the highest values are found in the finest fractions. Boron, together with sodium is considered a good geochemical indicator of marine (saline) or fresh-water environments, as its content in sediment depends primarily on the type of rock involved (HARDER, 1970). The low Na and uniform B reflects a lacustrine or fresh-water environment.

Age

The availability of data on lacustrine sediments in Serbia, regarding their age have until recently been scarce or only presented in local publications. The Serbian Lake sediments are older than the marine Middle Badenian, as they lie concordantly below it.

As they are also overlain by marine deposits of Late Badenian/Sarmatian age the lacustrine sediments were generally considered Early to Middle Badenian. The Valjevo-Mionica-Belanovica graben formed during the Ottnangian-Karpatian but later divided into the Valjevo-Mionica (west) and Belanovica (to the east) basins (MAROVIĆ et al., 2007). Index fossils are lacking in the Belanovica lake sediments but the presence of freshwater *Melanopsis* support their Middle Miocene age, as the earliest record of it dates back in the late Early Miocene (NEUBAUER et al., 2016). The lack of marine sediments in the Belanovica basin suggests that deposition ceased before the Late Badenian/Sarmatian when the Valjevo-Mionica basin was ingressed by marine water. The new data obtained for Lake Popovac reflect that the development of the Serbian lakes started around 14.5 Ma ago, in the Langhian, which corresponds to the Early Badenian Stage of the Central Paratethys (SANT et al., 2017).

The fission-track analysis is potentially useful for unraveling the age of the studied lacustrine sediments.

6. CONCLUSIONS

The Belanovica Lake developed during the Neogene in the area between the Brajkovac and Bukulja Mountains (granitoid and low-grade metamorphic rocks) to the North, and a broad area covered by Albian-Cenomanian flysch, Jurassic ultramafics and the Neogene volcanic mass of Slavkovica to the South. Alluvial and occasionally torrential flows coming from the South were responsible for the onset of deposition.

The lake bottom dipped southeast periodically revealing parts of the lake sediments and exposing them to subaerial conditions. The alluvial-lacustrine and marginal-lacustrine facies retained close to the basin margin, whereas the finest-grained, silty and clayey particles arrived in the central and deepest part of the basin contributing there to the intrabasinal open-lacustrine facies. The alluvial flows from both margins contributed more than the synchronous volcanism to basin infilling, which itself was responsible for increasing the lake-water acidity. The flows from the single northern margin into the western area (VA-1 and VA-2) indicate the gradual closure of the basin. The eastern area (VA-3) was frequently exposed to subaerial conditions giving rise to palaeosol development.

The three-stage evolution of the Belanovica basin, inferred from integrated chemical and petrographic data, was controlled by palaeorelief of the pre-Neogene basement, erosion rate, and intensity of alluvial flows. The influence of volcanic activity should also be taken into consideration. Lake sediments inherited signatures of the source rocks at the basin margins.

The whole succession, lacking age-diagnostic fossils, was tentatively correlated with the Middle Miocene. Tuffaceous rocks could hold the potential for unraveling the age of these lake sediments, as well as the fission-track low-temperature thermochronology.

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Supplementary Table

Contents of indicative chemical elements in the Belanovica basin lake deposits in ppm or in %, (as indicated), including detection limit(s). Lithofacies are marked as in the text (A, B and C). Shaded area considers volcaniclastic rocks.

				Cr (ppm)	Ni (ppm)	Mg (%)	Ba (ppm)	Sr (ppm)	Th (ppm)	Sc (ppm)	Th/Sc	U (ppm)	Na (%)	K (%)	B (ppm)	Li (ppm)
		limit(s)		1ppm-1%	1ppm-1%	0.01%-15%	5ppm-1%	0.5ppm-0.1%	0.1ppm-1000	0.5ppm-1%		0.05ppm-1%	0.01%-15%	0.01%-15%	10ppm-1%	1ppm-1%
		Interval (in m): from – to														
		65.40	66.40	41.50	65.30	1.14	112.20	220.00	6.80	7.20	0.94	1.27	0.02	0.33	20.00	49.80
		69.85	70.85	49.00	82.20	1.28	147.60	515.00	8.30	8.10	1.02	1.77	0.03	0.37	20.00	57.80
		78.00	79.00	55.20	93.30	1.30	115.40	451.00	8.60	8.70	0.99	1.61	0.02	0.34	15.00	53.30
		81.30	82.30	50.80	78.80	1.18	108.40	358.00	6.20	7.30	0.85	1.32	0.03	0.34	13.00	49.50
		85.70	86.70	29.60	41.10	0.66	115.80	129.00	4.70	5.00	0.94	0.83	0.04	0.24	11.00	28.30
		90.20	91.20	40.30	63.60	0.97	81.20	229.00	5.30	6.00	0.88	1.01	0.03	0.27	12.00	41.10
		94.70	95.70	29.00	40.20	0.64	89.80	176.00	3.90	4.00	0.97	0.82	0.03	0.16	11.00	23.00
		99.50	100.50	46.40	75.30	1.01	97.60	356.00	5.70	5.90	0.96	1.20	0.03	0.23	13.00	43.60
		103.70	104.70	44.60	77.40	1.06	122.60	466.00	6.00	5.90	1.01	1.12	0.04	0.28	18.00	46.00
		112.70	113.70	52.60	96.40	1.21	282.80	1666.00	5.50	3.80	1.44	2.56	0.06	0.22	25.00	50.80
		117.30	118.30	91.00	131.00	1.39	179.80	1017.00	6.20	4.30	1.44	1.86	0.07	0.23	16.00	45.20
		121.20	122.20	34.70	75.90	0.84	207.20	1379.00	4.50	2.60	1.73	2.22	0.07	0.16	13.00	27.20
		125.30	126.30	69.40	95.40	1.21	173.00	1140.00	5.60	3.50	1.60	1.85	0.07	0.18	12.00	37.70
		127.80	129.80	33.40	57.90	0.86	141.20	691.00	4.90	3.00	1.63	1.15	0.07	0.18	10.00	31.80
	B	138.70	139.70	94.10	146.00	1.37	228.20	1914.00	6.20	3.40	1.82	2.55	0.11	0.26	20.00	53.10
		139.70	140.70	92.50	140.00	1.67	178.20	1885.00	5.60	3.30	1.75	2.35	0.10	0.21	18.00	55.20
		141.98	142.98	135.00	163.00	1.61	137.80	713.00	6.20	3.90	1.54	1.23	0.09	0.22	12.00	51.50
		146.20	147.20	89.90	107.00	3.64	151.40	996.00	5.20	3.20	1.57	1.92	0.11	0.24	85.00	51.80
		147.20	148.20	149.00	177.00	4.61	121.40	447.00	6.80	4.40	1.50	2.25	0.11	0.30	90.00	68.60
		153.04	154.04	59.70	84.80	1.77	159.20	1213.00	4.10	2.60	1.57	0.79	0.08	0.20	58.00	34.60
		158.93	159.93	95.50	138.00	1.50	216.80	1648.00	6.00	4.00	1.50	2.04	0.14	0.31	59.00	48.60
VA-1		162.00	163.00	153.00	211.00	1.68	91.40	203.00	7.60	5.40	1.40	2.39	0.10	0.44	36.00	53.50
		163.00	164.00	59.90	80.80	1.10	150.60	252.00	21.00	5.00	4.20	2.19	0.25	0.65	64.00	35.80
		171.10	172.10	57.10	86.20	0.84	135.60	208.00	19.70	4.40	4.47	3.25	0.21	0.52	38.00	18.70
	Volc.	181.10	182.10	27.90	36.00	0.70	124.80	170.00	18.10	3.70	4.90	1.92	0.20	0.42	38.00	13.00
		184.33	185.33	49.30	96.60	1.15	113.40	296.00	11.30	4.00	2.82	4.51	0.15	0.72	62.00	23.10
		185.33	186.33	88.10	139.00	1.74	113.00	256.00	9.90	6.30	1.57	0.86	0.20	0.58	38.00	46.00
		186.33	187.33	63.50	78.70	0.90	141.60	141.00	17.80	7.30	2.43	3.32	0.19	0.60	40.00	25.50
		187.33	188.33	40.20	51.30	0.93	150.60	261.00	8.90	3.70	2.41	0.51	0.35	0.41	43.00	22.30
		188.33	189.33	55.10	67.30	0.80	121.40	187.00	13.60	4.40	3.09	0.57	0.26	0.42	43.00	18.10
		189.33	190.33	106.00	223.00	2.20	89.20	261.00	9.20	5.50	1.67	1.62	0.17	0.39	34.00	35.90
		190.33	191.33	275.00	302.00	3.23	88.80	237.00	6.80	6.30	1.08	0.54	0.18	0.50	36.00	21.20
		191.33	192.33	565.00	566.00	5.29	77.40	246.00	4.90	7.70	0.63	0.32	0.14	0.25	14.00	19.80
		192.33	193.33	686.00	760.00	5.88	82.40	272.00	2.80	10.10	0.27	0.24	0.17	0.27	5.00	17.70
		193.33	194.33	580.00	704.00	6.14	78.20	268.00	2.50	8.10	0.31	0.32	0.15	0.28	11.00	21.00
		194.33	195.33	450.00	568.00	4.23	45.40	156.00	2.80	7.00	0.40	0.65	0.09	0.57	24.00	17.80
	A	195.33	196.33	492.00	583.00	3.70	48.80	135.00	3.30	6.60	0.50	0.62	0.09	0.59	26.00	24.00
		196.33	197.33	351.00	520.00	6.00	50.20	277.00	2.80	6.00	0.46	0.30	0.09	0.31	14.00	28.70
		197.33	198.33	357.00	425.00	8.05	55.80	317.00	30.00	6.80	0.44	0.31	0.11	0.33	33.00	16.60
		198.33	199.33	349.00	509.00	6.49	50.60	305.00	2.30	6.50	0.35	3.45	0.10	0.35	28.00	32.90
		199.33	200.33	357.00	529.00	5.12	42.60	222.00	2.50	10.90	0.29	2.95	0.09	0.33	87.00	39.90
		200.33	201.33	826.00	843.00	5.56	103.20	365.00	3.20	10.30	0.31	0.36	0.22	0.59	67.00	38.90
		201.33	202.33	851.00	945.00	5.29	106.20	412.00	3.30	10.00	0.33	0.26	0.24	0.35	43.00	45.70
		202.33	203.33	615.00	983.00	7.33	108.20	436.00	2.90	9.60	0.30	0.27	0.23	0.32	30.00	65.70
		203.33	204.33	903.00	1056.00	5.96	107.80	379.00	2.40	11.90	0.20	0.24	0.24	0.36	26.00	79.90
		204.33	205.33	532.00	745.00	7.82	85.80	552.00	1.90	8.20	0.23	0.47	0.19	0.34	23.00	55.20
		205.33	206.33	936.00	1042.00	6.23	119.80	493.00	2.50	13.10	0.19	0.58	0.28	0.43	28.00	80.20
		206.33	207.33	713.00	969.00	5.79	99.60	583.00	3.50	10.90	0.32	0.21	0.24	0.33	21.00	68.10
		207.33	208.33	779.00	1046.00	5.38	108.40	542.00	2.90	12.30	0.23	0.23	0.26	0.37	27.00	76.90
		208.33	209.33	760.00	1004.00	5.65	99.80	583.00	2.40	11.60	0.21	0.26	0.24	0.32	26.00	80.90
		209.33	210.33	663.00	939.00	6.26	98.20	721.00	2.50	10.20	0.24	0.27	0.25	0.36	25.00	83.40
		210.33	211.33	742.00	988.00	5.76	100.80	592.00	2.30	11.70	0.19	0.50	0.33	0.27	23.00	126.00
		211.33	212.23	747.00	913.00	6.08	90.40	501.00	2.10	12.20	0.17	2.27	0.32	0.29	28.00	148.00
		212.23	213.13	700.00	1185.00	6.71	120.60	336.00	2.80	11.20	0.25	0.57	0.43	0.31	30.00	161.00
		215.00	216.00	791.00	1429.00	7.57	128.80	306.00	4.00	13.10	0.30	0.25	0.65	0.19	15.00	203.00
		216.00	217.00	658.00	1245.00	7.94	120.60	321.00	2.50	11.60	0.21	0.29	0.64	0.20	17.00	201.00

				Cr (ppm)	Ni (ppm)	Mg (%)	Ba (ppm)	Sr (ppm)	Th (ppm)	Sc (ppm)	Th/Sc	U (ppm)	Na (%)	K (%)	B (ppm)	Li (ppm)
		limit(s)		1ppm-1%	1ppm-1%	0.01%-15%	5ppm-1%	0.5ppm-0.1%	0.1ppm-1000	0.5ppm-1%		0.05ppm-1%	0.01%-15%	0.01%-15%	10ppm-1%	1ppm-1%
		Interval (in m): from – to														
		217.00	218.00	929.00	990.00	6.94	102.00	363.00	2.00	12.50	0.16	0.29	0.51	0.17	15.00	152.00
		218.00	219.00	749.00	1162.00	7.54	114.20	284.00	3.20	12.20	0.26	0.32	0.59	0.21	34.00	175.00
		219.00	220.00	908.00	1216.00	7.88	124.60	296.00	3.90	14.80	0.26	0.29	0.59	0.22	27.00	177.00
		220.00	221.00	707.00	1051.00	7.42	121.20	426.00	2.80	12.40	0.22	0.30	0.5	0.21	26.00	143.00
		221.00	222.00	731.00	985.00	7.56	117.00	263.00	2.20	11.10	0.20	0.22	0.42	0.16	27.00	131.00
		222.00	223.00	597.00	923.00	7.87	117.80	283.00	2.30	10.20	0.22	0.32	0.41	0.17	28.00	130.00
		232.00	233.20	766.00	1050.00	9.02	85.00	264.00	2.40	12.10	0.19	3.54	0.52	0.11	26.00	41.80
		242.00	243.00	992.00	1215.00	9.74	81.20	195.00	2.60	14.60	0.18	2.05	0.55	0.10	33.00	49.50
		250.50	251.50	816.00	1266.00	7.94	424.00	281.00	1.80	12.50	0.14	0.12	0.47	0.07	172.00	15.70
		256.00	257.00	740.00	1128.00	9.14	109.00	281.00	2.50	12.50	0.20	0.17	0.65	0.11	117.00	35.90
		267.20	268.30	934.00	1231.00	8.15	78.00	146.00	2.20	13.80	0.16	0.20	0.47	0.09	88.00	43.50
		278.00	279.00	775.00	1068.00	9.18	81.60	243.00	2.30	13.20	0.17	0.16	0.64	0.11	81.00	39.50
		290.20	291.20	838.00	1116.00	9.40	82.80	195.00	2.40	13.50	0.78	0.20	0.62	0.11	76.00	47.50
		300.00	301.20	845.00	1200.00	7.90	75.20	279.00	1.80	12.30	0.30	0.15	0.65	0.11	62.00	26.30
		309.50	310.50	406.00	652.00	9.95	53.20	184.00	3.60	12.00	0.16	0.21	0.38	0.10	79.00	81.00
		322.00	323.00	786.00	1083.00	8.40	67.00	202.00	2.00	12.50	0.15	0.14	0.53	0.10	62.00	35.60
		327.00	328.00	867.00	1205.00	8.20	65.40	174.00	1.90	12.60	0.15	0.15	0.48	0.09	56.00	34.40
		328.00	329.00	763.00	1036.00	8.30	64.00	208.00	1.80	11.50	0.15	0.15	0.49	0.09	56.00	36.40
		332.00	333.00	900.00	1135.00	9.08	60.40	249.00	2.20	14.00	0.15	0.14	0.63	0.12	71.00	46.10
		51.00	52.00	37.00	46.40	1.23	68.40	214.00	8.30	8.1	1.02	1.54	0.02	0.41	14.00	47.40
		65.15	66.10	75.80	94.40	1.20	197.80	1203.00	5.60	4.5	1.33	1.59	0.05	0.27	20.00	41.10
		71.00	72.00	82.70	112.00	1.17	272.20	1787.00	4.90	3.6	1.36	2.96	0.08	0.24	20.00	50.10
		76.15	76.80	415.00	306.00	3.12	66.20	416.00	7.80	6.8	1.14	0.97	0.06	0.31	14.00	86.30
		77.50	78.50	118.00	129.00	1.74	225.20	852.00	6.80	5.2	1.30	1.46	0.07	0.30	15.00	45.40
VA-2	C	84.50	85.50	435.00	337.00	3.32	75.20	607.00	6.80	6.3	0.09	2.23	0.07	0.21	15.00	72.80
		95.00	96.00	766.00	533.00	4.95	34.60	335.00	4.80	8.9	0.53	0.99	0.10	0.16	16.00	81.30
		102.00	103.00	920.00	667.00	6.08	47.60	405.00	5.60	10	0.56	1.06	0.15	0.22	23.00	86.30
		108.50	109.50	746.00	510.00	4.84	80.00	330.00	4.50	8.5	0.52	0.79	0.12	0.20	22.00	64.00
		112.00	113.00	602.00	460.00	4.47	114.80	456.00	5.60	8.3	0.67	1.35	0.14	0.25	24.00	66.50
		117.00	118.00	454.00	361.00	3.43	133.60	917.00	4.40	6.7	0.65	1.26	0.13	0.25	41.00	64.40
		120.10	121.27	822.00	633.00	6.07	49.80	353.00	6.30	11	0.57	0.87	0.2	0.30	37.00	112.00
		128.00	129.00	367.00	321.00	3.59	82.80	358.00	9.40	8.2	1.14	1.95	0.17	0.42	31.00	73.50
		130.60	131.50	507.00	445.00	3.49	328.20	267.00	9.00	9.7	0.92	2.82	0.20	0.71	56.00	78.70
		136.90	137.90	537.00	446.00	5.24	120.00	361.00	9.80	10.10	0.97	3.40	0.22	0.74	70.00	90.00
		146.00	147.00	121.00	149.00	8.43	248.40	800.00	4.80	5.30	0.91	7.19	0.18	0.40	36.00	39.40
		149.50	150.50	33.60	46.10	1.09	54.20	218.00	3.80	2.80	1.35	0.81	0.35	0.13	15.00	76.70
		150.50	151.50	42.50	52.70	0.98	122.80	208.00	3.80	2.80	1.34	1.16	0.27	0.15	14.00	67.50
		151.50	152.50	21.60	26.40	0.78	94.20	175.00	3.00	2.30	1.30	1.74	0.38	0.13	15.00	84.20
		152.50	153.10	35.40	49.20	1.31	445.00	516.00	5.60	3.00	1.86	12.1	0.34	0.16	22.00	103.00
		158.30	159.10	179.00	178.00	7.36	315.20	850.00	8.70	6.40	1.36	6.31	0.22	0.68	50.00	53.00
		162.00	163.00	315.00	274.00	5.36	246.80	588.00	12.20	8.90	1.37	3.33	0.21	1.30	75.00	73.60
		163.90	164.60	199.00	209.00	7.64	226.00	781.00	6.20	5.80	1.06	13.3	0.20	0.37	39.00	63.20
		168.75	169.65	109.00	131.00	7.09	141.80	868.00	5.10	4.00	1.27	5.43	0.17	0.39	44.00	48.30
		178.50	179.70	217.00	221.00	5.09	91.80	1111.00	8.60	6.20	1.38	8.16	0.25	1.06	100.00	93.80
	B	182.70	183.70	129.00	142.00	4.71	62.20	1760.00	7.10	5.00	1.42	2.94	0.22	0.67	57.00	61.70
		191.00	192.00	303.00	269.00	2.51	173.00	641.00	16.70	10.00	1.67	3.52	0.34	0.53	32.00	57.50
		193.20	194.20	527.00	405.00	3.52	52.60	419.00	9.40	9.60	0.18	1.86	0.23	0.35	21.00	79.10
		195.00	196.00	600.00	482.00	4.13	58.00	317.00	10.90	11.40	0.95	7.42	0.27	0.42	25.00	85.80
		201.70	202.50	296.00	241.00	8.29	2891.40	1564.00	5.80	6.20	0.93	4.54	0.22	0.37	31.00	60.50
		202.50	204.00	649.00	502.00	5.68	26.20	576.00	6.00	10.50	0.57	1.64	0.29	0.40	29.00	114.00
		209.50	210.50	369.00	295.00	2.71	36.60	384.00	7.40	8.20	0.90	1.11	0.24	0.43	26.00	65.70
		214.10	215.10	333.00	271.00	6.39	352.80	1214.00	6.40	6.60	1.03	7.48	0.33	0.50	57.00	142.00
		218.30	219.40	418.00	325.00	4.92	62.60	717.00	8.00	8.20	0.97	4.81	0.28	0.66	60.00	100.00
		221.50	222.40	70.70	88.70	3.07	64.60	917.00	6.90	4.30	1.60	10.5	0.22	0.84	73.00	84.80
		222.40	223.30	82.90	83.20	5.74	147.40	1820.00	5.90	3.50	1.68	19.8	0.43	0.66	64.00	96.30
		223.30	224.20	67.50	70.70	3.26	873.00	1888.00	7.40	3.00	2.40	39.6	0.43	0.46	51.00	85.10
		224.20	225.10	69.10	102.00	2.14	92.80	1240.00	7.70	4.20	2.46	22.4	0.23	0.74	56.00	64.70
		229.05	230.20	16.70	18.60	1.67	227.40	283.00	8.90	3.40	1.83	3.25	0.57	0.47	31.00	127.00
		230.20	231.00	11.20	8.80	1.13	321.00	149.00	5.10	3.10	2.69	2.03	0.56	0.47	18.00	75.10

				Cr (ppm)	Ni (ppm)	Mg (%)	Ba (ppm)	Sr (ppm)	Th (ppm)	Sc (ppm)	Th/Sc	U (ppm)	Na (%)	K (%)	B (ppm)	Li (ppm)
		limit(s)		1ppm-1%	1ppm-1%	0.01%-15%	5ppm-1%	0.5ppm-0.1%	0.1ppm-1000	0.5ppm-1%		0.05ppm-1%	0.01%-15%	0.01%-15%	10ppm-1%	1ppm-1%
		Interval (in m): from – to														
		231.00	231.80	8.50	5.60	1.48	360.20	274.00	8.80	3.20	1.64	3.02	0.64	0.49	24.00	108.00
		231.80	232.45	13.80	15.40	2.30	453.60	592.00	14.70	5.00	2.75	6.21	0.73	0.49	30.00	152.00
		240.00	241.00	213.00	199.00	2.01	42.40	292.00	11.50	6.40	2.67	2.24	0.19	0.58	45.00	54.90
		247.30	248.50	357.00	294.00	2.42	37.00	303.00	11.00	9.50	1.79	1.61	0.26	0.44	29.00	60.70
		252.00	253.20	111.00	128.00	1.40	48.80	299.00	12.70	5.80	2.19	2.55	0.26	0.55	36.00	34.60
	A	258.20	259.20	79.10	117.00	1.13	63.20	270.00	16.00	6.00	2.66	7.14	0.28	0.63	47.00	30.90
	A	259.20	260.20	64.80	105.00	1.10	52.80	185.00	14.00	6.10	2.29	1.36	0.27	0.62	34.00	31.40
	A	270.50	271.50	247.00	79.00	0.98	178.60	267.00	17.80	14.00	1.27	4.54	0.40	0.45	43.00	19.80
		273.50	274.50	75.30	34.50	0.97	114.80	206.00	24.30	8.90	2.73	5.13	0.33	0.61	37.00	17.20
		277.60	278.60	10.60	5.20	0.54	82.20	65.50	29.80	7.50	4.01	3.24	0.17	0.44	14.00	6.60
		287.00	288.00	9.80	4.40	0.58	115.20	58.00	28.90	7.20	4.19	2.75	0.18	0.48	5.00	13.10
		293.00	294.00	9.40	4.40	0.55	100.20	56.00	28.50	6.80	0.95	3.99	0.21	0.55	5.00	13.50
VA-3	C	84.50	85.50	32.40	43.90	0.93	96.40	140.00	6.80	7.1	1.04	3.21	0.02	0.34	18.00	36.30
VA-3	C	87.50	88.50	19.00	21.80	0.47	80.00	101.00	4.70	3.5	0.95	1.06	0.03	0.16	12.00	18.50
VA-3	C	89.50	90.50	51.60	79.10	1.14	119.20	297.00	9.50	8.2	1.34	1.73	0.03	0.36	18.00	47.80
VA-3	C	93.20	94.20	39.20	50.00	1.12	92.60	174.00	8.80	8.4	1.15	1.54	0.02	0.4	14.00	55.30
VA-3	C	96.20	97.20	36.20	49.30	1.04	86.80	196.00	9.10	7.9	1.04	1.81	0.02	0.35	12.00	48.10
VA-3	C	105.20	106.20	32.90	47.40	1.10	81.60	167.00	8.20	7.3	1.15	1.46	0.02	0.34	10.00	48.00
VA-3	C	109.70	110.70	23.80	32.90	0.76	120.00	134.00	6.00	5.4	1.12	1.12	0.03	0.27	5.00	33.00
VA-3	C	118.70	119.70	15.30	24.80	0.32	30.00	35.50	2.50	1.50	1.11	1.84	0.02	0.10	18.00	8.00
VA-3	B	128.20	129.20	22.00	32.40	0.66	68.80	93.80	5.70	4.40	1.29	0.90	0.02	0.22	18.00	21.10
VA-3	B	136.70	137.70	24.90	37.90	0.82	64.40	108.00	6.30	5.30	1.18	1.12	0.02	0.27	18.00	29.30
VA-3	B	154.70	155.70	35.40	54.20	1.00	62.80	133.00	6.90	6.50	1.06	0.98	0.02	0.35	15.00	43.00
VA-3	B	161.20	162.20	18.60	25.10	0.38	39.80	86.40	4.00	2.50	1.60	0.83	0.03	0.13	14.00	12.50
VA-3	B	168.20	169.20	39.10	77.50	1.16	72.00	298.00	9.60	8.70	1.10	1.67	0.03	0.39	42.00	48.60
VA-3	B	173.20	174.20	68.80	126.00	1.39	192.40	601.00	5.70	5.10	1.11	1.90	0.04	0.25	33.00	37.30
VA-3	B	180.50	181.50	49.50	90.00	0.94	246.60	1716.00	4.40	3.70	1.19	2.44	0.06	0.22	32.00	27.60
VA-3	B	186.78	187.28	28.10	51.60	0.71	594.00	333.00	13.70	3.00	4.53	4.53	0.03	0.23	16.00	40.00
VA-3	B	190.70	191.70	52.50	97.20	1.25	123.00	901.00	6.40	4.50	1.42	1.86	0.07	0.26	20.00	39.50
VA-3	B	194.00	195.00	47.20	84.80	1.04	76.00	444.00	7.30	5.50	1.32	2.08	0.08	0.28	21.00	31.20
VA-3	B	199.30	200.30	71.70	120.00	1.49	117.00	958.00	4.80	3.80	1.26	1.39	0.06	0.21	17.00	35.90
VA-3	B	202.70	203.70	53.10	79.90	1.28	72.40	295.00	7.50	5.40	1.38	2.47	0.07	0.42	18.00	56.60
VA-3	B	209.50	210.50	107.00	131.00	1.54	192.20	1569.00	5.60	4.10	1.36	2.04	0.09	0.23	26.00	51.60
VA-3	B	219.00	220.00	101.00	146.00	1.48	125.40	1010.00	4.50	3.80	1.18	1.59	0.08	0.19	23.00	38.10
VA-3	B	225.90	226.90	156.00	197.00	2.16	110.00	869.00	5.10	4.60	1.10	1.42	0.10	0.21	20.00	46.60
VA-3	B	229.40	230.40	160.00	220.00	2.03	56.00	331.00	8.40	5.90	1.42	1.43	0.11	0.34	21.00	57.40
VA-3	A	231.30	232.30	218.00	215.00	3.67	69.00	605.00	6.70	6.20	1.08	1.50	0.11	0.33	25.00	66.30
VA-3	A	257.30	258.30	400.00	338.00	3.68	40.60	314.00	10.30	9.70	1.06	1.27	0.16	0.46	23.00	66.90
VA-3	A	272.00	273.00	428.00	391.00	2.95	103.80	260.00	9.90	11.70	0.84	0.97	0.18	0.42	20.00	78.10
VA-3	A	84.50	85.50	32.40	43.90	0.93	96.40	140.00	6.80	7.10	0.95	3.21	0.02	0.34	18.00	36.30
VA-3	A	87.50	88.50	19.00	21.80	0.47	80.00	101.00	4.70	3.50	1.34	1.06	0.03	0.16	12.00	18.50
VA-3	A	89.50	90.50	51.60	79.10	1.14	119.20	297.00	9.50	8.20	1.16	1.73	0.03	0.36	18.00	47.80