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Splash-like marine biodiversity additions after the Cambrian

Dmitry A. Ruban[1]

Abstract. Some Phanerozoic biotic radiations in the marine realm led to marine biodiversity additions, i.e., increases in the global number of genera to unprecedented levels. Each of the two alternative biodiversity curves implies five post-Cambrian events of this kind, which coincided with parts of the biotic radiations. However, differences between these curves do not allow to find coherent marine biodiversity additions with the only exception of those occurred at the interval of the Great Ordovician Biodiversification. The attempted interpretations indicate that the marine biodiversity additions increased the number of marine genera by 10–30 % (from the previous unprecedented level to that new). All additions were relatively brief and occurred as splashes throughout the Phanerozoic. Peculiar intrinsic and extrinsic factors, as well as the speed of diversification should be considered when triggers of these events are looked for. Undoubtedly, splash-like marine biodiversity additions played an important role in the evolution of life in the sea, but a lot of research is required in order to understand their true nature.

Key words: marine biodiversity, radiation, evolution, Phanerozoic.

Апстракт. Поједине биотичке радијације које су се догодиле у морским областима током фанерозоика додатно су утицале на разноврсност морских организама (додатно морска радијација), односно утицале су на повећање бројности родова на глобалном нивоу које до тада није било познато. Свака од две алтернативне криве биодиверзитета указују на пет посткамбријумских догађаја овог типа, који се подударају са деловима биотичке радијације. Ипак, разлике између ове две криве не омогућавају да се закључи о јединственој појави повећавања морског биодиверзитета са изузетком који је присутан у периоду велике ордовицијумске биодиверсификације. Објашњење дато овом приликом указује да је додатно увећање морске разноврсности довело до повећања морских родова за 10–30 % (од предходног нивоа до новог нивоа). Сва додатна повећања разноврсности била су релативно краткотрајна и појавила су се као бљесак током фенерозоика. Посебни унутрашњи и спољашњи фактори, као и брзина диверзификације требало би да буду узети у обзир приликом разматрања узрока ових догађаја. Без сумње, муњевити додатни морски биодиверзитет игра важну улогу у еволуцији живота у мору, али неопходно су додатна истраживања како би се боље разумео његов прави карактер.

Кључне речи: морски биодиверзитет, радијација, еволуција, фенерозоик.

Introduction

Marine biodiversity neither remained stable, nor increased gradually through the Phanerozoic; it experienced significant fluctuations (Sepkoski *et al.* 1981; Raup & Sepkoski 1982; Sepkoski & Raup 1986; Sepkoski 1993; Benton 1995, 2002; Peters & Foote 2001; Foote 2003, 2007; Bambach *et al.* 2004; Bambach 2006; Benton & Emerson 2007; Stanley 2007; Alroy *et al.* 2008; Purdy 2008; Miller *et al.* 2009; Alroy 2010; Kiessling *et al.* 2010; Lieberman & Kaesler 2010; Marshall 2010; Bush & Bambach 2011; Hannisdal & Peters 2011; Heim & Peters 2011; Melott & Bambach 2011a,b; Peters & Heim 2011; Aberhan & Kiessling 2012; Aberhan *et al.* 2012; Valentine *et al.* 2013; Mannion *et al.* 2014). There were several major radiations in the history of the marine life, including those occurred in the Cambrian and the Ordovician (Sepkoski & Sheehan 1983; Droser & Sheehan 1995; Droser *et al.* 1996;

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MILLER & FOOTE 1996; GEYER 1998; CONWAY MORRIS 2000, 2003; CONNOLLY & MILLER 2001, 2002; MILLER & CONNOLLY 2001; WEBBY 2001; KIRSCHVINK & RAUB 2003; DZIK 2005; HARPER 2006; LIEBERMAN 2008; MARUYAMA & SANTOSH 2008; SERVAIS *et al.* 2008, 2009, 2010; TROTTER *et al.* 2008; BRASIER 2009; MASUDA & EZAKI 2009; MEYER 2009; VANNIER 2009; PLOTNICK *et al.* 2010; RUBAN 2010, 2013; MALETZ *et al.* 2014; SANTOSH *et al.* 2014). However, many of these radiations were only recoveries after precedent biodiversity losses. For instance, the number of genera increased strongly in the Middle Triassic, but this radiation did not permit marine invertebrates to reach the same diversity as it was before the Permian/Triassic mass extinction (ALROY *et al.* 2008; PURDY 2008). Therefore, it appears very important to focus on those time intervals, when the marine biodiversity reached unprecedented levels. Such radiations (often parts of longer radiations) can be called "biodiversity additions". An interest to them is also facilitated by the present discussions of thresholds for the global biodiversity and carrying capacity of the planetary ecosystem (ABERHAN & KIESSLING 2012; ABERHAN *et al.* 2012; RUBAN 2013).

The issues relevant to the marine biodiversity additions were considered earlier by ALROY *et al.* (2008), ABERHAN & KIESSLING (2012), ABERHAN *et al.* (2012), and RUBAN (2013), but in only general form. The main objective of the present brief paper is to establish biodiversity additions in the post-Cambrian evolution of the global marine fauna on the basis of the already-documented Phanerozoic biodiversity changes. The Cambrian is excluded from the present analysis because much has been told already about the so-called "Cambrian explosion" (GEYER 1998; CONWAY MORRIS 2000, 2003; KIRSCHVINK & RAUB 2003; DZIK 2005; LIEBERMAN 2008; MARUYAMA & SANTOSH 2008; BRASIER 2009; VANNIER 2009; PLOTNICK *et al.* 2010; RUBAN 2010; ERWIN & VALENTINE 2013; MALETZ *et al.* 2014; SANTOSH *et al.* 2014).

Terms, original biodiversity curves, and method

Marine biodiversity addition can be defined as a long-term event in the biotic evolution, when the biodiversity increased from the previous unprecedented level to the new unprecedented level (Fig. 1). Evidently, such an event differs from "usual" biotic radiations, including those Paleozoic major radiations recognized in the marine realm by RUBAN (2010). Radiation (*sensu lato*) is an increase in the biodiversity from the minimum to the maximum. If the minimum was below the previous unprecedented biodiversity level and the maximum was above it, the only part of the radiation corresponded to the marine biodiversity addition (Fig. 1). And in those rare cases, when the biodiversity reached unprecedented level, remained on its for some time, and then started to rise again, this latter rise marks the radiation, which completely coincides with the biodiversity addition. The definition presented above may leave an impression that each biodiversity addition is an "occasional" event. However, one should note that reaching unprecedented level of biodiversity means fundamental change in the ecological state of the planet, which begins to sustain a higher number of organisms than anywhen earlier. The proposed idea of the marine biodiversity addition is linked to the modern ideas on thresholds for biodiversity, global carrying capacity, etc. (ABERHAN & KIESSLING 2012; ABERHAN *et al.* 2012; RUBAN 2013).

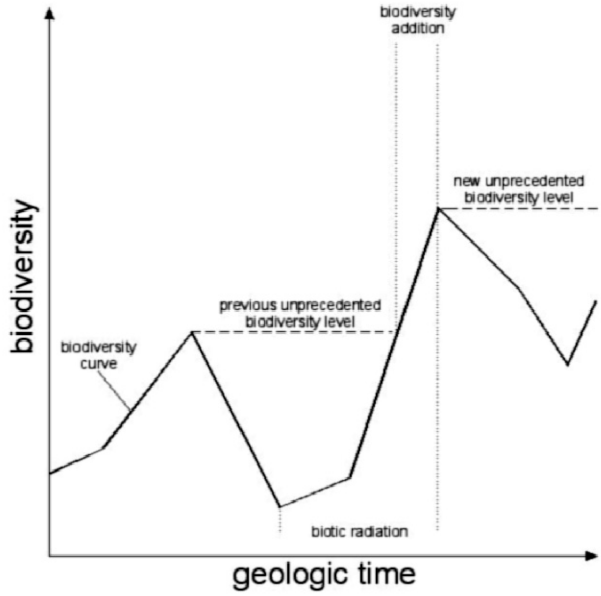

Fig. 1. A simple graph demonstrating biodiversity addition (projected on the geologic time line by dashed lines) and its relationship with biotic radiation (projected on the geologic time line by grey area).

Following its definition, the marine biodiversity additions can be identified on the basis of graphical analysis of "simple" biodiversity curves reflecting total number of taxa and their changes through the geologic time. Now, two curves are available (Fig. 2). The first curve was proposed by PURDY (2008, Fig. 1, p. 653) on the basis of the "classical" palaeontological database compiled by SEPKOSKI (2002) (this database is also available on-line: strata.geology.wisc.edu/jack/start.php). The second curve was proposed by ALROY *et al.* (2008, Fig. 1, p. 98) on the basis of the new palaeontological database (available on-line: paleodb.org). The both reflect changes in the number of genera of marine organisms (chiefly invertebrates) throughout the Phanerozoic. When the first curve is reconstructed via "simple" calculation of the number of genera per geologic time intervals, the second curve employs a more complex, sample-standardized approach (see

ALROY *et al*. (2008) for details and BENTON *et al*. (2011) for discussion of the utility of this approach). In the other words, these are alternative curves presenting different views on marine biodiversity, and the both should be considered in the analysis of marine biodiversity additions. The other reconstruction of ALROY (2008, Fig. 4, p. 100) is not considered in this article, because it does not depict really alternative curves.

Analysis of each biodiversity curve (ALROY *et al*. 2008; PURDY 2008) allows to outline radiations in the marine realm between the minima and maxima in the total number of genera. Presumably, the "Cambrian explosion" reflects the first Phanerozoic unprecedented level of biodiversity. The curves permit to find the forthcoming biodiversity increase, when this level was exceeded and, consequently, the new unprecedented level was established. This increase is the marine biodiversity addition. Projecting it on the geologic time line allows to evaluate its duration in the history of the Earth. Then, the procedure is repeated to look for the next biodiversity additions.

The present study is based on the modern relative and absolute time scales developed by the International Commission on Stratigraphy (GRADSTEIN *et al*. 2012; see on-line: www.stratigraphy.org). Differences between the time scales employed by ALROY *et al*. (2008) and PURDY (2008) and the modern chronostratigraphy should be considered. Some modern developments in the lower Paleozoic chrono- and biostratigraphy and absolute geochronology (OGG *et al*. 2008; COCKS *et al*. 2010; LOYDELL 2012; COMPSTON & GALLAGHER 2012) are also taken into account. Formal chronostratigraphical units are capitalized (e.g., Middle Ordovician, Late Cretaceous, etc.) in this article to be distinguished from those informal, which are not capitalized (e.g., early Paleozoic, late Oligocene, etc.).

Nomenclature of post-Cambrian marine biodiversity additions

A total of five post-Cambrian marine biodiversity additions can be established with each original curve (ALROY *et al*. 2008; PURDY 2008) to be labelled A1–5 and S1–5 respectively (Fig. 2, Tables 1, 2). The curve of PURDY (2008) permits to establish the only marine biodiversity addition in the Paleozoic and a series of such events in the late Mesozoic–Cenozoic (Fig. 2, Table 1). The curve of ALROY *et al*. (2008) implies "concentration" of marine biodiversity additions in the early Paleozoic and two "separate" events in the end-Paleozoic and the end-Mesozoic (Fig. 2, Table 2). The only A2 and S1 events coincided, whereas the other interpreted additions did not. The noted coinci-

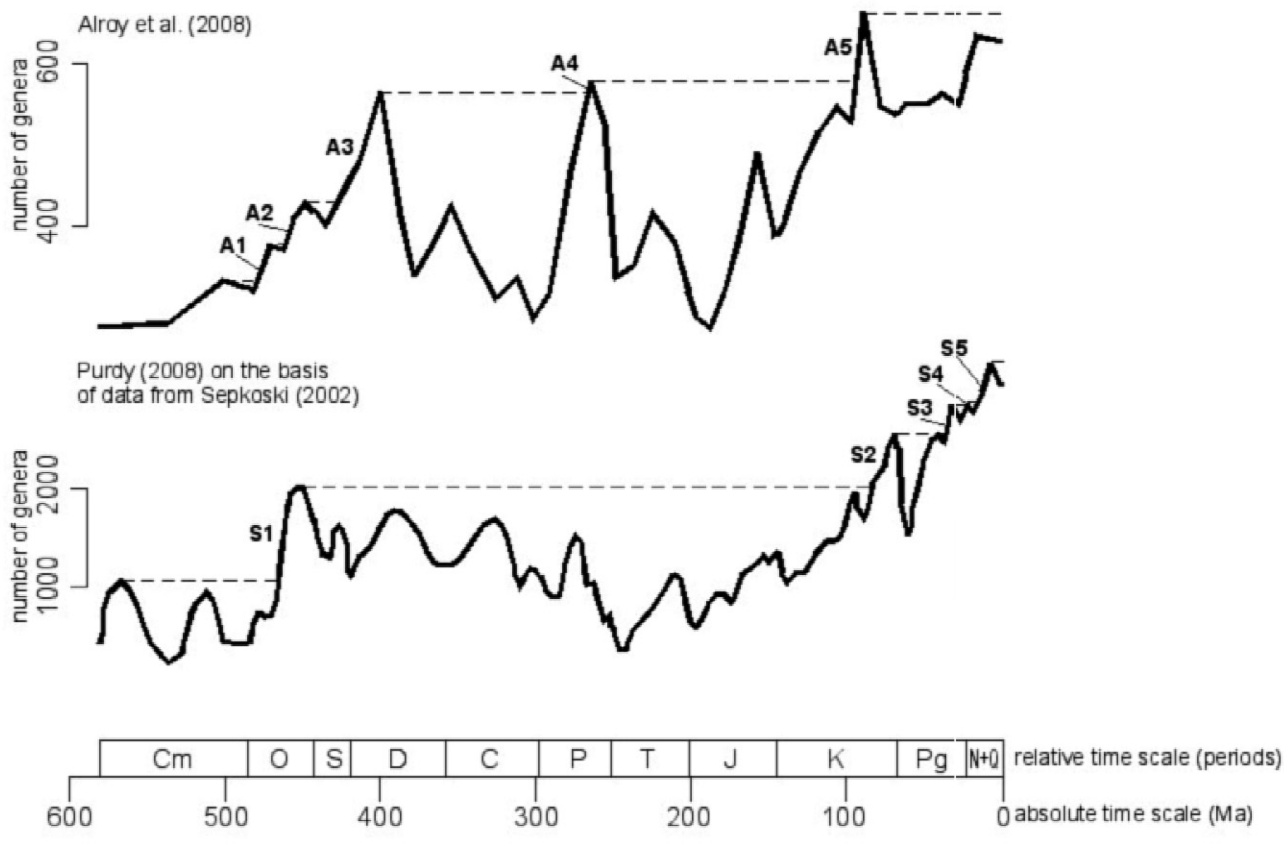

Fig. 2. Alternative curves of the marine biodiversity changes through the Phanerozoic and the relevant interpretations of the marine biodiversity additions. See Tables 1, 2 for more details. Chronostratigraphy follows the latest developments of the International Commission on Stratigraphy (see on-line: stratigraphy.org).

Table 1. Marine biodiversity additions established with the curve of PURDY (2008) on the basis of data from SEPKOSKI (2002).

Abbreviature (see Fig. 2)	Approximate timing	Approximate increase in the total number of taxa relatively to the previous unprecedented level	Correspondence to biotic radiation	Relevant interpretations*
S1	Dapingian–Katian (Middle–Late Ordovician)	+85–95 %	middle and last parts of the Ordovician radiation	major biotic radiation (DROSER *et al*. 1996; RUBAN 2010, 2013), regional biodiversity peak (KALJO *et al*. 2011)
S2	Campanian (late Late Cretaceous)	+20–30 %	second half of late Late Cretaceous radiation	threshold for biodiversity (ABERHAN & KIESSLING 2012)
S3	Priabonian (late Eocene)	+10–20 %	middle and last parts of the Priabonian radiation	
S4	Chattian (late Oligocene)	+1%	terminal part of the Chattian radiation	
S5	Burdigalian–Serravallian (mid-Miocene)	+10–20 %	second and last parts of the Early–Middle Miocene radiation	

* In all cases, there was only partial correspondence between the marine biodiversity additions and the earlier-interpreted events.

Table 2. Marine biodiversity additions established with the curve of ALROY *et al*. (2008).

Abbreviature (see Fig. 2)	Approximate timing	Approximate increase in the total number of taxa relatively to the previous unprecedented level	Correspondence to biotic radiation	Relevant interpretations*
A1	Early Ordovician	+5–15 %	first phase of the Ordivician radiation	major biotic radiation (DROSER *et al*. 1996; RUBAN 2010, 2013)
A2	Middle–Late Ordovician	+10–20 %	second phase of the Ordovidian radiation	major biotic radiation (DROSER *et al*. 1996; RUBAN 2010, 2013), regional biodiversity peak (KALJO *et al*. 2011)
A3	late Silurian (Ludlow?)–Early Devonian	+25–35 %	middle and last parts of the SilurianEarly Devonian radiation	major biotic radiation (RUBAN 2010), threshold or biodiversity (ABERHAN & KIESSLING 2012)
A4	late Early Permian and/or early Middle Permian	+1–5 %	end of Permian radiation	major biotic radiation (RUBAN 2010)
A5	early Late Cretaceous	+10–20 %	second half of early Late Cretaceous radiation	threshold for biodiversity (ABERHAN & KIESSLING 2012)

* In all cases, there was only partial correspondence between the marine biodiversity additions and the earlier-interpreted events.

dence is not surprising, because it corresponds to the Great Ordovician Biodiversification (DROSER & SHEEHAN 1995; DROSER *et al*. 1996; MILLER & FOOTE 1996; MILLER & CONNOLLY 2001; WEBBY 2001; HARPER 2006; SERVAIS *et al*. 2008, 2009, 2010; MASUDA & EZAKI 2009; RUBAN 2010, 2013). The absence of coincidence of the other established events (a challenge for the modern palaeobiologists) should be explained by the differences of the original curves of ALROY *et al*. (2008) and PURDY (2008) with regard to the data and the methods employed for their construction.

The both original curves (ALROY *et al*. 2008; PURDY 2008) permit to make some interesting observations. Firstly, the marine biodiversity additions can be subdivided into three categories, namely those that led to significant (up to 90%), moderate (10–30 %), and small (~1%) increases in the number of genera. The events of the second category prevailed (Tables 1, 2). However, the cumulative effect of the marine biodiversity additions was very significant. These rare events facilitated increase in the number of genera of marine organisms by several times after the Cambrian. Secondly, the marine biodiversity additions were relatively short-term events, except for the A3 and S1 events (Fig. 2). Thirdly (hypothetically), the marine biodiversity additions occurred in a splash-like mode, and some of them tended to "concentrate" at the 100 Ma-long intervals of the geologic time (Fig. 2). If so, the strength, brevity, and rarity, of the marine biodiversity additions echo the scenario of punctuated equilibrium proposed by ELDREDGE & GOULD (1972) and GOULD (2002, 2007), as well as some general ideas on critical transitions in evolution (SCHEFFER 2009). All above-said underlines the outstanding importance of marine biodiversity additions in the history of life on the Earth. The necessity of their separation from "usual" biotic radiations is also proven.

Yet another interesting observation is worth to made. One would expect that biodiversity additions were only culminations of "usual" biotic radiations, i.e., the former were the only terminal parts of the latter. However, the both biodiversity curves (ALROY *et al*. 2008; PURDY 2008) (Fig. 2) and the interpretations made in this article (Tables 1, 2) do not support this idea. In contrast, the majority of the marine biodiversity additions corresponded to significant parts of the relevant biotic radiations (the S4 and A4 events are exceptions). On the one hand, this observation provides an evidence against "occasional" nature of the marine biodiversity additions. On the other hand, the same observation allows to hypothesize that there was a specific category of biotic radiations that quickly "lifted" biodiversity to new unprecedented levels.

Possible triggers: a general framework for analysis

Various intrinsic (biological) and extrinsic (palaeoenvironmental) processes and events, as well as their combinations might have triggered marine biodiversity additions, similarly to how this occurred with "usual" biotic radiations (RUBAN 2010, 2013; ABERHAN & KIESSLING 2012; ABERHAN *et al*. 2012). However, it should be noted that the former were very peculiar events, because they changed the state of the planetary ecology (see above). Extraordinary forces were required. One should take into account several assumptions. The first assumption is the action of very specific factor(s) influencing the carrying capacity of the global ecosystem at the intervals of the marine biodiversity additions. E.g., the latter might have been triggered by the highest position of the global sea level, extraordinary global warming, etc., i.e., by processes/events that were extraordinary at the interval of the marine biodiversity addition. The second assumption is as follows. If all post-Cambrian marine biodiversity additions were triggered by the same force (or combination of several forces), this force strengthened at the time of the younger additions, because the latter needed more "support" to exceed the previous additions.

The third assumption is that a given marine biodiversity addition requires certain time. It is possible that one extraordinary intrinsic or extrinsic process or event did not necessarily lead to the biodiversity addition if there was not enough time for the relevant acceleration in the number of taxa. Sudden catastrophes (like mass extinctions) or gradual development of unfavourable conditions were able to interrupt a trend towards biodiversity acceleration. As a result, the similarly strong (but not stronger!) trigger repeated later could facilitate diversification above the unprecedented level. In the other words, the potential of each biotic radiation to culminate as a biodiversity addition can be realized either in full or partly. Most probably, more assumptions can be formulated in the same manner. Consideration of them reveals a diversity of models explaining marine biodiversity additions (Fig. 3). Development and further discussion of these models in the light of the available palaeontological and geological data will permit to judge about triggers of the marine biodiversity additions. The complexity of the "Cambrian explosion" (BRASIER 2009; ERWIN & VALENTINE 2013; SANTOSH *et al*. 2014) demonstrates how challenging is this task.

An agenda for further research

This brief article stresses the importance of splash-like marine biodiversity additions in the history of life in the Earth's seas. However, much work is yet to be done for correct and comprehensive understanding of these events. The urgent tasks for further studies are as follows. Firstly, the new, globally-representative biodiversity curve is required in order to bring the nomenclature of marine biodiversity additions in order. The absence of coherence of the "classical" (PURDY 2008) and "innovative" (ALROY *et al*. 2008) curves is a serious challenge. Achievement of the noted task will also permit to establish the exact duration of each marine biodiversity addition.

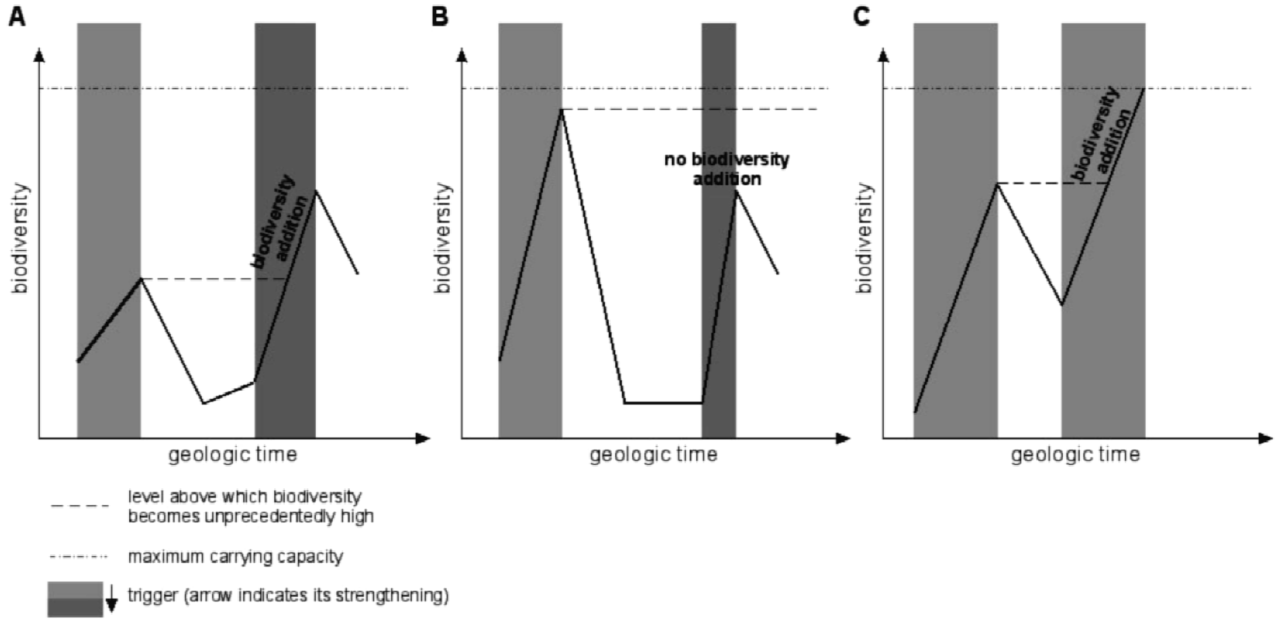

Fig. 3. Selected examples of possible relationships between biodiversity changes and potential single triggers of biodiversity additions. **A,** biodiversity addition as a result of the strengthened trigger. **B,** no biodiversity addition occurred despite the strengthened trigger, because the time, when the latter persisted, was not enough for recovery from the previous biodiversity loss. **C,** biodiversity addition did not require a stronger trigger, because the previous unprecedented level was below the maximum carrying capacity.

Secondly, it should be understood whether marine biodiversity additions involved all or some fossil groups and whether they occurred in all or some regions. A correspondence to coeval events in the evolution of terrestrial biota should be also discussed. Thirdly, a diverse set of models explaining marine biodiversity additions have to be developed and tested, and the assumptions presented above need to be verified. The works of ABERHAN & KIESSLING (2012), ABERHAN *et al*. (2012), and RUBAN (2013) are the first stepts in this direction. This third task can be achieved partially by special attention to biological and palaeoenvironmental peculiarities of time intervals of these events and their comparison.

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References

ABERHAN, M. & KIESSLING, W. 2012. Phanerozoic Marine Biodiversity; A Fresh Look at Data, Methods, Patterns and Processes. *In*: TALENT, J.A. (ed). *Earth and Life: Global Biodiversity, Extinction Intervals and Biogeographic Perturbations Through Time*, 3–22. Springer, Dordrecht.

ABERHAN, M., NURNBERG, S. & KIESSLING, W. 2012. Vision and the diversification of Phanerozoic marine invertebrates. *Paleobiology*, 38: 187–204.

ALROY, J. 2010. The Shifting Balance of Diversity Among Major Marine Animal Groups. *Science*, 329: 1191–1194.

ALROY, J., ABERHAN, M., BOTTJER, D.J., FOOTE, M., FÜRSICH, F.T., HARRIES, P.J., HENDY, A.J.W., HOLLAND, S.M., IVANY, L.C., KIESSLING, W., KOSNIK, M.A., MARSHALL, C.R., MCGOWAN, A.J., MILLER, A.I., OLSZEWSKI, T.D., PATZKOWSKY, M.E., PETERS, S.E., VILLER, L., WAGNER, P.J., BONUSO, N., BORKOW, P.S., BRENNEIS, B., CLAPHAM, M.E., FALL, L.M., FERGUSON, C.A., HANSON, V.L., KRUG, A.Z., LAYOU, K.M., LECKEY, E.H., NÜRNBERG, S., POWERS, C.M., SESSA, J.A., SIMPSON, C., TOMAŠOVÝCH, A. & VISAGGI, C.C. 2008. Phanerozoic Trends in the Global Diversity of Marine Invertebrates. *Science*, 321: 97–100.

BAMBACH, R.K. 2006. Phanerozoic biodiversity and mass extinctions. *Annual Review of Earth and Planetary Sciences*, 34: 127–155.

BAMBACH, R.K., KNOLL, A.H. & WANG, S.C. 2004. Origination, extinction, and mass depletions of marine diversity. *Paleobiology*, 30: 522–542.

BENTON, M.J. 1995. Diversification and extinction in the history of life. *Science*, 268: 52–58.

BENTON, M.J. 2001. Biodiversity on land and in the sea. *Geological Journal*, 36: 211–230.

BENTON, M.J. & EMERSON, B.C. 2007. How did life become so diverse? The dynamics of diversification according to the fossil record and molecular phylogenetics. *Palaeontology*, 50: 23–40.

Benton, M.J., Dunhill, A.M., Lloyd, G.T. & Marx, F.G. 2011. Assessing the quality of the fossil record: insights from vertebrates. *In*: McGowan, A.J. & Smith, A.B. (eds). *Comparing the Geological and Fossil Records: Implications for Biodiversity Studies. Geological Society, London, Special Publications* 358, 63–94.

Brasier, M. 2009. *Darwin's Lost World. The Hidden History of Animal Life*. Oxford University Press, Oxford, 304 pp.

Bush, A.M. & Bambach, R.K. 2011. Paleoecologic Megatrends in Marine Metazoa. *Annual Review of Earth and Planetary Sciences*, 39: 241–269.

Cocks, L.R.M., Fortey, R.A. & Rushton, A.W.A. 2010. Correlation for the Lower Palaeozoic. *Geological Magazine*, 147: 171–180.

Compston, W. & Gallagher, K. 2012. New SHRIMP zircon ages from tuffs within the British Palaeozoic stratotypes. *Gondwana Research*, 21: 719–727.

Connolly, S.R. & Miller, A.I. 2001. Global Ordovician faunal transitions in the marine benthos: proximate causes. *Paleobiology*, 27: 779–795.

Connolly, S.R. & Miller, A.I. 2002. Global Ordovician faunal transitions in the marine benthos: ultimate causes, *Paleobiology*, 28: 26–40.

Conway Morris, S. 2000. Nipping the Cambrian "explosion" in the bud? *BioEssays*, 22: 1053–1056.

Conway Morris, S. 2003. The Cambrian "explosion" of metazoans and molecular biology: would Darwin be satisfied? *International Journal of Development Biology*, 47: 505–515.

Droser, M.L. & Sheehan, P.M. 1995. Paleoecology of the Ordovician Radiation and the Late Ordovician extinction event. *In*: Cooper, J. (ed.), *Ordovician of the Great Basin: fieldtrip guidebook and volume for the Seventh International Symposium on the Ordovician System*, 64–106. Pacific Section, SEPM, Fullerton.

Droser, M.L., Fortey, R.A. & Li, X. 1996. The Ordovician Radiation. *American Scientist*, 84: 122–132.

Dzik, J. 2005. Behavioral and anatomical unity of the earliest burrowing animals and the cause of the "Cambrian explosion". *Paleobiology*, 31: 503–521.

Eldredge, N. & Gould, S.J. 1972. Punctuated equilibria: An alternative to phyletic gradualism. *In*: Schoft, T.J.M. (ed). *Models in Paleobiology*, 82–115. Freeman Cooper, San Francisco.

Emerson, M.J. & Emerson, B.C. 2007. How did life become so diverse? The dynamics of diversification according to the fossil record and molecular phylogenetics. Palaeontology, 50: 23–40.

Erwin, D.H. & Valentine, J.W. 2013. *The Cambrian Explosion: The Construction of Animal Biodiversity*. Roberts & Company, Greenwood Village, 406 pp.

Foote, M. 2003. Origination and Extinction through the Phanerozoic: A New Approach. *Journal of Geology*, 111: 125–148.

Foote, M. 2007. Extinction and quiescence in marine animal genera. *Paleobiology*, 33: 261–272.

Geyer, G. 1998. Die kambrische Explosion. *Paläontologische Zeitschrift*, 72: 7–30.

Gould, S.J. 2002. *The Structure of Evolutionary Theory*. Belknap Press, Cambridge, 1433 pp.

Gould, S.J. 2007. *Punctuated Equilibrium*. Belknap Press, Cambridge, 396 pp.

Gradstein, F.M., Ogg, J.G., Schmitz, M. & Ogg, G. (eds) 2012. *The Geologic Time Scale 2012*. Vols. 1–2. Elsevier, Oxford, 1176 pp.

Hannisdal, B. & Peters, S.E., 2011. Phanerozoic Earth System Evolution and Marine Biodiversity. *Science*, 334: 1121–1124.

Harper, D.A.T. 2006. The Ordovician biodiversification: Setting an agenda for marine life. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 232: 148–166.

Heim, N.A. & Peters, S.E. 2011. Covariation in macrostratigraphic and macroevolutionary patterns in the marine record of North America. *Geological Society of America Bulletin*, 123: 620–630.

Kaljo, D., Hints, L., Hints, O., Mannik, P., Martma, T. & Nolvak, J. 2011. Katian prelude to the Hirnantian (Late Ordovician) mass extinction: a Baltic perspective. *Geological Journal*, 46: 464–477.

Kiessling, W., Simpson, C. & Foote, M. 2010. Reefs as Cradles of Evolution and Sources of Biodiversity in the Phanerozoic. *Science*, 327: 196–198.

Kirschvink, J.L. & Raub, T.D., 2003. A methane fuse for the Cambrian explosion: carbon cycles and true polar wander. *Comptes Rendus Geosciences*, 335: 65–78.

Lieberman, B.S. 2008. The Cambrian radiation of bilaterians: Evolutionary origins and palaeontological emergence; earth history change and biotic factors. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 258: 180–188.

Lieberman, B.S. & Kaesler, R. 2010. *Prehistoric Life: Evolution and the Fossil Record*. Wiley-Blackwell, Chichester, 385 p.

Loydell, D.K. 2012. Graptolite biozone correlation charts. *Geological Magazine*, 149: 124–132.

Maletz, J., Steiner, M., Weber, B. & Zhu, M. 2014. The Cambrian bioradiation event: A Chinese perspective. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 398: 1–3.

Mannion, P.D., Upchurch, P., Benson, R.B.J. & Goswami, A. 2014. The latitudinal biodiversity gradient through deep time. *Trends in Ecology & Evolution*, 29: 42–50.

Marshall, C.R. 2010. Marine Biodiversity Dynamics over Deep Time. Science, 329: 1156–1157.

Maruyama, S. & Santosh, M. 2008. Models on Snowball Earth and Cambrian explosion: A synopsis. *Gondwana Research*, 14: 22–32.

Masuda, F. & Ezaki, Y. 2009. A Great Revolution of the Earth-Surface Environment: Linking the Bio-Invasion Onto the Land and the Ordovician Radiation of Marine Organisms. *Paleontological Research*, 13: 3–8.

Melott, A.L. & Bambach, R.K. 2011a. A ubiquitous ~62-Myr periodic fluctuation superimposed on general trends in fossil biodiversity. I. Documentation. *Paleobiology*, 37: 92–112.

MELOTT, A.L. & BAMBACH, R.K. 2011b. A ubiquitous ~62-Myr periodic fluctuation superimposed on general trends in fossil biodiversity. II. Evolutionary dynamics associated with periodic fluctuation in marine diversity. *Paleobiology*, 37: 383–408.

MILLER, A.I. & FOOTE, M. 1996. Calibrating the Ordovician Radiation of marine life: implications for Phanerozoic diversity trends. *Paleobiology*, 22: 304–309.

MILLER, A.I. & CONNOLLY, S.R. 2001. Substrate affinities of higher taxa and the Ordovician Radiation. *Paleobiology*, 27: 768–778.

MILLER, A.I., ABERHAN, M., BUICK, D.P., BULINSKI, K.V., FERGUSON, C.A., HENDY, A.J.W. & KIESSLING, W. 2009. Phanerozoic trends in the global geographic disparity of marine biotas. *Paleobiology*, 35: 612–630.

OGG, J.G., OGG, G. & GRADSTEIN, F.M. 2008. *The Concise Geologic Time Scale*. Cambridge University Press, Cambridge, 177 pp.

PETERS, S.E. & FOOTE, M. 2001. Biodiversity in the Phanerozoic: a reinterpretation. *Paleobiology*, 27: 583–601.

PETERS, S.E. & HEIM, N.A. 2011. Stratigraphic distribution of marine fossils in North America. *Geology*, 39: 259–262.

PLOTNICK, R.E., DORNBOS, S.Q. & CHEN, J. 2010. Information landscapes and sensory ecology of the Cambrian Radiation. *Paleobiology*, 36: 303–317.

PURDY, E.G. 2008. Comparison of taxonomic diversity, strontium isotope and sea-level patterns. *International Journal of Earth Sciences*, 97: 651–664.

RAUP, D.W. & SEPKOSKI, J.J., JR. 1982. Mass extinctions in the marine fossil record. *Science*, 215: 1501–1503.

RUBAN, D.A. 2010. Palaeoenvironmental setting (glaciations, sea level, and plate tectonics) of Palaeozoic major radiations in the marine realm. *Annales de Paléontologie*, 96: 143–158.

RUBAN, D.A. 2013. Was there more space in the late Early Devonian for marine biodiversity to peak than in the early Late Ordovician? A brief note. *Geološki anali Balkanskoga poluostrva*, 74: 1–8.

SANTOSH, M., MARUYAMA, S., SAWAKI, Y. & MEERT, J.G. 2014. The Cambrian Explosion: Plume-driven birth of the second ecosystem on Earth. *Gondwana Research*, 25: 945–965.

SCHEFFER, M. 2009. *Critical Transitions in Nature and Society*. Princeton University Press, Princeton, 384 pp.

SEPKOSKI, J.J. 1993. Ten years in the library: New data confirm paleontological patterns. *Paleobiology*, 19: 43–51.

SEPKOSKI, J.J., JR. 2002. A compendium of fossil marine animal genera. *Bulletins of American Paleontology*, 363: 1–560.

SEPKOSKI, J.J., JR. & SHEEHAN, P.M. 1983. Diversity, faunal change and community replacement during the Ordovician radiations. *In*: TEVESZ, M. J.S. & MCCALL, P.M. (eds). *Biotic interactions in Recent and fossil benthic communities*, 673–717. Plenum, New York.

SEPKOSKI, J.J., JR. & RAUP, D. 1986. Periodicity in mass extinction events. *In*: ELLIOTT, D.K. (ed). *Dynamics of Extinction*, 3–36. Wiley, New York.

SEPKOSKI, J.J., BAMBACH, R.K., RAUP, D.M. & VALENTINE, J.W. 1981. Phanerozoic marine diversity and fossil record. *Nature*, 293: 435–437.

SERVAIS, T., LEHNERT, O., LI, J., MULLINS, G.L., MUNNECKE, A., NUTZEL, A. & VECOLI, M. 2008. The Ordovician Biodiversification: revolution in the oceanic trophic chain. *Lethaia*, 41: 99–109.

SERVAIS, T., HARPER, D.A.T., MUNNECKE, A., OWEN, A.W. & SHEEHAN, P.M. 2009. Understanding the Great Ordovician Biodiversification Event (GOBE): Influences of paleogeography, paleoclimate, or paleoecology. *GSA Today*, 19: 4–10.

SERVAIS, T., OWEN, A.W., HARPER, D.A.T., KRÖGER, B. & MUNNECKE, A. 2010. The Great Ordovician Biodiversification Event (GOBE): The palaeoecological dimension. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 294: 99–119.

STANLEY, S.M. 2007. An Analysis of the History of Marine Animal Diversity. *Paleobiology*, 33 (supplement): 1–55.

VALENTINE, J.W., JABLONSKI, D., KRUG, A.Z. & BERKE, S.K. 2013. The sampling and estimation of marine paleodiversity patterns: implications of a Pliocene model. *Paleobiology*, 39: 1–20.

VANNIER, J. 2009. L'Explosion cambrienne ou l'émergence des écosystèmes modernes. *Comptes Rendus Palevol*, 8: 133–154.

WEBBY, B.D. 2001. IGCP Project 410: The Great Ordovician Biodiversification Event: Reports of the Riverside (California) clade group meeting, June 21-25, the Mongolian field meeting, August 21 - September 6, 2001, and activities planned in 2002. *The Australian Geologist*, 121: 23–24, 29.

Резиме

Пост-камбријумско бљесковито увећање морског биодиверзитета

Биодиверзитет морских средина током фенерозоика није био стабилан, а такође се није ни увећавао постепено, већ се одликовао значајним варирањем. Историју морских организама карактерише неколико великих радијација у које спадају и оне које су се дешавале у камбријуму и ордовицијуму. Међутим, многе од ових радијација представљале су само опоравак биодиверзитета који је уследио након катастрофичних догађаја. Због тога је веома важно обратити пажњу на оне временске интервале у којима је морски биодиверзитет достизао више нивое који се раније нису јављали. Оваква радијација (која често представља део веће радијације) могла би се назвати "додатним биодиверзитетом". Додатни морски биодиверзитет може да се установи на основу графичких анализа "простих" криви биодиверзитета које су одраз целокупног броја таксона и њихових промена кроз геолошко време. Сваки од пет посткамбријских додатних

морских биодиверзитета може се утврдити двема доступним кривима. Помоћу прве криве издвојен је једини додатни марински биодиверзитет у палеозоику, као и серије таквих догађаја током горњег мезозоика и кенозоика. Друга крива указује на "концентрацију" додатних морских биодиверзитета у раном палеозоику, као и на два "раздвојена" догађаја на крају палеозоика и на крају мезозоика. Овакво подударање није изненађујуће с обзиром да одговара великој ордовицијумској биодиверсификацији. Одсуство подударања других већ познатих догађаја може се објаснити разликама оригиналне криве у односу на податке и методе примењених у њиховој реконструкцији. Додатни морски биодиверзитет може бити подељен у три категорије, оне које воде до значајног (до 90%), умереног (10–30%), и слабог (~1%) повећања броја родова. Преовлађују догађаји секундарне категорије. Додатни марински биодиверзитет је релативно краткотрајни догађај са неколико изузетака. Могло би се очекивати да су додатни биодиверзитети само кулминација "обичне" биотске радијације, тј. да су оне само њихови завршни делови. Међутим, обе биодиверзитске криве и њихова интерпретација у овом раду не подржавају ову идеју. Насупрот томе, већина додатних морских биодиверзитета одговара значајним деловима одређених биотичких радијација. Различити унутрашњи (биолошки) и спољашњи (утицај палеосредине) процеси и догађаји, као и њихове комбинације могу да изазову додатни морски биодиверзитет, Ипак, требало би нагласити да су поменути догађаји били веома ретки, јер су утицали на промену еколошких услова на читавој планети. Неопходно је установити и пробати различите моделе који би објаснили појаву додатног морског биодиверзитета, а такође је потребно и проверити претпоставку која је овде изнета.

Б. Р.

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The role of conodonts in the global stratigraphic correlation on example of southern Siberia (Russia) and eastern Serbia

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Abstract. Conodonts are very precise tools for global stratigraphic correlation of Devonian deposits. They can be correlated at the level of standard conodont zones even for basins having very different geological structure. In this paper Devonian conodont correlations between north-western margin of the Kuznetsk Basin (Siberia) and eastern Serbia are demonstrated. The geology of both regions is quite different. East Serbian zone is the southern tip of the Carpathian folded area (Carpatho-Balkanides). Middle Paleozoic carbonate and terrigenous deposits (Silurian, Devonian and Lower Carboniferous) are replaced by Hercynian molasse, and sedimentation continued throughout the Mesozoic and Cenozoic Eras. Rocks were exposed to repeatedly tectonic effects, olistoliths, olistostromes are widespread. Middle Paleozoic sediments, including Devonian, are localized within separate small tectonic blocks, often shifted from its place and form allochthons. In the western part of the Altai-Sayan folded area the Middle Paleozoic sediments have undergone folding and orogeny during the Hercynian phase of tectonic and magmatic activity, but since that time the continental conditions have been dominant in this region. The Devonian deposits are well represented in the marginal parts of the Kuznetsk Basin. In both regions the Devonian rocks have been well studied and the standard conodont zones varcus, gigas (rhenana) – linguiformis, crepida, expansa and praesulcata were established.

Key words: conodonts, correlation, Devonian, Serbia, Siberia.

Апстракт: Конодонти су веома значајни за глобалну стратиграфску корелацију девонских седимената. Они могу послужити за корелацију стандардних конодонтских зона чак и за басене са различитом геолошком структуром. У овом раду приказана је корелација девонских конодоната северозападног обода Кузњетског басена (Сибир) и источне Србије. Геологија ових региона је сасвим различита. Источна Србија представља јужни крај Карпатске наборне области (Карпато-Балканиди). Средњопалеозојски карбонати и теригени седименти (силур, девон и доњи карбона) су замењени херцинским моласама, чија се седиментација наставља кроз мезозоик и кенозоик. Стене су биле изложени вишеструким тектонским утицајима. Олистолити и олистростроме су честе. Средњопалеозојски седименти, укључујући и девонске, налазе се унутар издвојених мањих тектонских блокова и често су премештени са свог места формирајући алохтоне. У западним деловима Алтаи – Саиан наборне области средњоплаеозојски седименти су били подвргнути набирању и орогену током тектонске и магматске активности херцинске фазе После тог времена у овом региону су преовладали континентални услови. Девонски седименти су добро развијени у маргиналним деловима Кузњетског басена. У оба региона девонски седимент су добро проучени и установљене су стандардне конодонтске зоне: varcus, gigas (rhenana) – linguiformis, crepida, expansa и praesulcata.

Кључне речи: конодонти, корелација, девон, Србија, Сибир.

Introduction

The significance of conodonts as a supervising faunistic group for Paleozoic stratigraphy is very high. They were abundant in the Middle Paleozoic seas, particularly in the Devonian ones. The Standard Conodont Zones Scale based on the evolutionary development of deep-sea conodonts. This scale is a recognized world standard of all Devonian boundaries. It was constantly being improved and updated (Fig. 1). Unfortunately, in its latest edition some regular zones names were changed and zones have been divided into several new ones (Becker *et al.* 2012). These innovations do not cause approval from the specialists for other faunal groups. Standard conodont scale cannot be fully used in sections of shallow-water deposits. But conodonts still

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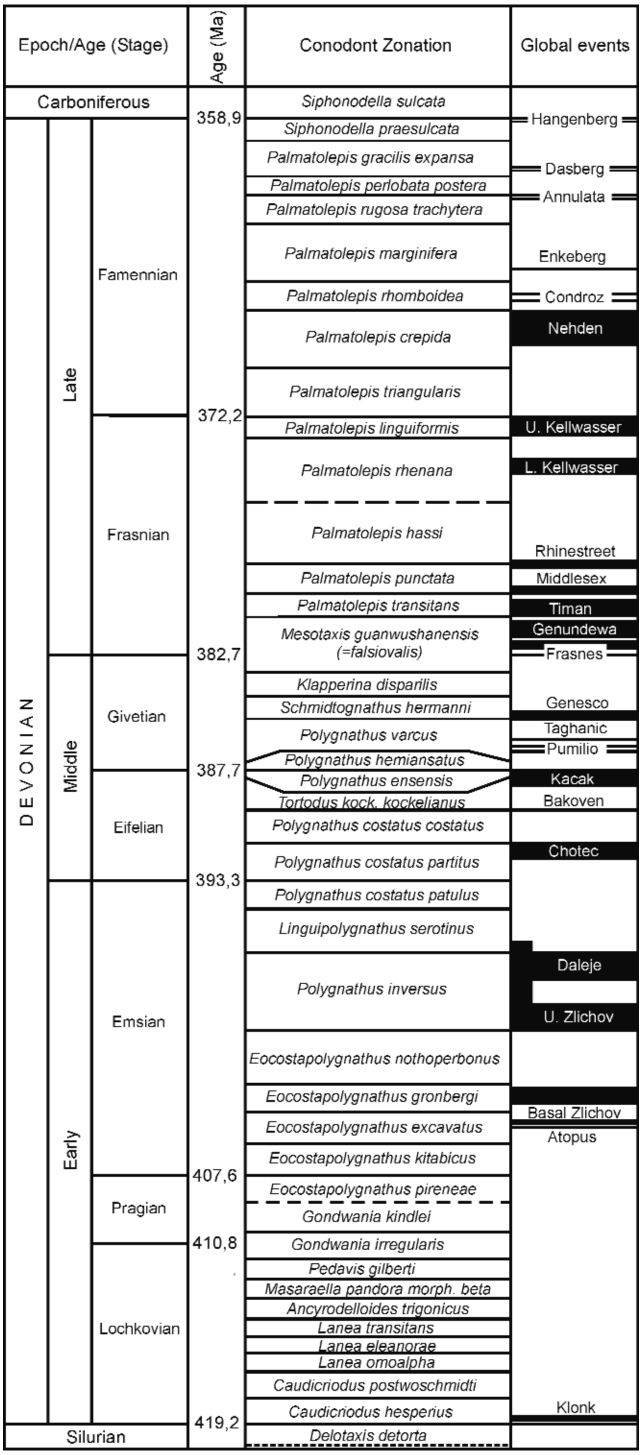

Fig. 1. The Standard Conodont Zonation in the Devonian (BECKER *et al.*, 2012, abridged).

remain the major biostratigraphical correlation tools. By studying the distribution of conodonts in certain sections, every specialist tries always to tie their subdivisions to zones of the standard conodont scale and to implement the inter-regional and global correlation of strata. The Devonian subdivisions of southern Siberia and eastern Serbia can serve as an example of such correlation (RODYGIN 2014).

Methods

Ten years ago during geological excursions in eastern Serbia the author could see that the geology of this area is very differing from the geology of southern Siberia. East Serbian zone is the southern tip of the Carpathian folded area (Carpatho-Balkanides). Middle Paleozoic carbonate and terrigenous deposits (Silurian, Devonian and Lower Carboniferous) are replaced here by Hercynian molasse, and sedimentation continued throughout the Mesozoic and Cenozoic Eras (ĆIRIĆ 1996). Rocks were exposed to repeatedly tectonic effects, particularly strong in Alpine phase of tectonic and magmatic reactivation. Overthrusts, olistoliths, olistostromes are widespread there; Middle Paleozoic sediments, including Devonian are localized within separate small tectonic blocks, often shifted from its place and formed allochthons. Tectonic blocks are interpreted as terranes, significantly changed its initial spatial position (KRSTIĆ *et al.* 2004).

In the western part of the Altai-Sayan folded area the Middle Paleozoic sediments have undergone folding and orogeny during the Hercynian phase of tectonic and magmatic activity, but since that time the continental conditions have been dominant in this region. The Kuznetsk coal basin (Kuzbass) began to form. The Kuznetsk Basin is an intermountain depression filled in its middle part by coal-bearing Carboniferous and Permian sediments. The Devonian deposits are well represented in the marginal parts of the Kuzbass. They are confined to the Givetian Stage of the Middle Devonian, to Frasnian and Famennian of the Upper Devonian. The studied sections are located in the vicinity of the town of Anzhero-Sudzhensk, in the Yaya, Barzas rivers basins, in the Tom' basin downstream of the city of Kemerovo (the northern district of the Kemerovo Region) and in the vicinity of village Vassino of the Novosibirsk Region (Type sections, 1992; RODYGIN 2011, 2014). The sections are composed of terrigenous and carbonaceous, mainly shallow deposits bearing rich associations of benthic fauna with brachiopods, rugoses, tabulates and stromatoporoids predominantly. Crinoids, ostracodes, tentaculites, bivalves are encountered; less common are gastropods, cephalopods, trilobites and fish integument fragments. Along with the fauna, stromatolites, algae, vegetable debris and spores were found from certain of the sections.

For many years these sections were tested for conodonts being of great stratigraphic importance. Representative conodont assemblages were established, which enabled the stratigraphical position of horizons to be defined more precisely and the correlation between the sections and the Standard Conodont Scale to be made. L.M. Aksenova and V.G. Halymbadzha took part in studying conodonts jointly with the present author (AKSENOVA *et al.* 1994; Type sections.., 1992; RODYGIN 2011, 2014).

Results

Lower Devonian and Eifelian deposits are absent in this region. The Givetian deposits compose the Mazalovsko-Kitatskyi Horizon subdivided into the Mazalovsko-Kitatskaya, Siberian-Lebedyanskaya and formations. The Mazalovsko-Kitatskaya Formation encloses the conodonts: *Polygnathus timorensis* Klapper, Philip *et* Jackson, *Icriodus obliquimarginatus* Bischoff *et* Ziegler, *I. brevis* Stauffer and others indicating its belonging to the Lower varcus conodont zone. The Siberian-Lebedyanskaya Formation containing the Conodont species *Polygnathus ansatus* Ziegler *et* Klapper, *P. timorensis* Klapper, Philip *et* Jackson, *P. ovatinodosus* Ziegler *et* Klapper, *P. varcus* Stauffer, *Icriodus brevis* Stauffer, *Ozarkodina semialternans* (Wirth), among others, is assigned to the Middle and Upper varcus zones and, probably, to the hermanni-cristatus zone. The Izylinskaya Formation, containing *Polygnathus* cf. *webbi* Stauffer, *P.* cf. *decorosus* Stauffer, *P. dubius* Hinde, *Icriodus brevis* Stauffer, *I. difficilis* Ziegler *et* Klapper, *I.* cf. *difficilis* Ziegler *et* Klapper, *I.* aff. *expansus* Branson *et* Mehl, *I. expansus* Branson *et* Mehl and other conodont species, is correlatable to the Early falsiovalis (norrisi) zone (Rodygin 2011, 2014).

The Frasnian Stage of the Kuzbass is subdivided into the Vassinskyi, Glubokinskyi and Solominskyi horizons. The Vassinskyi Horizon contains the conodont assemblage including the following species: *Polygnathus webbi* Stauffer, *P. alatus* Huddle, *P. decorosus* Stauffer, *P. aequalis* Klapper *et* Lane, *P.* aff. *angustidiscus* Youngquist, *Ancyrodella lobata* Branson *et* Mehl, *Icriodus expansus* Branson *et* Mehl, *I. brevis angustulus* Seddon, *I. subterminus* Youngquist, and others. This horizon can be confined to the interval of the falsiovalis – hassi – jamieae zones. In the limestones of the Glubokinskyi horizon (Izvestkoviy Zavod section) follows conodonts were found: *Polygnathus* ex gr. *brevilaminus* Branson *et* Mehl, *P. alatus* Huddle, *P. foliatus* Bryant, *Ancyrodella nodosa* Ulrich *et* Bassler, *Icriodus symmetricus* Branson *et* Mehl, *I. brevis angustulus* Seddon, allowing to position the horizon to the interval of the hassi – jamieae zones. The Solominskyi Horizon contains the conodont assemblage composed of *Polygnathus decorosus* Stauffer, *P. evidens* Klapper *et* Lane, *P.* cf. *normalis* Miller *et* Youngquist, *P. webbi* Stauffer, *Ozarkodina gradata* Youngquist and others is confined to the interval of the rhenana – linguiformis conodont zones (Rodygin 2011, 2014).

In the Famennian Stage (northern margin of the Kuzbass) the Kosoutesovskyi, Mitikhinskyi, Podoninskyi and Topkinskyi horizons are established. The conodont assemblage distinguished in the Kosoutesovskyi Horizon includes *Palmatolepis triangularis* Sannemann, *Pa. minuta minuta* Branson *et* Mehl, *Pa. subperlobata* Branson *et* Mehl, *Pa. delicatula delicatula* Miller *et* Youngquist, *Pa.* aff. *quadrantinodosalobata* Sannemann, *Polygnathus brevilaminus* Branson *et* Mehl, *P. politus* Ovnatanova, *P.* aff. *xylus* Stauffer, *Icriodus iowaensis ancylus* Youngquist *et* Peterson, *I.* cf. *subterminus* Youngquist, *I. alternatus* Branson *et* Mehl, *I. cornutus* Sannemann, etc. This assemblage is indicative of the possibility to confine this horizon to the interval of the conodont triangularis – trachytera zones. There is very small conodont assemblage in the Mitikhinskyi Horizon deposits. Only quite recently some conodonts were collected from the Mitikhinskyi Horizon stratotype and Glubokaya River section, but their study yet will be implemented. The Podoninskyi Horizon contains the conodont complex (J.M. Gutak's sampling) composed of *Polygnathus delicatulus* Ulrich *et* Bassler, *P. inornatus* E.R. Branson, *Siphonodella praesulcata* Sandberg, and some others, which is characteristic for the praesulcata zones of the uppermost Famennian. In the limestones of the Topkinskyi Horizon the following conodonts are distinguished (Plate 1): *Polygnathus* aff. *parapetus* Druce, *Neopolygnathus lectus* Kononova, *Polygnathus inornatus* E.R. Branson, *Icriodus costatus costatus* (Thomas), *Icriodus costatus darbyensis* Klapper Morphotype 2, *Pseudopolygnathus primus* Branson *et* Mehl; *Mehlina strigosa* (Branson *et* Mehl). They are widely occurring in the expansa and praesulcata zones of the uppermost Devonian (Gutak *et al*. 2004; 2007; Gutak & Rodygin 2011; Rodygin 2011, 2014).

Consequently, the deposits of the northern margin of the Kuznetsk Basin represent the section that is almost continuously characterized by conodonts and confidently comparable with the Standard Conodont Zones Scale.

Discussion

B. Krstić and M. Sudar during 1989–1994 made efforts on the conodonts study of the Devonian in Eastern Serbia. These researchers had complexes similar to those that we have been identified in Kuzbass. This is particularly important, given that both regions have quite different geological history (Krstić & Sudar 1989, 1990a, b, 1991, 1992, 1993, 1994).

For example, the conodont complex found in the location of Donja Nevlja: *Polygnathus linguiformis linguiformis* gamma Morphotype Bultynck, *P. pseudofoliatus* Wittekindt, *P. varcus* Stauffer, *P. xylus xylus* Stauffer is typical for Givetian Lower varcus zone (Krstić & Sudar, 1990b), connecting these beds with the Mazalovsko-Kitatskaya formation developed on the river Mazalovskyi Kitat near the town of Anzhero-Sudzhensk (Rodygin, 2014).

In the south-eastern Serbia, near the spa Zvonačka Banja in a small interlayer of dolomitic limestone among clastic rocks, quite a rich conodont complex was found: *Palmatolepis gigas* Miller *et* Young-

QUIST, *Pa. semichatovae* OVNATANOVA, *Pa. subrecta* MILLER *et* YOUNGQUIST, *Pa. linguiformis* MÜLLER, *Ancyrodella lobata* BRANSON *et* MEHL, *Anc. curvata* (BRANSON *et* MEHL), *Anc. nodosa* ULRICH *et* BASSLER, *Polygnathus decorosus* STAUFFER, *P. webbi* STAUFFER, *Icriodus alternatus* BRANSON *et* MEHL. These conodonts occur together at the top of the Frasnian, gigas (rhenana) – linguiformis zone (KRSTIĆ & SUDAR, 1989). In Devonian of the Kuznetsk Basin margins similar complex conodonts was established on the top of Vassinskyi and Solominskyi horizons.

In the Rtanj Mts., southern Srpska Kosa, such conodonts are present: *Icriodus alternatus alternatus* BRANSON *et* MEHL, *I. alternatus helmsi* SANDBERG *et* DREESEN, *Palmatolepis crepida* SANNEMANN, *Pa. minuta loba* HELMS, *Pa. quadrantinodosalobata* SANNEMANN, *Pa. subperlobata subperlobata* BRANSON *et* MEHL, *Polygnathus brevilaminus* BRANSON *et* MEHL etc. They are of the crepida zone characteristic (KRSTIĆ & SUDAR, 1990b). Towards the bottom of the same zone treat conodonts from the vicinity of the village Miljkovac: *Icriodus alternatus alternatus* BRANSON *et* MEHL, *Palmatolepis triangularis* SANNEMANN, *Pa. quadrantinodosaloba-ta* SANNEMANN (KRSTIĆ & SUDAR, 1993). These conodonts bring enclosing beds together with Kosoutesovskyi horizon on the Kuzbass margins (Tom' River).

Variety of conodonts were extracted from olistoliths of Kučaj-Zvonce flysch near Gornja Studena on Suva Planina (KRSTIĆ & SUDAR, 1991). Among them there are Famennian conodonts: *Polygnathus inornatus* E.R. BRANSON, *P. communis communis* BRANSON *et* MEHL, *Mehlina strigosa* (BRANSON *et* MEHL) etc., which resemble conodont complexes of expansa and praesulcata zones of Podoninskyi and Topkinskyi horizons in Kuzbass (RODYGIN, 2014).

Conclusions

Eastern Serbia and Kuznetsk Basin with their margins both have different geological structure and history. Devonian terrigenous-carbonate deposits on Kuzbass margins were mainly deposited in shallow marine conditions, with often reef constructions, brachiopod banks and rich benthic fauna. Along Devonian sections near the town of Anzhero-Sudzhensk, rivers Yaya and Tom, representative conodont complexes were collected and standard conodont zones of Middle and Upper Devonian and regional stratigraphic horizons were established. But in the north-western margins of Kuzbass a complete stratigraphic Devonian succession was not preserved. In the absence of zonal conodont species, the age was sometimes determined on benthic fauna (RODYGIN 2011, 2014). In the Eastern Serbia the Devonian sediments are preserved in separate tectonic blocks. There are both autochthonous and allochthonous blocks. From rare limestone beds the representative collection of conodonts containing many zonal species was obtained (KRSTIĆ & SUDAR, 1995; RODYGIN, 2014). Standard conodont zones were established for the Devonian beds of Eastern Serbia. Conodonts have high correlation potential, whereby the opportunity to compare the Devonian of Eastern Serbia with many regions around the world, in particular, with the margins of the Kuznetsk Basin in southern Siberia, where similar conodont complexes were also found and the standard conodont zones were established.

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References

AKSENOVA, L.M., RODYGIN, S.A. & HALYMBADZHA, V.G. 1994. Conodonts of the Middle-Upper Devonian boundary deposits on the northern margin of the Kuzbass. *Geological Matters of Siberia*, 2: 320–337. (in Russian).

BECKER, R.T., GRADSTEIN, F.M. & HAMMER, O. 2012. The Devonian Period. *In*: GRADSTEIN, F.M., OGG, J.G., SCHMITZ, M.D. & OGG, G.M. (Eds.), *The Geologic Time Scale*. 559–601.

ĆIRIĆ, B. 1996. Geology of Serbia. Geokarta, Belgrade, 273 p. (in Serbian).

GUTAK, YA. M. & RODYGIN, S.A. 2004. Conodonts, Brachiopods and the Stratigraphy of the Middle-Upper Devonian Boundary Deposits of the Altay-Sayan Folded Area (Russia). *Bulletin de l'Academie Serbe des sciences et des arts*, *Classe des sciences mathematiques et naturelles*, T. CXXVIII, Sciences naturelles, 42: 131–138.

GUTAK, YA.M., RODYGIN, S.A. & TOLOKONNIKOVA, Z.A. 2007. The Carboniferous Lower Boundary in the western part of the Altay-Sayan Folded Area. Upper Palaeozoic in Russia: Stratigraphy and Palaeogeography. Kazan' Univ. Press., 94–97. (in Russian).

GUTAK, YA.M. & RODYGIN, S.A. 2011. Late Famennian shallow conodonts of the Kuznetsky Basin. *Proceeding of the Sixth International Conference "Environmental Micropaleontology, Microbiology and Meiobenthology",* Russia, Moscow, September 19-22., Moscow: PIN RAS, 116–117.

KRSTIĆ, B. & SUDAR, M. 1989. Paleozojski konodonti istočne Srbije, Jugoslavija, I. Konodonti franskog kata iz okoline Zvonačke banje. *Geološki anali Balkanskoga poluostrva*, 53: 305–318. (in Serbian).

KRSTIĆ, B. & SUDAR, M. 1990a. Paleozojski konodonti istočne Srbije, Jugoslavija, II. Konodonti gornjeg silura – ladlovskog kata Kucajskih planina (Paleozoic conodonts of Eastern Serbia, Yugoslavia, II. Conodonts of the Upper Silurian, Ludlovian of Kucaj Mts.). *Geološki anali Balkanskoga poluostrva* 54: 237–258.

KRSTIĆ, B. & SUDAR, M. 1990b. Paleozojski konodonti istocne Srbije, Jugoslavija, III. *Radovi Geoinstituta*, 24: 193–211. (in Serbian).

KRSTIĆ, B. & SUDAR, M. 1991. Paleozojski konodonti istocne Srbije, Jugoslavija, IV. Gornjodevonski (famenski) i donjokarbonski (turneski) konodonti iz olistostroma Suve planine (Paleozoic conodonts of Eastern Serbia, Yugoslavia, IV. Upper Devonian (Famennian) and Lower Carboniferous (Tournaisian) Conodonts from Olistostromes of Suva Planina). *Geološki anali Balkanskoga poluostrva*, 55/1: 131–162.

KRSTIĆ, B. & SUDAR, M. 1992. Paleozojski konodonti istocne Srbije, Jugoslavija, V. (Paleozoic conodonts of Eastern Serbia, Yugoslavia, V). – Ibid., 56/1, Beograd, 185-210.

KRSTIĆ, B. & SUDAR, M. 1993. Paleozojski konodonti istocne Srbije, Jugoslavija, VI. (Paleozoic conodonts of Eastern Serbia, Yugoslavia, VI). *Geološki anali Balkanskoga poluostrva*, 57/1: 139–158.

KRSTIĆ, B. & SUDAR, M. 1994. Paleozojski konodonti istocne Srbije, Jugoslavija, VII. (Paleozoic conodonts of Eastern Serbia, Yugoslavia, VII). *Geološki anali Balkanskoga poluostrva*, 58/1: 139–148.

KRSTIĆ, B., MASLAREVIĆ, LJ., ERCEGOVAC, M., SUDAR, M. & DJAJIĆ, S. 2004. Devonian in the Carpatho-Balkanides of Eastern Serbia. *Bulletin de l'Academie Serbe des sciences et des arts, Classe des sciences mathematiques et naturelles*, T. CXXVIII, Sciences naturelles, 42: 7–16.

RODYGIN, S.A. 2011. Conodonts in Middle and Upper Devonian sections from the Kuznetsk Basin margins. Biostratigraphy, paleogeography and events in Devonian and Lower Carboniferous (SDS – IGCP 596 joint field meeting): Contributions of International Conference in memory of Evgeny A. Yolkin. Ufa, Novosibirsk, July 20 – August 10, 2011., Novosibirsk: Publishing House of SB RAS., 139–140.

RODYGIN, S.A. 2014. Conodonts as an instrument of global correlation by the example of southern Siberia (Russia) and eastern Serbia. Optimal research and sustainable usage of the geological resources: Proceedings of the XVI Serbian Geological Congress (Donji Milanovac, 22-25.05.2014). – Belgrade: Serbian Geological Society. 135–139.

Type sections of the boundary Middle and Upper Devonian beds, Frasnian and Famennian Stages of the Kuznetsk Basin's margins. 1992. Edited by V.I. KRASNOV & M.A. RZHONSNITSKAYA. – Novosibirsk: SNIIGGiMS. – 136 p. (In Russian)

Резиме

Улога конодоната у глобалној стратиграфској корелацији на примеру јужног Сибира (Русија) и источне Србије

Стандардне конодонтске зоне засноване су на еволуционом развоју дубоководних конодоната. Ове зоне представљају стандард за све девонске границе. Према новијим подацима неке већ познате зоне су подељене у неколико нових зона. Сваки специјалиста који проучава конодонте покушава да их употреби за међурегионалну и глобалну корелацију слојева. Девонска подела јужног Сибира и источне Србије може да буде пример такве корелације.

Аутор је пре десет година, током геолошке екскурзије у источној Србији приметио да је геологија ових простора веома различита од геологије јужног Сибира. Источна Србија представља јужни крај Карпатске наборне области (Карпато-Балканиди). Средње палеозојске карбонатне и теригене стене биле су изложене учесталим тектонским покретима. Навлаке, олистолити и олистостроме су широко распрострањени. Средњопалеозојски седименти, укључујући и девонске, налазе се унутар издвојених мањих тектонских блокова.

За време тектонске и магматске активности херцинске фазе у западном делу Алтаи – Саиан наборне области средњопалеозојски седимети су подвргнути набирањима и орогену, али након тога у овој области доминирају континентални услови. Кузњетски басен је међупланинска депресија која је у средишњим деловима запуњена угљоносним карбонским и пермским седиментима. Девонски седименти су добро развијени у ободним деловима Кузбаса. Изданци су изграђени од теригених и карбонатних стена, углавном плитководних, са богатом асоцијацијом бентонске фауне у којој преовлађују брахиоподи, корали (Rugosa и Tabulata) и строматопориди.

Живетски седименти који изграђују Мазаловско-Китатски хоризонт су подељени у следеће формације: Мазаловско-Китатска, Сибирско-Лебедианска и Изилинска. Мазаловско-Китатска формација садржи конодонте: *Polygnathus timorensis* KLAPPER, PHILIP *et* JACKSON, *Icriodus obliquimarginatus* BISCHOFF *et* ZIEGLER, *I. brevis* STAUFFER и др. (доња varcus конодонтна зона). У Сибирско-Лебедианска формацији од конодоната се јављају: *Polygnathus ansatus* ZIEGLER *et* KLAPPER, *P. timorensis* KLAPPER, PHILIP *et* JACKSON, *P. ovatinodosus* ZIEGLER *et* KLAPPER, *P. varcus* STAUFFER, *Icriodus brevis* STAUFFER (средњи и горњи део varcus зона). Изилинска формација садржи: *Polygnathus* cf. *webbi* STAUFFER, *P. dubius* HINDE, *Icriodus brevis* STAUFFER, *I. difficilis* ZIEGLER *et* KLAPPER, *I. expansus* BRANSON et MEHL etc. (доњи део falsiovalis (norrisi) зоне).

Фразниан Кузбаса је подељен на Васински, Глубокински и Соломински хоризонт. Васински хоризонт садржи конодонтску заједницу: *Polygnathus webbi* STAUFFER, *P. alatus* HUDDLE, *P. decorosus* STAUFFER, *P. aequalis* KLAPPER *et* LANE, *Ancyrodella lobata* BRANSON *et* MEHL, *Icriodus expansus* BRANSON *et* MEHL, *I. brevis angustulus* SEDDON, *I. subterminus* YOUNGQUIST и др. (falsiovalis – hassi – jamieae зоне). Глубокински хоризонт садржи следеће конодонте: *Polygnathus* ex gr. *brevilaminus* BRANSON *et* MEHL, *P. alatus* HUDDLE, *P. foliatus* BRYANT, *Ancyrodella nodosa* ULRICH *et* BASSLER, *Icriodus symmetricus* BRANSON *et* MEHL, *I. brevis angustulus* SEDDON (hassi – jamieae зоне). Соломински хоризонт садржи: *Polygnathus decorosus* STAUFFER, *P. evidens* KLAPPER *et* LANE, *P. webbi* STAUFFER, *Ozarkodina gradata* YOUNGQUIST и др. (rhenana – linguiformis конодонтске зоне).

У фамениану су успостављени Косоутесовски, Митихински, Подонински и Топкински хоризонти. Конодонтску заједницу Косоутесовског хоризонта чине: *Palmatolepis triangularis* SANNEMANN, *Pa. minuta minuta* BRANSON *et* MEHL, *Pa. subperlobata* BRANSON *et* MEHL, *Pa. delicatula delicatula* MILLER *et* YOUNGQUIST, *Pa.* aff. *quadrantinodosalobata* SANNEMANN, *Polygnathus brevilaminus* BRANSON *et* MEHL, *P. politus* OVNATANOVA, *Icriodus iowaensis ancylus* YOUNGQUIST *et* PETERSON, *I. alternatus* BRANSON *et* MEHL, *I. cornutus* SANNEMANN и др. (triangularis – trachytera зоне). Подонински хоризонт садржи: *Polygnathus delicatulus* ULRICH *et* BASSLER, *P. inornatus* E.R. BRANSON, *Siphonodella praesulcata* SANDBERG и др. (praesulcata зона највишег фаменианa). У Топкинском хоризонту срећу се: *Polygnathus* aff. *parapetus* DRUCE, *Neopolygnathus lectus* KONONOVA, *Polygnathus inornatus* E.R. BRANSON, *Icriodus costatus costatus* (THOMAS), *Icriodus costatus darbyensis* KLAPPER Morph. 2, *Pseudopolygnathus primus* BRANSON *et* MEHL; *Mehlina strigosa* (BRANSON *et* MEHL). Ове врсте су широко распрострањени у ehpansa и praesulcata зонама највишег девона.

Б. КРСТИЋ & М. СУДАР (1989–1994) су детаљно проучавали девонске конодонте источне Србије. Поменути истраживачи су издвојили јединице сличне онима које су утврђене у Кузбасу.

На пример, конодонтска асоцијација нађена у локалитету Доња Невља садржи: *Polygnathus linguiformis linguiformis* gamma морph. BULTYNCK, *P. pseudofoliatus* WITTEKINDT, *P. varcus* STAUFFER, *P. xylus xylus* STAUFFER (доња varcus зоне), повезује ове слојеве са Мазаловско-Китатском формацијом.

У југоисточној Србији, у близини Звоначке Бање, у танким прослојцима доломитичних кречњака између кластичних стена нађена је богата конодонтска асоцијацијација: *Palmatolepis gigas* MILLER *et* YOUNGQUIST, *Pa. semichatovae* OVNATANOVA, *Pa. subrecta* MILLER *et* YOUNGQUIST, *Pa. linguiformis* MÜLLER, *Ancyrodella lobata* BRANSON *et* MEHL, *Anc. curvata* (BRANSON *et* MEHL), *Anc. nodosa* ULRICH *et* BASSLER, *Polygnathus decorosus* STAUFFER, *P. webbi* STAUFFER, *Icriodus alternatus* BRANSON *et* MEHL (gigas (rhenana) – linguiformis зоне). Слична девонска асоцијација такође је нађена у ободу Кузњетског басена, при врху Васинског и Соломинског хоризонта.

На Ртњу, јужна Српска Коса, слична конодонтска асоцијација је представљена са: *Icriodus alternatus alternatus* BRANSON *et* MEHL, *I. alternatus helmsi* SANDBERG *et* DREESEN, *Palmatolepis crepida* SANNEMANN, *Pa. minuta loba* HELMS, *Pa. quadrantinodosalobata* SANNEMANN, *Pa. subperlobata subperlobata* BRANSON *et* MEHL, *Polygnathus brevilaminus* BRANSON *et* MEHL и др. Они имају карактеристике crepida зоне. Према бази исте зоне, у близини села Миљковац, одређени су: *Icriodus alternatus alternatus* BRANSON *et* MEHL, *Palmatolepis triangularis* SANNEMANN, *Pa. quadrantinodosalobata* SANNEMANN. Ови конодонти су такође нађени у Косоутесовском хоризонту Кузбаске маргине (река Томј).

Разноврсна конодонтска асоцијација је издвојена из олистолита Кучајско-звоначког флиша, близу Горње Студене на Сувој планини. Међу њима су фаменски конодонти: *Polygnathus inornatus* E.R. BRANSON, *P. communis communis* BRANSON *et* MEHL, *Mehlina strigosa* (BRANSON *et* MEHL) и др. који су блиски конодонтним комплексима expansa и praesulcata зона Подонинског и Топкинског хоризоната Кузбаса.

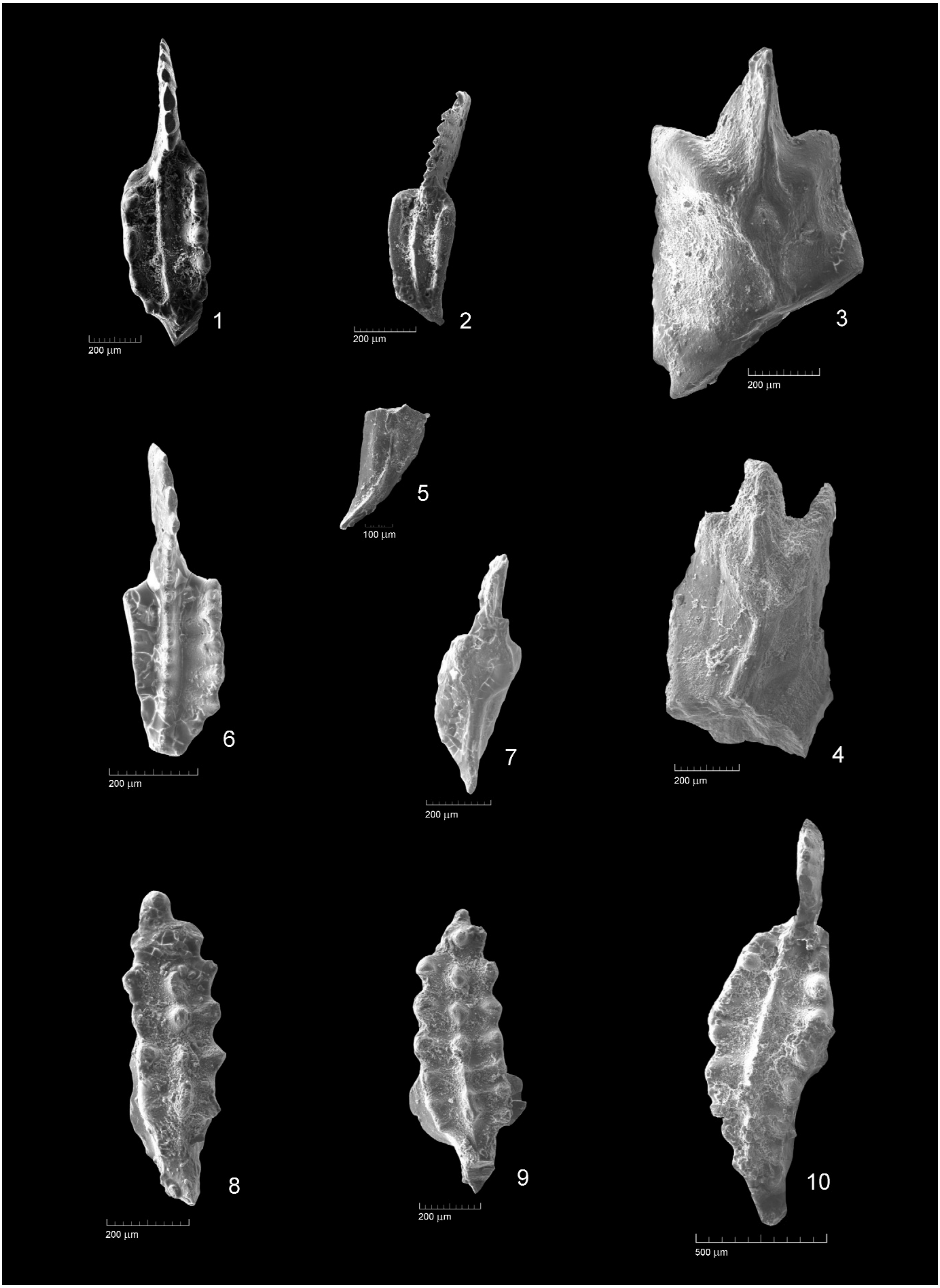
Конодонти пружају велику могућност за корелацију, девона источне Србије са многим регионима у свету а нарочито са ободом Кузњетског басена у јужном Сибиру где су такође пронађене сличне конодонтске асоцијације и установљене стандарне конодонтске зоне.

Б. Р.

PLATE 1.

Late Famennian Conodonts from Topkinskyi Horizon of the Kuznetsk Basin:
(see also GUTAK & RODYGIN, 2011). Sample G-08-46, Collection of TSU Paleontological Museum, No. 68:

Figs. 1, 6, 7. *Polygnathus* aff. *parapetus* DRUCE
Figs. 2, 5. *Neopolygnathus lectus* KONONOVA
Figs. 3, 4. *Polygnathus inornatus* E.R. BRANSON
Fig. 8. *Icriodus costatus costatus* (THOMAS)
Fig. 9. *Icriodus costatus darbyensis* KLAPPER, Morphotype 2
Fig. 10. *Pseudopolygnathus primus* BRANSON ET MEHL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Discrimination of tectonic dynamism, quiescence and third order relative sea level cycles of the Cauvery Basin, South India

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Abstract. Application of integrated stratigraphic modeling of sedimentary basins with the help of sequence and chemostratigraphic methods for improved understanding on the relative roles of depositional pattern and history of a Barremian-Danian stratigraphic record of the Cauvery Basin, India was attempted. Through enumeration of facies characteristics, tectonic structures and geochemical characteristics of the sedimentary rocks the use of geochemical signatures in distinguishing the relative roles of major factors has been evaluated. The results indicate that the geochemical signatures of the sedimentary rocks accurately record the prevalent geological processes and an ability to distinguish them through employing stratigraphic variations of compositional values and discrimination diagrams help in understanding the basinal history better. In addition, predomination of relative sea level fluctuations and active nature of tectonic movements during few time slices, which in turn was overwhelmed by sea level fluctuations are also inferred.

Key Words: Barremian-Danian relative sea level, tectonic events, source area weathering, tectonic setting, Cauvery Basin, India.

Апстракт: У раду је покушана примена интегрисаних стратиграфских модела на седиментне басене уз помоћ секвенционих хемостратиграфских метода у циљу бољег разумевања одговарајућих улога депозиционих образаца и историје баремско-данског стратиграфског записа у Кувери басену. Путем класификације фацијалних карактеристика, тектонских структура и геохемијских особина седиментних стена извршена је процена употребе геохемијских показатеља за разликовање одговарајућих улога које су имали главни фактори. Резултати указују да геохемијска својства седиментних стена прецизно одражавају главне геолошке процесе као и да могућност њиховог препознавања путем употребе стратиграфских варијација композиционих вредности и дијаграма разврставања помаже бољем разумевању историје басена. Поред тога, разматране су и значајне промене нивоа мора као и тектонски покрети који су били активни током дужег временскиог периода а што је за последицу имало колебање нивоа мора.

Кључне речи: Баремско-дански релативни ниво мора, тектонски догађаји, површинско распадање у зони порекла материјала, тектонски услови, Каувери басен, Индија.

Introduction

The theory of sequence development defines the sedimentation system under the control of four major variables, namely, tectonic subsidence, eustatic sea level change, volume of sediment influx and climate (Sarg 1988). The relative sea level cycles, first published by Vail *et al*. (1977), revised by Haq *et al.* (1987) espoused that the sedimentary sequences are produced principally under the influence of sea level cycles that vary between few tens of millions of years (1st order cycle) to few million years (3rd order cycle). Successive studies have shown that distinct sedimentary sequences could be traced to sea level cycles up to infra seventh order (Nelson *et al*. 1985; Williams *et al.* 1988; Carter *et al.* 1991). Vail *et al.* (1977) stated that the sea level chart published by them is incomplete and cycles of varying order could be added, so that, more complete chart could be established. The aim behind this statement is to incorporate sea level cycles at Milankovitch scale, to which the response of the sedimentation system is proved beyond doubt (Carter *et al.* 1991). Ruben *et al.* (2012), Haq (2014) and Ruban (2015) have present-

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ed the updates based on the progress made in this field of research so far.

HAYS *et al.* (1976) have convincingly demonstrated that climatic records were dominated by frequencies characteristic of variations in the Earth's tilt, precession and eccentricity relative to the Sun. In the years since, numerous studies have upheld the validity of the Milankovitch climatic cycles in terms of 100, 41, 23 Ka orbital periods that influence or control variations in global ice volume, thermohaline circulation, continental aridity and run off, sea surface temperature, deep ocean carbonate preservation and atmospheric CO_2 and methane concentrations (RAYMO *et al.* 1997; GALE *et al.* 2002, 2008; GALEOTTI *et al.* 2009). While examining the compiled data on the sediment volumes (mass) or sediment fluxes of the continental and marine subsystems to determine the complete routing in terms of mass conservation for specific time periods since Cenozoic, HINDERER (2012) reported that the response times of the large sedimentary systems are within the Milankovitch band. HILGEN *et al.* (2014) opined that despite fragmentary sedimentation, stratigraphic continuity as revealed by cyclostratigraphy unequivocally established the dominant role of depositional processes at the Milankovitch scale.

Global chemostratigraphic signals such as those carried by organic matter (MIDDLEBERG *et al.* 1991; PASLEY *et al.* 1993; MEYERS & SIMONEIT 1989; TU *et al.* 1999; CALVER 2000) oxygen isotope (ANDERSON *et al.* 1996; VEIZER *et al.* 1999) and strontium isotope (VEIZER 1985; VEIZER *et al.* 1999; MUTTERLOSE *et al.* 2014) and their relationships with sea level changes, and in turn, the climatic fluctuations are well known. The global carbon cycle varies on a million year time scale affecting the isotopic and chemical composition of the global carbon (WALLMANN 2001). The glacial intervals coincide with shifts in $\delta^{18}O$ and $\delta^{13}C$. For the carbon isotope record, rate of burial of C_{Org} and thereby changes in atmospheric CO_2 and for the oxygen isotopic records, temperature and ice volume effects on the seawater reservoirs and thereby sea level changes may be linked (KAMPSCHULTE *et al.* 2001).

Spectral analysis of $\delta^{18}O$ and $\delta^{13}C$ shows that their significant variances are concentrated at 100, 43, 23 and 19 Ka spans (OPPO *et al.* 1990; OPPO & FAIRBANKS 1989). While examining $\delta^{18}O$ of Phanerozoic seawater, VEIZER *et al.* (1997) observed high frequency cycles within first order cycle. STRAUSS (1997) recorded fourth order cycles of sulphur isotope that stack up to form 3rd order cycle fluctuations that in turn accommodated within 2nd order cycles. GOLDHAMMER *et al.* (1991) showed that the sequences of Paradox Basin exhibited a hierarchical stacking pattern of 5th order (80 Ka duration) shallowing upward cycles grouping into 4th order (400 Ka duration) cycles, which in turn stacked vertically into part of a 3rd order cycle. Large number of studies has documented the occurrences of high frequency sea level changes within major sea level cycles (for example, GIL *et al.* 2006; KULPECZ *et al.* 2009; ELRICK & SCOTT 2010; PELLENARD *et al.* 2014; ULIČNÝ *et al.* 2014). These abilities of sequence and chemostratigraphy helped successfully reinterpret the basinal history, and establish regional and global stratigraphic correlation and are being widely applied for petroleum exploration, inter-well correlation and reservoir characterization, etc. (RAMKUMAR *et al.* 2010, 2011). On the contrary, there are many studies that have questioned the veracity of the sequence stratigraphic concepts (MIALL 1991; 2009), especially the third order cycles (for example, CLOETING 1988; MIALL 1991; HISCOTT 2001; SPALLETTI *et al.* 2001; STEPHENS & SUMNER 2003) and the precision of the cycle durations and the applicability of such cycles on a global scale (MIALL & MIALL 2001).

Nevertheless, there are reports that have documented the occurrences of sedimentary records typical of high-frequency cycles deposited under the primary control of tectonics (for example, BHATTACHARYA & WILLIS 2001; VAKARELOV *et al.* 2006) though doubts have been raised over the rate at which the tectonic movements can mimic high-frequency cycles (GOLDHAMMER *et al.* 1987; MASETTI *et al.* 1991). Influence of regional-global plate movements over third order cycles has also been reported by BACHMANN *et al.* (2003) and VEIGA & SPALLETTI (2007). In an innovative study, VAN DER MEER *et al.* (2014) recently demonstrated the control exercised by tectonics over atmospheric CO_2 through a complex and intrinsically coupled chain of processes and thereby over climate–continental weathering and sea level fluctuations, and ensuing sedimentary records. HISCOTT (2001), SPALLETTI *et al.* (2001), BACHMANN *et al.* (2003) and BRETT *et al.* (2004) opined that it is a common phenomenon of sedimentary records to have sea level cycles affected by local tectonics either positively or negatively. Depending on the local, regional and global scale of processes, these cyclic changes may get preserved in the ensuing sedimentary strata, the temporal scale of which may vary from few thousand years to few or few tens of millions of years – a postulate widely utilized in seqeuence and chemostratigraphy.

Thus, the enigma of relative roles of tectonics-sea level fluctuations over depositional pattern remains to be there where it had all started when VAIL *et al.* (1977) proposed the sequence stratigraphic concepts. It has also raised questions on the very fundamentals of sequence and chemostratigraphic applications. At this juncture, it becomes essential to address the problem of discrimination relative influences of tectonics and relative sea level fluctuations over sedimentary records.

The Cauvery Basin (Fig. 1) is located in the southern part of Indian peninsula. It contains a near complete stratigraphic record of Barremian–Danian. It is

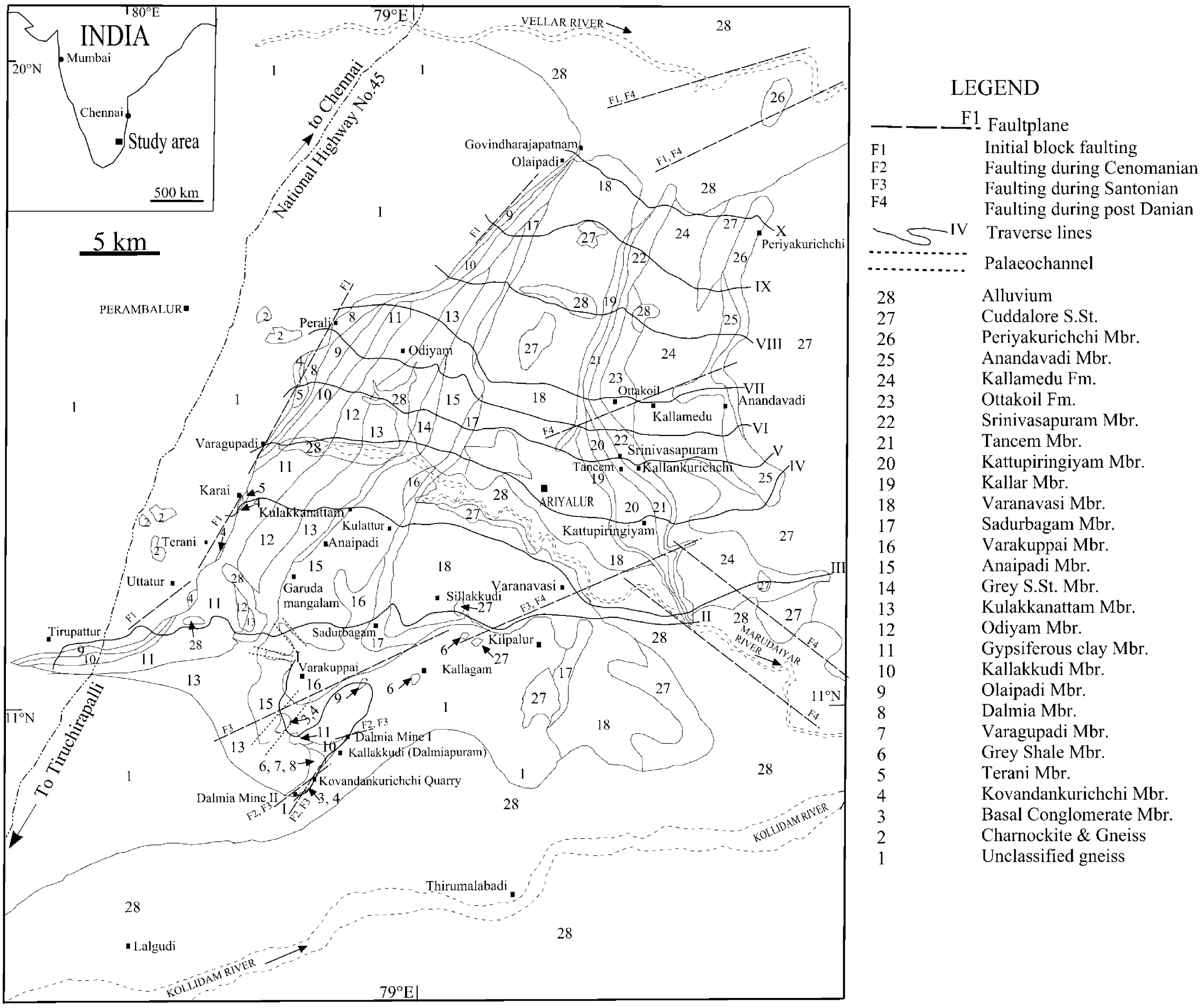

Fig. 1. Location and Geology of the study area (After RAMKUMAR *et al.* 2004a).

one of the most studied basins (ACHARYYA & LAHIRI 1991). In a first ever basin-scale temporally long range chemostratigraphic study, RAMKUMAR *et al.* (2011) recognized six major chemozones, separated by type 1 sequence boundaries and other correlative surfaces coeval with third order cycles of sea level, which in turn contained high frequency cycles, probably in the order of 10^4–10^6 years and found to be consistent with the timescale-sea level curve of GRADSTEIN *et al.* (2004). Though there are disagreements on the connectedness of Indian subcontinent with other continental plates during Barremian to Danian, (ALI & AITCHISON 2008), the enclosed nature of Indian subcontinent by sea and its behavior as an Island akin to the present day Australia was not questioned. As the climatic conditions of Island continents are predominantly controlled by the temperature of surrounding seawater and the Cretaceous Period had experienced extended greenhouse effect (VEIZER *et al.* 2000; BICE & NORRIS 2002; COCCIONI & GALEOTTI 2003; HERRLE *et al.* 2003; NAJARRO *et al.* 2010), changes in seawater temperature would have affected the glaciers to retreat or advance, causing high-frequency sea level oscillations that in turn might have influenced the depositional system of the Cauvery Basin.

As the provenance area of the Cauvery basin sediments were confined to adjacently located horsts and hinterland (RAMKUMAR *et al.* 2004a, 2006) the sea level changes and the tectonic events might have been exacerbated (VEIGA & SPALLETTI, 2007) and reflected in the sedimentary records. The basin fill shows textural immaturity all through is sedimentary history. In addition, high-frequency sea level cycles during Barremian–Santonian and Late Cretaceous–Danian, overlap of much older lithostratigraphic units by younger units and angular unconformity surfaces characterize the basin fill and indicate the involvement of certain amount of tectonism (VEIGA *et al.* 2005) over deposi-

Table 1. Lithostratigraphy of the exposed part of the Cauvery Basin (*after* RAMKUMAR *et al.* 2004a).

Age	Group	Formation	Member	Thickness (m)
Mio- Pliocene		Cuddalore S.St. Fm.		>150
		Unconformity		
Danian		Niniyur Fm	Periyakurichchi biostromal Mbr	26
			Anandavadi arenaceous Mbr	30
	Ariyalur Group	*Unconformity*		
Maastrichtian	Ariyalur Group	Kallamedu Fm.		100
	Ariyalur Group	*Unconformity*		
	Ariyalur Group	Ottakoil Fm.		40
	Ariyalur Group	*Unconformity*		
	Ariyalur Group	Kallankurichchi Fm.	Srinivasapuram gryphean L.St. Mbr.	18
			Tancem biostromal Mbr.	8
			Kattupiringiyam inoceramus L.St. Mbr.	8
			Kallar arenaceous Mbr.	6
	Ariyalur Group	*Unconformity*		
Campanian	Ariyalur Group	Sillakkudi Fm.	Varanavasi S.St. Mbr.	270
Santonian			Sadurbagam pebbly S.St. Mbr.	80
			Varakuppai lithoclastic conglomerate Mbr.	45
		Unconformity		
Coniacian		Garudamangalam Fm.	Anaipadi S.St. Mbr.	215
			Grey S.St. Mbr.	35
			Kulakkanattam S.St. Mbr.	123
		Unconformity		
Turonian		Karai Fm.	Odiyam Sandy clay Mbr.	175
			Gypsiferous clay Mbr.	275
		Unconformity		
Cenomanian		Dalmiapuram Fm.	Kallakkudi Calcareous S.St. Mbr.	60
			Olaipadi conglomerate Mbr.	65
Albian			Dalmiya biohermal L.St. Mbr.	15
			Varagupadi biostromal L.St. Mbr.	23
			Grey shale Mbr.	7
		Unconformity		
Aptian		Sivaganga Fm.	Terani clay Mbr.	30
Barremian			Kovandankurichchi S.St. Mbr.	24
			Basal Conglomerate Mbr.	18
		Unconformity		
		Basement Rocks (Granitic gneiss, charnockite, pegmatite, etc.)		

tional history and creation of accommodation space. By these traits, the Cauvery Basin offers a test site to discriminate relative influences of tectonics and sea level fluctuations. As the stratigraphic record is the outcome of an exogenic system consisting of geologic setting, changes in sea level, changes in geochemical reactions between the sea and earth and climate (SRINIVASAN 1989) and as the sedimentary geochemistry is a faithful recorder of provenance, tectonic setting and palaeoclimatic conditions prevalent (BHATIA 1983; BHATIA & CROOK 1986; ROSER & KORSCH 1986; TAYLOR & MCLENNAN 1985; MONGELLI *et al.* 1996; CINGOLANI *et al.* 2003), this paper attempts understanding the dynamics of provenance, tectonic setting and sea level fluctuations of the Cauvery Basin and to discriminate them through geochemistry.

Thus, the objectives of this paper are set to examine **a)** hierarchical variations of geochemical signatures (sensu RAMKUMAR, 2015) in tune with prominent controls of sequence-chemostratigraphic cycles, **b)** ability of geochemical signatures to distinguish the relative significances of various depositional agents, provenance and tectonic setting, etc. and **c)** utility of application of integrated chemo-sequence stratigraphic modeling for characterizing basin fill on a long-short term cycles.

Geological setting

Among the NE–SW trending Late Jurassic–Early Cretaceous pericratonic rift basins created all along east coast of the Indian peninsular shield (SASTRI *et al.* 1981; POWELL *et al.* 1988; CHARI *et al.* 1995; JAFAR 1996; CHATTERJEE *et al.* 2013), in response to the fragmentation of Gondwana super continent and rifting of Africa–India–Antarctica (LAL *et al.* 2009), the Cauvery Basin (Fig. 1) is located at the southern part of the Indian peninsula. The basin continued evolving till the end of Tertiary through rift, pull-apart, shelf sag and tilt phases (PRABAKAR & ZUTSHI, 1993). It lies between the latitudes 08°30'N and the longitudes 78°30'E and covers an exposed area of about 25,000 km^2 onland and 17,500 km^2 in the offshore (SASTRI *et al.* 1981) of the Bay of Bengal upto 200 m isobath. It is a structurally elongated basin with NE–SW trending half-graben morphology and a regional dip of 5–10° E and SE directions.

This basin is well differentiated into sub-basins and horsts (ACHARYA & LAHIRI, 1991; CHANDRA, 1991; PRABHAKAR & ZULCHI, 1993; Chari *et al.* 1995) namely, Ariyalur - Pondicherry sub-basin, Tanjore - Tranquebar - Nagapattinam sub-basin, Ramnad - Palk Bay sub-basin, Pattukottai - Mannargudi - Karaikal ridge, Kumbakonam - Mandanam ridge, and Mandapam - Delft ridge. The evolutionary (SASTRI *et al.* 1981; PRABHAKAR & ZUTCHI, 1993; CHARI *et al.* 1995; LAL *et al.* 2009), stratigraphic (RAMANATHAN, 1968; BANERJI, 1972; SUNDARAM & RAO, 1986, TEWARI *et al.* 1996; SUNDARAM *et al.* 2001; RAMKUMAR *et al.* 2004a, 2005a), palaeontologic (CHIPLONKAR, 1987; GOVINDHAN *et al.* 1996; BHATIA, 1984; JAFAR & RAI, 1989; KALE & PHANSALKAR, 1992; KALE *et al.* 2000; GUHA, 1987; GUHA & SENTHILNATHAN, 1990, 1996; RAMKUMAR & CHANDRASEKARAN, 1996; RAMKUMAR *et al.* 2010a; RAI *et al.* 2012), and geochemical (RAMKUMAR, 2007; RAMKUMAR *et al.* 2004b, 2005b, 2006, 2010b, 2010c, 2011) characteristics of this basin are well-documented. The sedimentary succession of this basin exceeds 5500 m in thickness (GOVINDAN *et al.* 2000). Lithofacies associations and fossil data indicate periodic sediment-starved nature and basin filling process of depositional pattern (AYYASAMY, 1990). Based on the facies characteristics, comprehensive lithostratigraphy of the onland part this basin was presented by TEWARI *et al.* (1996) and was modified by SUNDARAM *et al.* (2001) and later a systematic revision was made by RAMKUMAR *et al.* (2004a) following standard stratigraphic procedures and terminologies. The lithostratigraphic sub-divisions (Table 1; Fig. 1) are separated by sequence boundaries and other correlative surfaces (RAMKUMAR *et al.* 2011) and are geochemically distinct to the tune of 100% from each other (RAMKUMAR *et al.* 2010b). A brief description on facies characteristics of the Barremian-Danian sedimentary sequence is presented in the table 2.

Materials and methods

Systematic field mapping in the scale of 1:50,000 was conducted through ten traverses (Fig. 1) in which 308 locations were logged and sampled. At each location and along the traverses, information on lithofacies, contact relationships, sedimentary and tectonic structures and occurrences of mega and ichnofossil assemblages were recorded. For characterizing the strata for sequence analysis, the conceptual standard workflow of CATUNEANU (2006) and CATUNEANU *et al.* (2009, 2010, 2011) were followed. It included definition of type sections, recognition of sequence stratigraphic surfaces (among the seven types of surfaces), defining them into sequence boundaries, and relating them with any of the four events of the base-level cycle, and then with any of the three systems tracts (forced regression, normal regression and transgression) based on the outcrop, facies and other relevant criteria. The sequence model so developed was presented earlier (RAMKUMAR *et al.* 2004a).

Based on the field data, a composite stratigraphic profile of Barremian-Danian strata was constructed that allowed selection of 157 rock samples for analyzing trace elemental composition. From these 157 samples, 70 samples were further selected and analyzed by XRF for major elemental composition following the procedures discussed in KRAMAR (1997) and STÜBEN *et al.* (2002). Stable isotopic analyses were performed as per the procedures presented in KELLER *et al.* (2004). Analyses of 157 samples for petrography and whole-rock mineralogy, 70 samples for clay mineralogy were also performed. The geochemical data were interpreted with stratigraphic variation, plotting in established discrimination diagrams (for example, ROSER & KORSCH, 1986) and computation of weathering indices (NESBITT & YOUNG, 1982), and corroboration with major geological events. Collation of all these information along with the published data allowed elucidation of the prevalent changes in provenance, tectonic setting, and fluctuations in relative sea level with which, the relative influences of various processes were interpreted and discussed.

Results

Tectonic events

All along its western margin, basin margin faults are recognizable (Fig. 1) which separate the Archaean shield from the sedimentary deposits. Based on the field structural criteria, contact relationships, and lithological association and displacement, basin scale tectonic movements and their relative timings were interpreted viz., initial block faulting (F1 in Fig. 1), movement of fault blocks during Albian-Cenomanian boundary interval (F2 in Fig. 1), reactivation of older fault blocks and creation of new fault during Santonian (F3 in Fig. 1) and reactivation of fault blocks during post Danian–pre

Table 2. Lithofacies characteristics of the Barremian-Danian strata of the Cauvery Basin.

Formation	Member	Facies characteristics
Niniyur	Periyakurichchi	Thick arenaceous bioclastic limestone bed followed by medium to thick, parallel, even bedded recurrent biostromal limestone and marl typify this member. Regionally varying concentrations of shell fragments and whole shells of bivalve, gastropod and remains of amphibia, pisces, algae, foraminifera and ostracoda are also observed.
	Anandavadi	Isolated coral mounds, impure arenaceous limestone and lenses of sandstone and clay, deposited in a restricted marine regime under subtidal to intertidal regions. Occurrence of localized concentrations of shell fragments, coralline limestone and reef derived talus deposits are characteristics of this member. This member rests over the Kallamedu Formation with distinct disconformity. At top, an erosional surface is recognizable
Kallamedu		Unconsolidated, well rounded and poorly sorted barren sands with rare-scarce dinosaurian bone fragments. Towards top, these grade to medium to thin bedded, relatively highly argillaceous sandstones. Local occurrence of clays and silts with dispersed detrital quartz grains and sandy streaks, non-bedded nature, rare lamination and mud cracks in them indicate sedimentation as over bank deposits. Towards top, this formation has paleosol indicating return of continental conditions.
Ottakoil		The rocks are coarse to medium sized, well-sorted, fossiliferous, low angle cross-bedded and planar to massive bedded sandstones with regionally varying sparse calcareous cement. They also show recurrent fining upward sequences. Abundant *Stigmatophygus elatus* and few trace fossils indicative of shallow marine environment of deposition. This formation rests over Kallankurichchi Formation with disconformity and overlapped by Kallamedu Formation.
Kallankurichchi	Srinivasapuram	Uniform, parallel, thick-very thick-bedded gryphean shell banks with *Terebratula*, *Exogyra*, bryozoa and sponge. Extensive boring in gryphean shells, synsedimentary cementation, colonies of encrusting bryozoa over gryphean shells and micritization of bioclasts deposition of this member in inner shelf.
	Tancem	Biostromal limestone beds with thin to thick, parallel, even bedded nature, cross bedding, normal grading, hummocky cross stratification, feeding traces, escape structures and tidal channel structures. Local concentrations of various fossils, sporadic admixture of siliciclastics and intraclasts.
	Kattupiringiyam	Dusty brown friable carbonate sands with parallel, even and thick to very thick bedding that contains only *Inoceramus* and bryozoa. This member has diagenetic bedding and abundant geopetal structures filled with mm to cm sized dog tooth spars of low magnesian non-ferroan calcite. This member has non-depositional surface at bottom and has erosional surface at top.
	Kallar	Normal graded conglomerates in which well-rounded clasts of basement rocks, fresh feldspar, resedimented colonies of serpulids and other older sedimentary rocks that range in size from coarse sand to boulder are observed. Lower contact of this member is an erosional surface. The upper contact is non-depositional surface resulted from marine flooding.
Sillakkudi	Varanavasi	Featureless, massive, thick to very thick bedded, coarse to medium grained sandstones. Occasional very coarse sandstone lenses, pockets of shell hash, intraformational lithoclastic bounders in association with vertical cylindrical burrows and resedimented petrified wood logs are observed. The rocks rest over the pebbly sandstone member with non-depositional surface Upper surface of this member represents erosional surface associated with regression.

Table 2. continued.

Formation	Member	Facies characteristics
Sillakkudi	Sadurbagam	Coarse siliciclastics with abundant marine fauna, shell fragments and varying proportions of calcareous matrix At the base, an erosional surface followed by distinct cobble-pebble quartzite conglomerate is observed. The rocks show normal grading, low angle cross bedding, massive, thick to medium, even and parallel bedding. At places, pockets of shell rich carbonate lenses with abundant siliciclastic admixture are found to occur. Load casts, slump folds, pillow structures and synerasis cracks, occasional development of algal mounds are also found.
	Varakuppai	It rests over older sedimentary rocks with typical erosional surface. The erosional intensity was such high that, the beds have direct contact with much older Karai Formation. Fluviatile sandstones with well-rounded basement rocks, quartzite and older sedimentary rock boulders in addition to unsorted coarse sand-pebble sized siliciclastics constitute this member. These are typically reverse graded and show cyclic bedding, large scale cross bedding and lack any body fossils. Large scale cross bedding, mud drapes, fresh feldspar and sandstone clasts are also recorded. Towards top,*thalassinoid* burrows are reported, that indicate gradual submergence of the depocentre by rising sealevel.
Garuda mangalam	Anaipadi	Massive and thin-bedded claystones, silty claystones and clayey sandstones in south that gradually grade to silty clay in south center and thin down. Again, from there, thickness of these beds and sediment grain size increaseand contain abundant large ammonites. Further north, these were observed to be clayey siltstones with abundant shell fragments and ammonites.
	Grey sandstone	Highly well cemented, sorted and rounded grains giving massive appearance. The beds are cyclic, parallel, even bedded alternative layers of barren and highly fossiliferous and sandy layers with regionally varying thicknesses. This member rests conformably over the Kulakkanattam member and has distinct erosional and non-depositional surface. Upper contact is non-depositional surface associated with marine flooding.
	Kulakkanattam	Massive, yellowish brown ferruginous sandstones with abundant admixture of silt and clay. Localized concentrations of shell fragments, bivalves and gastropods and ammonites are common. It also contains abundant wood fragments with extensive oyster boring. Cross bedding, channel courses, planar bedding and feeding traces are also common. The depositional surface was strongly bioturbated and riddled by roots. An angular erosional unconformity separates this member from underlying Karai Formation.
Karai	Odiyam sandy clay	Siltyclays and sandy clays with abundant ammonites. Load structures and syndepositional slump folds are frequently observed. Upper portion of this member has localized pockets of fine sandstone along with ammonites. While the lower contact is conformable with underlying member, upper contact is erosional.
	Gypsiferous clay	Unconsolidated deep marine clays and silty clays. These beds contain thick population of belemnite rostrum and phosphate nodules. While a non-depositional unconformity surface separates this member from the underlying member, upper contact is non-depositional and erosional. From south to north, gradual reduction of thickness, population of belemnite and phosphate nodules and frequency of gypsum layers are observed. Repetitive occurrences of 1–3 cm thick red and green colored clay layersthat can be traced for many kilometers are ubiquitous.

Table 2. continued.

Formation	Member	Facies characteristics
Dalmiapuram	Kallakkudi	Fine-coarse sandstones with alternate medium to thick beds of silty clay, calcareous siltstones, bioclastic arenaceous limestone and gypsiferous clay. In the southern region, these beds show recurrent bands of fining upward sequences of siliciclastics with calcareous cements. The intercalations are recurrent and show typical Bouma sequences, normal grading, load casts and channel and scour structures. Towards northern regions, this member grades to more silty and clayey, but gradation and gypsiferous bands are persistent with an addition of ferruginous silty clay bands.
	Olaipadi	Basinal silty clays and clays in which chaotic blocks are embedded. The beds contain large blocks of angular and subrounded basement rocks, coralline limestone blocks, claystones (lithoclasts of carbonates and greenish claystones typical of Karai Fm.) and lithoclasts of older conglomerates, etc. Towards the top, deep marine clays grade into calcareous siltstone and include granitic cobbles and minor amounts of siliciclastic sands.
	Dalmia	Pure algal and coral facies limestone beds that form reef core. Upper contact of this member is a forced regression surface.
	Varagupadi	Limestone beds typical of reef flank biostromal beds deposited under high-energy conditions. Thin to thick bedded, even to parallel, bioclastic limestone beds that have drawn their detritus from reefs predominate. These beds are found to be directly overlying the Grey shale member. The rocks show wack stone to rudstone fabric and have clasts of redeposited boundstones.
	Grey shale	Grey shale beds with frequent thickening upward interbeds of fossiliferous grey limestone and minor to significant admixture of silt sized siliciclastics. Lower contact of this member is an unconformity surface associated with marine flooding and the upper contact is non-depositional and erosional.
Sivaganga	Terani Clay	White to brownish colored clay and argillaceous siltstone that show transition from Kovandankurichchi member. Beds are massive to very thick in nature. Lower contact of this member is non-depositional surface.
	Kovandankurichchi	Grain supported coarsening upward cyclic beds (20-100cm thick each) of very coarse sandstones that show parallel, even and thin to thick bedding. Grains are well sorted within each lamina and show rounded-well rounded shape. These represent recurrent sheet flow deposits probably in a sub-aqueous fan deltaic environment.
	Basal conglomerate	Recurrent fining upward sequences of lithoclastic conglomerates of fluviatile and coastal marine environments. Lithoclasts are of gneissic basement rocks. Rests over basement rocks with distinct erosional surface. Upper contact is a non-depositional surface.

Quaternary (F4 in Fig. 1). It is to be stated that, in addition to these major fault movements, there were minor and local scale tectonic movements, namely across Aptian–Albian boundary interval, during Cenomanian (during the deposition of Olaipadi member), and during Santonian (during the deposition of Varakuppai member) all of which were confined only to adjustment of fault blocks along the preexisted fault planes. There exists a difference in trends of post Danian fault movements (F4 in Fig.1) that have affected the Miocene to Pliocene sandstones, Danian Limestones, and Maastrichtian deposits by folding, fracturing and faulting (RAMKUMAR 2007). Enumeration of tectonic structures and depositional history of the Cauvery Basin indicated that after initial block faulting and inception of sedimentation during Late Jurassic–Early Cretaceous, intensity of tectonic control over sedimentation was diminutive (PRABAKAR & ZUTCHI 1993; RAMKUMAR 1996; RAMKUMAR *et al.* 2005a). WATKINSON *et al.* (2007) recognized three major tectonic stages and resultant stratigraphic groups for this basin; viz., syn-rift Gondwana Group (Early Cretaceous), syn-rift Uttatur Group (Albian–Coniacian) and post-rift Ariyalur Group (Santonian–Maastrichtian) and are in conformity with the present observations.

Relative sea level fluctuations

Sedimentation in this basin took place in an epicontinental sea and the bathymetry was at shallow – modest levels (<50 m – as indicated by the linear curve in Fig. 2) although variations from supratidal to basinal levels were inferred. Based on the foraminifer data, RAJU & RAVINDRAN (1990) and RAJU *et al.* (1993) documented six 3rd order cycles of glacio-eustatic origin. RAMKUMAR *et al.* (2004a) constructed a sea level curve for this basin based on bathymetric trends of lithofacies data, which is similar to the curves presented by RAJU *et al.* (1993) except that it additionally recorded fourth and higher order sea level cycles (Fig. 2). The global sea level peaks during 104 Ma (Early–Late Albian), 93.7 Ma (±0.9; Middle to Late Cenomanian), 92.5 Ma (±1; Early to middle Turonian), 86.9 Ma (±0.5; Early to Late Coniacian), 85.5 Ma (±1; Early to Late Santonian), 73 Ma (±1; Late Campanian), 69.4 Ma (Early to Late Maastrichtian) and 63 Ma (±0.5; Early to middle Danian) were observed to occur in this basin (RAJU & RAVINDRAN, 1990; RAJU *et al.* 1993; RAMKUMAR *et al.* 2004a). The 3rd order cycles are separated by type I sequence boundaries (recognized through shift of shoreline crossing shelf break as explicit in lithologic information, contact relationship between strata, evidences of subaerial exposure and erosion, advancement of fluvial channels over former offshore regions, etc.). The period from Barremian to Coniacian shows frequent occurrence of sea level lows and highs that may be interpreted as prevalent high frequency/higher order cycles. The period from Coniacian to Danian shows sea level rise and fall punctuated with lesser frequency of higher order cycles. The sea level rise during Santonian–Early Campanian shows steadily increasing pattern.

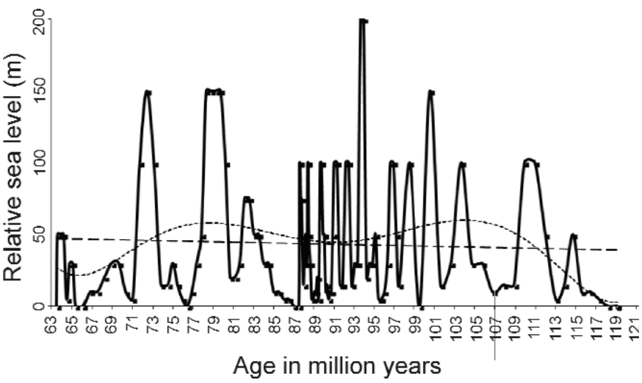

Fig. 2. Relative sea level fluctuations during Barremian-Danian in the Cauvery basin (after RAMKUMAR *et al.* 2004a). Solid line curve is indicative of absolute values of RSL; —- linear trend; ….. polynomial trend.

Geochemical characteristics

Geochemical elemental data having predominant affiliation with detrital (Si, Ti, Zr), biogenic (Ca), and tectonic processes (Y) and computed values of plagioclase alteration index (PIA) as climatic indicator were plotted in stratigraphic profiles (Fig. 3). These profiles depict the occurrences of inverse relationships between detrital elements and biogenic element, six major enrichment-depletion cycles coeval with 3rd order sea level cycles within which many high-frequency enrichment-depletion cycles, significant change of the pattern across Santonian, sudden positive excursions of Y during Cenomanian and Santonian, and a major positive excursion of PIA during Turonian–Coniacian.

Plotting few selected oxides percentages against Al_2O_3 shows sympathetic nature of SiO_2, TiO_2, and K_2O, strongly anti-sympathetic nature of CaO, slightly positive yet scattered nature of MgO and Na_2O (Fig. 4). The plot of Al_2O_3 against CaO shows an interesting phenomenon of distinctly recognizable twin clusters. Other plots also show feebly recognizable but scattered twin clusters. Textural discrimination of the samples based on oxides percentages shows that most of the samples fall in the texturally immature fields viz., litharenite, wacke, arkose, subarkose, and only very few in the quartz arenite field (Fig. 5). Plotting the SiO_2–Al_2O_3*5–CaO*2 in ternary diagrams that have average shale, smectite, illite, kaolinite fields and enrichment indicators of detrital (significant sediment influx), biogenic (warm climate, sea level high), and clay (significant weathering in the provenance) fields show that all the samples fall either near siliciclastic or biogenic fields (Fig. 6). Ternary plot of CN–A–K also shows that most of the samples fall below the feldspar join and only a few fall above the join (Fig. 7). Plot of the data in tectonic setting discriminant diagram (SiO_2 Vs K_2O/Na_2O) shows that the samples fall in the Arc, active continental margin and passive continental margin (Fig. 8) fields. The tectonic discrimination diagrams of SiO_2 Vs K_2O/Na_2O and SiO_2/Al_2O_3 Vs Na_2O/K_2O show interesting phenomenon of plot of Barremian––Santonian samples in the active continental margin field, Campanian–Danian samples except few samples of Kallamedu Formation (Late Maastrichtian) in passive continental margin field and few samples of Kallamedu and Ottakoil formations in the island arc field (Fig. 8).

Discussion

Geological events and Depositional cycles of the Cauvery Basin

All along the western margin of the exposed area of the basin, the Precambrian basement rocks show the

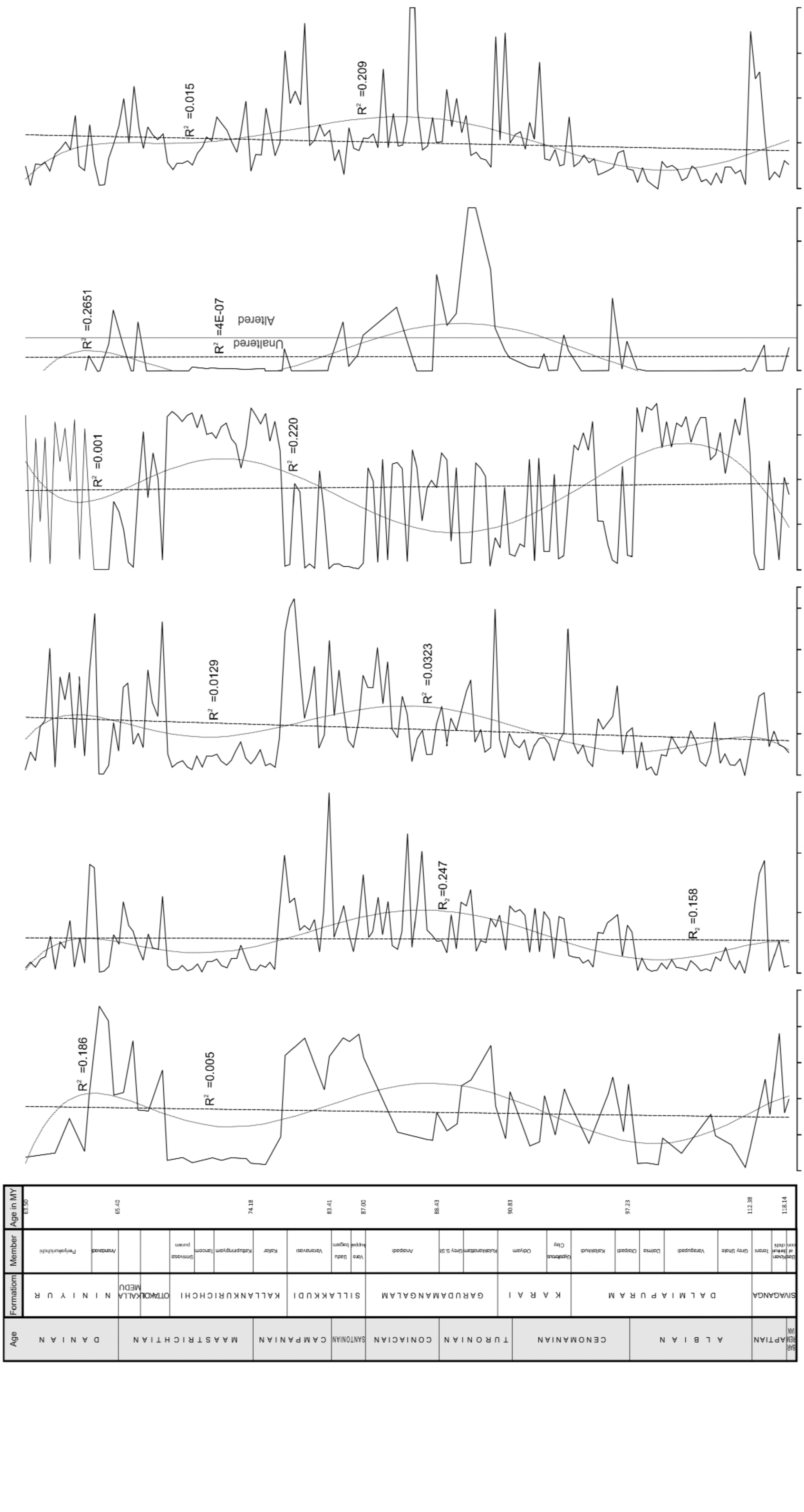

Fig. 3. Stratigraphic variations of selected elemental and alteration index values. The Si, Zr, Ti, and Ca are expressed in weight percentages, the Y is expressed in ppm and the PIA is expressed in index value.

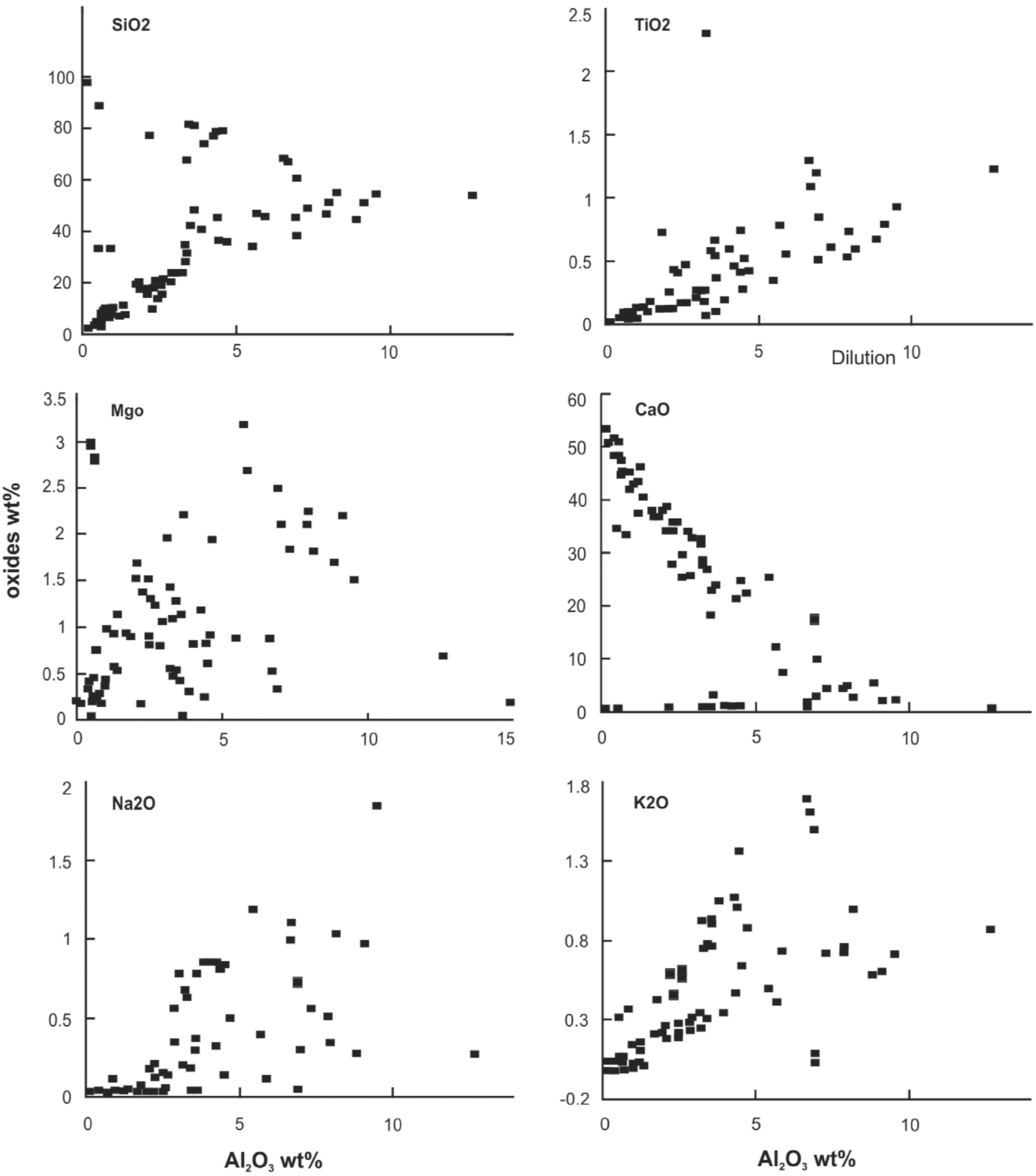

Fig. 4. Bivariate diagrams showing relationships among elemental oxides. Note the uniform dispersal pattern among detrital elemental oxides, distinct clustering of CaO and scattered yet recognizable similar clustering among other oxides. All these may be indicative of the existence of either siliciclastic or carbonate dominated depositional system at a given time period and climate-sea level fluctuation controlled nature of the depositional pattern.

occurrences of fault lines aligned NE–SW (F1 in Fig. 1; Plate 1.1) that mark the initial block faulting, perhaps during Barremian. This faulting had resulted in transgression and commencement of sedimentation of the Sivaganga Formation. The basement rocks located at west of the basin margin were severely eroded and transported to the depocenter before inheriting alteration and maturity and thus fresh, angular to sub-

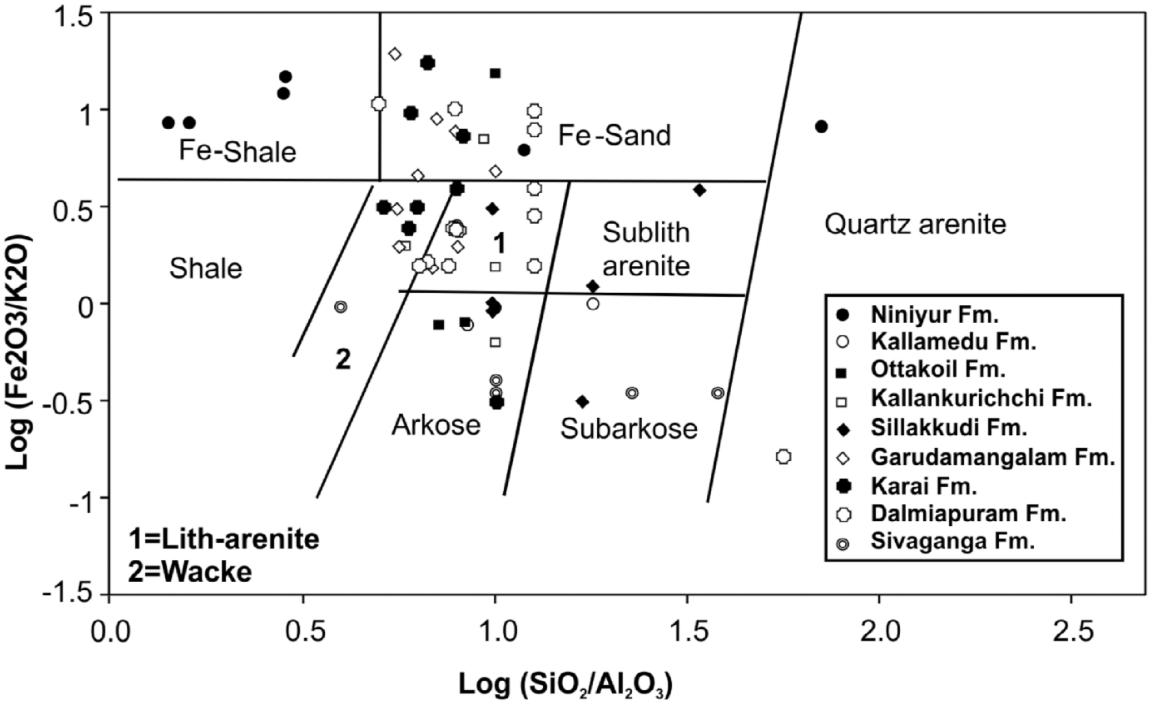

Fig. 5. Discriminant diagram showing textural maturity of the rocks studied. Note that most of the samples fall in the fields of litharenite, wacke, arkose and subarkose suggestive of predominance of mechanical weathering, and subdued nature of chemical weathering. Among these also, litharenite dominates, suggestive of recurrent erosion of basement as well as former marine regions and recycling of sediments. It also suggests sediment starved nature of the basin.

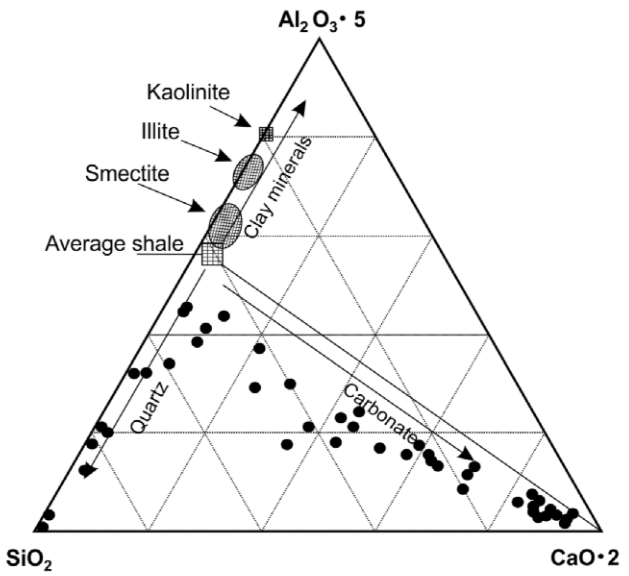

Fig. 6. Discriminant diagram showing the absence of any significant weathering as all the samples fall far below the average shale discriminant line. In addition, the diagram shows a grouping of the samples studied either with siliciclastic or carbonate dominated nature, suggestive of the predomination of relative sea level fluctuation controlled nature of the depositional cycles/pattern.

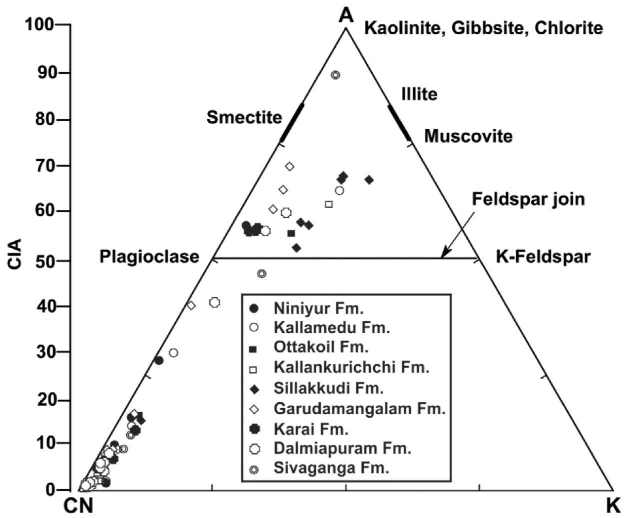

Fig. 7. Discriminant diagram of CN-A-K showing the subdued nature of chemical weathering. Note that most of the samples fall below the feldspar join. Few samples of the Dalmiapuram Foramtion, Karai Formation, Garudamangalam Formation, the Sillakkudi Formation are found above this join, indicative of episodes of chemical weathering too.

angular basement rock boulder-cobble sized clasts and feldspar pebbles typify this formation (Plate 1.2). As the intensity of energy conditions reduced, sediment grain size also got reduced. Significant sedimentation commenced with the establishment of fluvial

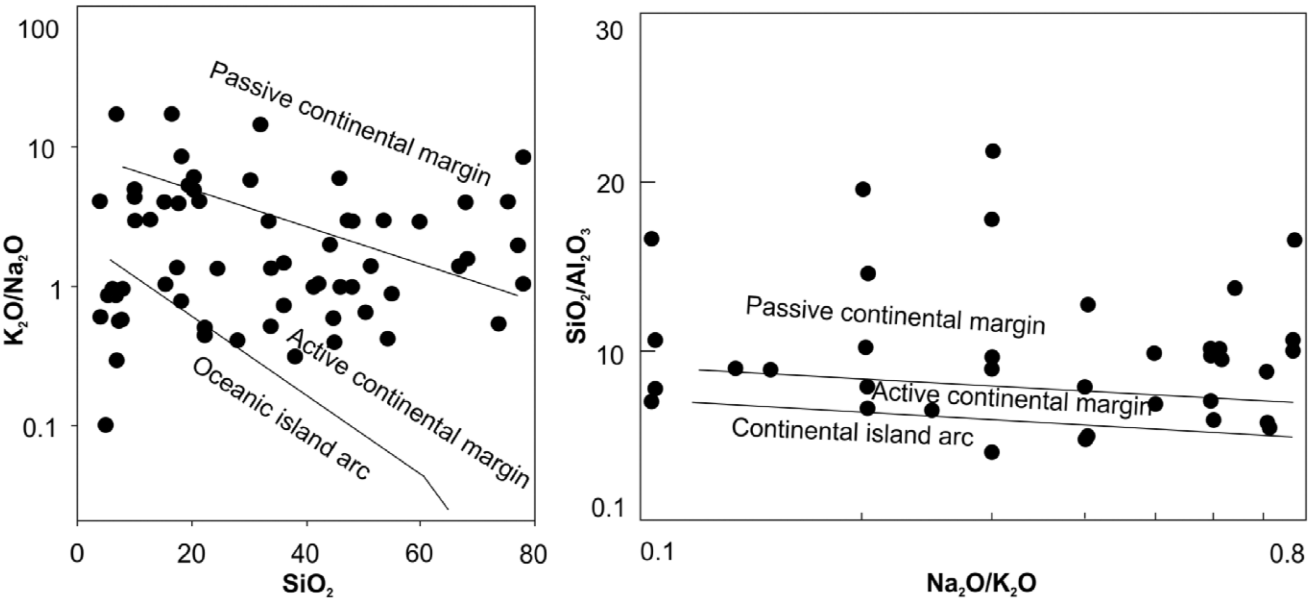

Fig. 8. Discriminant showing tectonic setting of the samples studied. Most of the samples in the Active continental margin field are of Barremian–Santonian while most of the samples in the Passive continental margin field are of Campanian-Danian and the samples found in the Oceanic island arc are from the late Maastrichtian, particularly from the Kallamedu and Ottakoil Formations.

source onland and submarine fan delta in the basin (represented by the Kovandankurichchi sandstone member). Gradation of this sandstone member into deep marine claystone-siltstone member (Terani member) indicates prevalence of stabilized environmental conditions until the end of deposition of the Terani member. It was brought to an end due to renewed faulting introducing an angular unconformity associated with erosion and redeposition of older sedimentary rocks.

The rejuvenated sedimentation was through deposition of shale and shale-limestone alternate beds of the Grey shale member of the Dalmiapuram Formation. The depocenter was partially and periodically closed, while grey shale was deposited. Whenever open conditions of sea circulation were prevalent, bioclastic limestone beds were deposited. These limestone interbeds show thickening upward character indicating increase in durations of openness of the sea that culminated in the development of biostromal member over the Grey shale member. The biostromal member contains principally coral clasts and algal fragments with varying proportions of bioclasts of bryozoa, bivalvia and gastropoda in addition to reef dwelling microfauna. Siliciclastic admixture is significant to minor in proportion and varies randomly. Beds of this member are parallel, even to uneven, thin to thick and have frequent erosional surfaces in between. All these signify deposition in subtidal to storm weather wave base regions under photic zone. Typical coral reef deposits developed over this member that moved gradually towards offshore regions owing to fall of sea level. At the top of this biohermal limestone member, major erosional surface associated with faulting (F2 in Fig. 1; Plate 1.3, 1.4, 1.5) and regression is observed.

This faulting had exposed the subtidal-storm weather wave base deposits to subaerial conditions that led to karstification. It also paved way for the deposition of the Olaipadi conglomerate member which contains large boulders (many of which are more than 10 m in diameter) of basement rocks, and lithoclasts of similar size, drawn from underlying bioclastic and coral limestone, Terani claystone and lithoclasts of older sedimentary conglomerates, all embedded in basinal clay sediments! Angular to sub rounded nature of the boulders, presence of basement as well as lithoclasts of older sedimentary rocks in basinal sediments clearly indicate a major faulting event, creation of steep slope and short distance of transportation. Presence of argillaceous siltstone over these boulders with lamination parallel to the boulder boundaries indicates restoration of normal depositional conditions and gradual increase of sea level. A detailed facies and sequence analysis of these deposits suggested (Ramkumar, 2008) the prevalence of turbiditic current controlled depositional pattern coeval with seismicity related mechanical erosion and gravity driven deposition that acted independently. Deposition of argillaceous sediments was brought to an end by rejuvenation of fluvial source resulting in influx of coarse-finer clastics and suspended sediment load. This new set of environmental conditions led to the deposition of the Kallakkudi calcareous sandstone member. This member is sandy in southern region and clayey in northern region. Occurrence of recurrent

Bouma sequences that always top with a gypsiferous layer followed by an erosional surface and again by another Bouma sequence in this member indicates deposition under the influence of turbidity currents and gradual facies change from near shore to deep sea. On the whole, it could be interpreted that, deposition of this member took place in a slowly sinking basin and/or deposition with episodic sea level rise and fall coupled with active fault block adjustment (in minor scale) after major movement.

With due sinking of the coastal basin and/or sea level rise, deep marine conditions were established and thick pile of Karai Formation clays were deposited. Deposition of about 450 m thick clay alternated with ferruginous silty clays and gypsiferous layers suggests well developed fluvial system onland that supplied suspended sediment load continuously to deep marine regions. Thick population of belemnites, silty admixture, alternate thin-thick lamina of ferruginous silty clay and gypsiferous clay bands are frequent in the southern region indicative of deposition also in shallower regions of paleosea. These shallower regions were periodically exposed subaerially due to minor sea level oscillations to produce evaporites. The top surface of this formation is marked by a pronounced erosional surface that suggests major regression at the end of the deposition. This erosional surface is overlain immediately by subtidal-supratidal ferruginous sandstones along with shell banks typical of estuary and shell hash typical of shallow water shoals/distributary mouth bars that represent Kulakkanattam and Grey sandstone members of the Garudamangalam Formation. Together, their occurrences indicate shoreline retreat and associated advancement of fluvial system over former offshore areas. This inference is substantiated by sudden appearance of large tree trunks in these sandstones. Although the boundary between the Karai clays and the Kulakkanattam sandstones is an erosional unconformity, presence of conformable relationship and near parallel bedding planes of rocks between them suggests simple sea level variation and introduction of newer environmental conditions rather than fault controlled environmental change across the boundary. The deep-water conditions were restored again in this part of the basin with the introduction of deposition of the Anaipadi sandstone member that shows gradual increase of sea level. Break in sedimentation, probably influenced by major regression was witnessed at the end of deposition of the Anaipadi sandstone member.

Renewed transgression initiated during the Middle Santonian covered the regions located north and south that were not transgressed previously. This widespread transgression, associated with downwarping of fault blocks, had submerged the coastal tracts up to Pondicherry in the north resulting in generation of Archaen–Santonian and Archaen–Campanian contact (faultline located north of Kilpalur – refer F3 in Fig. 1; Plate 1.6, 1.7, 1.8, 1.9). This period was associated with widespread erosion of basement rocks and older sedimentary rocks and their redeposition in the newly created depocenters. The Sillakkudi Formation of the Ariyalur Group, which has been the product of this widespread transgression, has three members. The lowermost member is a fluvial unit and shows transition to deposition under marine influence towards top. Major channels with a width of more than a kilometer and 30 m deep that incised older sedimentary rocks (Fig.1), were recognized in the field. The strata of this member have reverse graded basement boulder and lithoclastic conglomerates (Plate 1.6, 1.7, 1.8). They also show large scale advancing cross beds (Plate 1.7), alternate with ferruginous sandstone foresets. From the detailed facies and sequence analysis and tectonic structural information recognized in the field, RAMKUMAR *et al.* (2005a) interpreted overwhelming influence of sea level fluctuations over the depositional pattern, and continued seismicity influenced mechanical erosion and gravity assisted fluvial transport until the deposition of the Sadurbagam member. Continued rise of sea level had submerged the fluvial/estuarine mouth sediments and deposition in subtidal to intertidal environments occurred. This sea level rise has been overwhelming and covered large tracts of western part of the basin that remained positive since inception of the basin, as indicated by the contact between Archaen–Varanavasi member of the Sillakkudi Formation (Plate 1.9). Towards top, the Varanavasi member shows frequent occurrences of pebbly sandstone layers may be as a result of prevalent periodic higher energy conditions (RADULOVIĆ *et al.* 2015) and/or seismic aftershocks, erosional surfaces and reworked fauna. Localized occurrences of serpulid colonies at the top of this member indicate cessation of sediment supply, reducing sea level, reduced circulation and lower energy conditions. A major erosional unconformity separates this formation from overlying Kallankurichchi Formation.

The renewed transgression during the Latest Campanian–Early Maastrichtian was marked with widespread erosion of basement rocks and older sedimentary rocks. However, the size of the basement boulders and lithoclasts of older sedimentaries in the basal conglomerate member of this formation, rarely exceed 30 cm and are more rounded than their older counter parts. These clasts seem to be recycled from older sedimentary rocks rather than sourced fresh from basement rocks. Thus, the Kallar arenaceous member has lithoclastic conglomerate deposits at its base and rests over the Sillakkudi Formation (Plate 1.10) with distinct angular erosional unconformity. Biohermal and biostromal deposits constitute the Kallankurichchi Formation and denote cessation of Santonian-Campanian fluvial sediment supply. As the initial marine flooding started to wane out, the deposits show reduction in proportion and size of siliciclastics that were increasingly replaced by *gryphea* colonies. As the sea level was gradually increasing, the *gryphea* bank shifted towards shallower regions and the locations previously occupied by coastal conglomerate became middle shelf wherein typical *inoceramus* limestone started developing. Break in sedimentation of this member was associated with regression of sea level that had transformed the middle - outer shelf regions into intertidal - fair weather wave base regions.

These newer depositional conditions resulted in erosion of shell banks and middle shelf deposits and redeposition of them into biostromal deposits (Tancem biostromal member). As the energy conditions were high and deposition took place in shallower regions, frequent non-depositional and erosional surfaces, punctuated with cross bedded carbonate sand beds and tidal channel grainstones and storm deposits with hummocky cross stratification were deposited. Again, the sea level rose to create marine flooding surface and as a result of which, *gryphea* shell banks started developing more widely than before that represent the Srinivasapuram gryphean limestone member. Towards top of this member, shell fragments and minor amounts of siliciclastics are observed that indicate onset of regression and associated introduction of higher energy conditions and detrital influx. The occurrence of non-depositional surface at the top of this formation and deposition of shallow marine siliciclastics (Ottakoil Formation) in a restricted region immediately over the predominantly carbonate depocenter and conformable offlap of much younger fluvial sand deposits (Kallamedu Formation) are all suggestive of gradual regression associated with re-establishment of fluvial system (Plate 1.11) at the end of Cretaceous Period. Towards top of the Kallamedu Formation, paleosols are recorded implying abandonment of river system and restoration of continental conditions at the end of the Cretaceous Period.

At the beginning of Danian, transgression took place that covered only the eastern part of the Kallamedu Formation. Presence of conformable contact between the Anandavadi member and the Kallamedu Formation and initiation of carbonate deposition from the beginning of Danian are indicative of absence of any major tectonic activity and fluvial sediment supply at this time. Increase in sea level and establishment of shallow, wide shelf with open circulation paved way for the deposition of the Periyakurichchi member with cyclic marl-limestone couplets (Plate 1.12). At the top, this member has distinct erosional unconformity, which in turn, when interpreted along with the presence of huge thickness of continental sandstone (>4000 m thick Miocene–Pliocene Cuddalore sandstone Formation), indicates restoration of continental conditions in this basin. Absence of any other marine strata over the Cuddalore sandstone Formation suggests that the sea regressed at the end of Danian had never returned to this part of the Cauvery Basin.

The depositional cycles in the light of lithofacies characteristics (table 2) and succession (table 1) and geological events described above are summarized in the table 3. From these tables, it follows that, under favorable climatic and other conditions, significant influx of detrital materials (either with or without chemical weathering in the provenance area) to the depositional basin and resultant reduction in carbonate accumulation during sea level lowstands and conversely, reduction of detrital influx owing to the limited availability of terrestrial areas, shortening and/or drowning of fluvial channels and significant carbonate accumulation during sea level highstands, which are considered to be the fundamental processes of sequence development were in operation in this basin for the whole of its depositional history except during the major tectonic events. From the tables 2 and 3, it could also be observed that at each change (either tectonic or sea level fluctuation), there were significant erosion (either the provenance area or former marine regions or both) and sediment recycling events, that have removed former sedimentary records partially or completely and obliterated the depositional continuum.

The sedimentation system is dominated by cyclic processes that operate on a hierarchy of temporal and spatial scales on which short-lived events are superimposed (Veizer *et al.* 1997). As a consequence, only a net result of cycles and events could be recognized in rock records. Cyclic sedimentation has been documented in several sedimentary basins and there are many lines of evidences that relate those cycles to short-term (Milankovitch band) glacio-eustatic pulses (Grammer *et al.* 1996). At this juncture, report of occurrences of all the six global sea level peaks of eustatic in origin, occurrences of 100% distinct six chemozones (Ramkumar *et al.* 2010b, 2011) in tune with third order sea level cycles, pristine nature of geochemical characteristics of the rocks (Ramkumar *et al.* 2006) are all suggestive of predominance of climate-sea level cycle controlled depositional pattern in this basin. However, the major faulting during Barremian and reactivation of faults during depositional history, as observed from field and lithofacies characteristics necessitates examining the impact of these events over the depositional system.

Relative influences of tectonics and sea level fluctuations over the depositional cycles

The general knowledge about a geochemical system allows establishing a definite number of processes governing the sedimentary system namely, the redox conditions, detrital input, changes in provenance and quantum of sediment influx and climate, etc, (Pinto *et al.* 2004; Montero-Serrano *et al.* 2010). The occurrences of inverse relationships between the Si, Ti, Zr and Ca, (Fig. 3), when corroborated with the lithofacies alternations between siliciclastics and carbonates (table 2) and

Table 3. Geological events of the Cauvery Basin as inferred from the exposed area.

	AGE	FORMATION	MEMBER	EVENTS
Tertiary	Mio-Pliocene	Cuddalore S.st. Fm.		Continental deposition, tropic climate
		~ Unconformity ~		Total regression, sequence boundary
	Danian	Niniyur Fm.	Periyakurichchi biostromal Mbr.	Marine flooding
			Anandavadi arenaceous Mbr.	
		~ Unconformity ~		Major transgression, K-T boundary
Upper Cretaceous	Maastrichtian	Kallamedu Fm.		
		~ Unconformity ~		Total regression
		Ottakoil Fm.		
		~ Unconformity ~		Sealevel fall, cessasion of carbonate deposition
		Kallankurichchi Fm.	Srinivasapuram gryphean L.st. Mbr.	Marine flooding
			Tancem biostromal Mbr.	Regression, tidal channel & storm deposits
			Kattupiringiyam inoceramus L.st. Mbr.	Marine flooding
			Kallar arenaceous Mbr.	
	Campanian	~ Unconformity ~		Sequence boundary, regression & transgression
		Sillakkudi Fm.	Varanavasi S.st. Mbr.	Marine flooding
			Sadurbagam pebbly S.st. Mbr.	Transgression
	Santonian		Varakuppai lithoclastic conglomerate Mbr.	Fluvial, estuarine & coastal deposition
		~ Unconformity ~		Faulting, regression, sequence boundary
	Coniacian	Garudamangalam Fm.	Anaipadi S.st. Mbr.	
			Grey S.st. Mbr.	Marine flooding
	Turonian		Kulakkanattam S.st. Mbr.	Regression
		~ Unconformity ~		Major sequence boundary, regression
		Karai Fm.	Odiyam sandy clay Mbr.	Sealevel fall, fluvial influx increase
			Gypsiferous clay Mbr.	
	Cenomanian	~ Unconformity ~		Major flooding surface
		Dalmiapuram Fm.	Kallakkudi calcareous S.st. Mbr.	Gradual sealevel fall
			Olaipadi conglomerate Mbr.	Faulting, erosion, resedimentation
Lower Cretaceous	Albian		Dalmia biohermal L.st. Mbr.	Marine flooding and slow fall
			Varagupadi biostromal L.st. Mbr.	Sealevel rise & open marine conditions
			Grey shale Mbr.	Periodic Restricted marine sedimentation
		~ Unconformity ~		Sequence boundary, faulting, erosion
	Aptian	Sivaganga Fm.	Terani clay Mbr.	Severe continental weathering, facies variation
			Kovandankurichchi S.st. Mbr.	Erosional unconformity, flooding
	Barremian		Basal conglomerate Mbr.	
		~ Unconformity ~		Initial block faulting, sequence boundary
		Archaen granitic gneiss		

their synchronicity with sea level lows and highs respectively (Fig. 2), allow interpretation of sea level controlled depositional pattern in this basin. Decrease in Si and many metals typical of heavy minerals are observed from these profiles (Fig. 3) and can be interpreted as the result of transgressions (HILD & BRUMSACK, 1998). Similarly, the reduction of Ca content is found to be associated with regressions. As could be observed elsewhere (RACHOLD & BRUMSACK, 2001; HOFMANN *et al.* 2001; BOULILA *et al.* 2010), whenever siliciclastic deposition ceased, carbonate deposition was initiated (WARZESKI *et al.* 1996) in this basin. From the Falcon Basin, northwestern Venezuela, MONTERO-SERRANO *et al.* (2010) reported similar geochemical elemental grouping in terms of either detrital or carbonate as a result of siliciclastic-carbonate lithofacies alternations. SARG (1988) observed that, sedimentary basins starve for detrital sediments during high stands that lead to development of carbonates. A recent review of previously published information on evolutionary stages and sequence development in the Cauvery Basin (KALE 2011) suggested the availability of larger accommodation space than the sediment influx all through its evolutionary history. It also means that there might be climatic control over the observed lithofacies-geochemical grouping alternations.

RUFFEL & RAWSON (1994) and SOREGHAN (1997) opined that dry periods might cause a deficit in detrital supply and favor deposition of carbonates. It supports the interpretation of occurrences of sea level highstands during interglacial periods (warmer than glacial periods) and resultant general aridity and deprivation of clastic sediment supply. The glacial periods promote enhanced terrigenous supply to the depocenters in view of shelf erosion (KAMPSCHULTE *et al.* 2001) and fluvial system advancement (SARG, 1988; CARTER *et al.* 1991). Occurrences of paleochannel courses (Fig. 1) and their association with siliciclastic deposits, erosion during the periods of lower sea level, influenced also by the proximity to source rocks and adequate slope could be inferred from the configuration of the Cauvery Basin. Occurrences of unaltered lithoclasts and feldspar clasts in rocks that immediately follow regressive surfaces also suggest the prevalent mechanical erosion, rapid and short duration of transport and quick burial. Such rapid physical erosion and textural immaturity of ensuing sediments could have produced the co-variation of Si and other elements associated with quartz, feldspar and other silicates. Based on the occurrences of all the six global sea level peaks, recognized independently through foraminifer (RAJU & RAVINDRAN, 1990; RAJU *et al.* 1993) and geochemical data (RAMKUMAR *et al.* 2005b; 2010b; 2011), influence of climate controlled eustatic sea level changes, over the depositional pattern of the basin is affirmed.

The element Y shows a peculiar polynomial peak across Aptian–Albian boundary (Fig. 3), subdued nature during most of the successive period until latter part of middle Albian and gradual increase then onward, a significant peak during Coniacian and finally a gradual decrease. In magnitude and scale, it mimics Zr (Fig. 3). As the element Y undergoes little or no diagenetic alterations (ANDREW *et al.* 1996; DAS 1997; PINTO *et al*. 2004; MONTERO-SERRANO *et al.* 2010), presence of its short and significantly prominent peaks exactly coinciding faulting events (Fig. 1) and associated change in sedimentation pattern (Table 2) indicates influx of Y immediately after major tectonic movements and resultant change in nature, quantum and composition of detrital influx into the basin. Sedimentation pattern and nature of sediments of the periods between Barremian–Coniacian and Santonian–Danian were different and are reflected in the patterns of Y and Zr during these two time spans. The differences between these elements in terms of temporal resolution may be a consequence of their differential response (WHITFORD *et al.* 1996) to prevalent depositional environmental conditions as enforced/introduced by the major tectonic event. DUBICKA *et al*. (2014) also observed significant changes in environmental conditions due to Subhercynian tectonic movements in Ukrine during Coniacian–Santonian. Enrichment of these elements up to Coniacian and their subdued nature after Coniacian could be attributed to the changes brought in by major tectonic activity occurred during Santonian, across which significant changes in proximity of sediment source and nature and quantum of detrital influx were witnessed (SUNDARAM & RAO, 1986).

The abundance of Zr in clastic rocks was interpreted to be the result of detrital influx as well as sediment recycling (SPALLETTI *et al*. 2008). Occurrences of generally higher levels of Zr all through the Barremian–Danian with the exception of latest Campanian–middle Maastrichtian (Kallankurichchi Formation) and many episodes of positive excursions over this general trend suggest sediment starved nature of the basin and significant recycling of older sedimentary rocks. Ti and Zr are generally assumed to represent detrital inputs into a sedimentary basin and their variations should be related with changes in weathering conditions in the hinterland or changes of provenance (BELLANCA *et al.* 2002). Zr and Ti are considered to be effective in discriminating volcanoclastic sediments and also sediments of different diagenetic and tectonic histories (ANDREOZZI *et al.* 1997). Zirconium is mostly concentrated in zircons, which accumulate during sedimentation while less resistant phases are preferentially destroyed (ALVAREZ & ROSER, 2007). Peak enrichments of Zr during middle Cenomanian (Gypsiferous clay member), latest Cenomanian (Odium member), middle Campanian (Varakuppai member), middle-late Maastrichtian (Ottakoil Formation), early Danian (Anandavadi member) are observed and interpreted as the durations of influx and cessation of terrigenous materials which in turn might have been controlled by variations in source area weathering and/or a change from more humid to more arid conditions or tectonic movements (MUNNECKE & WESTPHAL, 2004). SANDULLI & RASPINI (2004) interpreted the elemental cycles as the precession and obliquity periodicities, the bundles and superbundles into short and long eccentricity cycles and similar inference could be made to the rocks under study.

The source area consists of granitic gneisses in low lying plains and massive hills of charnockite. These rocks consist of very coarse grained plagioclase, smaller grains of quartz, hypersthene, and amphibole as major minerals, magnetite, garnet, and biotite as minor minerals and zircon, rutile and apatite as accessory phases (SHARMA & RAJAMANI, 2001). Cutting across the granitic gneiss, pegmatite veins composed of large to very large feldspar crystals (at places ranging upto many tens of centimeters) occur frequently. The nature and extent of source rock weathering, physical sorting during transport and environmental conditions during deposition at the depocenters exert significant control over sediment geochemistry (SHARMA & RAJAMANI, 2001). The samples under study show that the period from Cenomanian–Coniacian have very high PIA values with a peak value during middle Turonian meaning that the plagioclase was almost totally destroyed by source area weathering during Cenomanian–Coniacian and during other periods, there was no such wholesome alteration. This observation, when compared with the conditions of chemical weathering at lower latitudes listed by BOUCOT & GREY (2001), and with paleogeographic location of the Cauvery Basin in the lower latitudes during Barremian–Maastrichtian, limited extent of the provenance and the configurations of the depositional basin and provenance, support the inference of weaker chemical weathering. SINGH & RAJAMANI (2001) studied the floodplain sediments of the modern (present day) Kaveri River and observed striking similarity of trace elemental and REE patterns between the rocks of the source area and the modern floodplain sediments. SHARMA & RAJAMANI (2000) reported weaker chemical weathering, exposure of fresh unaltered rocks in the provenance and interpreted these phenomena as the result of continued tectonic movements, due to which, only limited weathering profiles are exposed at the provenance. Taking clue from this, occurrences of unaltered basement rock clasts in rocks deposited during Barremian, Cenomanian, Aptian–Albian, Coniacian–Santonian, are interpreted as the durations of tectonic activity in this basin. These durations are also accompanied by significant positive excursions of Si, Ti, Zr and Y. This inference necessitates checking the consistency and dynamism of provenance and tectonic setting of these rocks.

The geochemical characteristics of clastic rocks have been used to decipher the provenance (TAYLOR & MCLENNAN 1985; PINTO *et al.* 2004). The SiO_2/Al_2O_3 ratio is sensitive to sediment recycling and the weathering process and can be used as an indicator of sediment maturity (ROSER & KORSCH, 1986). The average SiO_2/Al_2O_3 ratios in unaltered igneous rocks range from ~3.0 (basic) to ~5.0 (acidic), while values >5.0–6.0 in sediments are an indication of progressive maturity (ROSER *et al.* 1996). Examination of the rocks under study in the light of these precepts and by plotting the data in established discrimination diagrams of textural maturity, and tectonic setting have revealed the following.

The plots of two distinct clusters in the bivariate diagrams of oxide percentages (Fig. 4), most of the samples in the texturally immature fields (Fig. 5) namely, (litharenite, wacke, arkose, subarkose etc), all the samples below the average shale discriminant line, existence of two-cluster nature (Fig. 6), all the samples below the feldspar join together with selective samples of Dalmiapuram, Karai, Garudamangalam and Sillakkudi formations above the feldspar join (Fig. 7) are all supportive of the inferences of limited extent of provenance, proximity to provenance, sediment starved nature of the sedimentary basin, prevalence of less significant chemical weathering, and predomination of siliciclastic-carbonate alternate cycles under the influences of relative sea level fluctuations.

The Indian subcontinent was located at the southern latitudes during the deposition of the Ottakoil and Kallamedu formations (RAI *et al.* 2012). The studies of LAL *et al.* (2009), KALE (2011), CHATTERJEE *et al.* (2013), have shown that the Indian subcontinent was on a flight at various rates and directions since its breakup from Africa-Antartica and was above the Reunion hotspot (MORGAN 1981; SHETH & CHANDRASEKHARAM 1997; CHATTERJEE *et al.* 2013) or the Vishnu Fracture (SHETH 1999) during the late Cretaceous. The present observations of plot of Barremian–Santonian samples in the active continental margin field, Campanian-Danian samples in the passive continental margin field and plot of few samples of Ottakoil and Kallamedu formations (Late Maastrichtian) in the island arc field (Fig. 8) are all supportive of changing palaeogeographic positions and tectonic dynamism of the Indian plate. The change of depositional pattern across Santonian as indicated by lithofacies and geochemical characteristics are also supported by the change of tectonic setting across Santonian (from active to passive continental margin), suggestive of the sensitivity of geochemical parameters to climate-sea level fluctuations, tectonic movements, rates of sediment influx and chemical weathering.

The recognition of island arc setting in the sedimentary records of the Kallamedu Formation is important from the point of Cretaceous–Tertiary transitional environmental conditions in this part of the country. Though previous studies have either presumed or suggested the influence of Deccan volcanism and the presence of vitrified volcanic ash deposits in this formation, due to the inherent lithological characteristics (thin lamina of fine grained and also diagenetically altered sediments amidst coarse, recycled sediments of varying bed thicknesses which in turn were cut across by calcrete and silcrete veins), and scattered and weathered nature of the exposures, usually thwarted characterizing these deposits so far. This is the first time, the affinity of argillaceous siltstone beds of the Kallamedu Formation are unequivocally affiliated with volcanogenic sediment source. ANDREOZZI *et al.* (1997) commented that distinctive beds, particularly volcaniclastic layers which may be useful for stratigraphic and environmental reconstruction, may escape field identification because their recognition generally depends on a marked lithological contrast with the surrounding sediments. Because of several factors such as fine grain size, intense diagenetic modifications, and selective weathering may hinder their identification. This statement stands true to the case of Kallamedu Formation.

Conclusions

The Barremian-Danian strata of the Cauvery Basin record all the six third order sea level cycles within which many high-frequency cycles could be recognized. These are reflected in the lithofacies and enrichment-depletion patterns of sensitive geochemical proxies.

The northward flight of the Indian subcontinent, in which the Cauvery Basin is located has experienced active and passive nature of the tectonic setting and passed through active volcanic plume, all of which are explicitly shown by the geochemical characteristics of the rocks contained in the Cauvery Basin.

The depositional system was under the predominant influence of climate-sea level fluctuations despite the recurrent major tectonic movements of fault blocks. Few of the tectonic fault movements have coincided with sequence boundaries (Barremian, Aptian–Albian, Coniacian–Santonian, Maastrichtian–Danian) and may have contributed to exacerbation of sea level cycles, particularly during the deposition of the Olaipadi, Varakuppai and Sadurbagam members. Thus, the present study supports the influence of tectonics, to the development of third order cycles of depositional system.

The predominance of mechanical weathering, prevalence of insignificant chemical weathering of the source rocks as indicated by textural immaturity and the occurrences of high-frequency cycles in the

Barremian–Coniacian deposits that have experienced syndepositional tectonic events and the prevalence of relatively stable environmental conditions during the period of tectonic quiescence (Campanian–Danian) are all suggestive of dominant role played by climate-relative sea level fluctuations.

While the recurrent sediment recycling events suggest reduced rates of subsidence (BUCHBINDER *et al.* 2000), the predominance of textural immaturity and mechanical erosion suggest dynamic nature of tectonism (SHARMA & RAJAMANI, 2000) suggesting the existences of balance between eustatic sea level fluctuations by tectonic events.

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References

ACHARYYA, S.K. & LAHIRI, T.C. 1991. Cretaceous palaeogeography of the Indian subcontinent: A review. *Cretaceous Research*, 12: 3–26.

Ali, J.R. & Aitchison, J.C. 2008. Gondwana to Asia: Plate tectonics, paleogeography and the biological connectivity of the Indian sub-continent from the Middle Jurassic through latest Eocene (166–35 Ma). *Earth Science Reviewes*, 88: 145–166.

ALVAREZ, N.O.C. & B.P. ROSER, B.P. 2007. Geochemistry of black shales from the Lower Cretaceous Paja Formation, Eastern Cordillera, Colombia: Source weathering, provenance, and tectonic setting. *Journal of South American Earth Sciences,* 23: 271–289.

ANDERSON, J.B., ABDULAH, K. & SARZALEJO, S. 1996. Late Quaternary sedimentation and high-resolution sequence stratigraphy of the east Texas shelf. *In*: DE BATIST, M. & JACOBS, P. (Eds), *Geology of siliciclastic shelf seas*, 95–124. Geological Society Special Publication, 117.

ANDREW, A.S., WHITFORD, D.J., HAMILTON, P.J., SCARANO, S. & BUCKLEY, M. 1996. Application of chemostratigraphy to petroleum exploration and field appraisal. An example from the Surat basin. *Proceedings of Seminar on Asia Pacific Oil and Gas*, 421–429.

ANDREOZZI, M., DINELLI, E. & TATEO, F. 1997. Geochemical and mineralogical criteria for the identification of ash layers in the stratigraphic framework of a foredeep: The Early Miocene Mt. Cervarola sandstones, northern Italy. *Chemical Geology*, 137: 23–39.

AYYASAMY, K. 1990. Cretaceous heteromorph ammonoid biostratigraphy of southern India. *Newsletters in Stratigraphy*, 22: 111-118.

BACHMANN, M., AMIN, M., BASSIOUNI, A. & KUSS, J. 2003. Timing of mid-Cretaceous carbonate platform depositional cycles, northern Sinai, Egypt. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 200: 131–162.

BANERJI, R.K. 1972. Stratigraphy and micropalaeontology of the Cauvery basin. Part I, exposed area. *Journal of the Palaeontological Society of India*, 17: 1–24.

BELLANCA, A., ERBA, E., NERI, R., SILVA, I.P., SPROVIERI, M., TREMOLADA, F. & VERGA, D. 2002. Palaeoceanographic signifiance of the Tethyan 'Livello Selli' (Early Aptian) from the Hybla Formation, northwestern Sicily: Biostratigraphy and high-resolution chemostratigraphic records. *Palaeogeography Palaeoclimatology Palaeoecology*, 185: 175–196.

BHATIA, M.R. 1983. Plate tectonics and geochemical composition of sandstones. *Geology*, 91: 611–627.

BHATIA, S.B. 1984. Ostracode faunas of the Indian subcontinent-their palaeozoogeographic and palaeoecologic implications. *Journal of the Palaeontological Society of India*, 20: 1–8.

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

Bhattacharya, J.P., & Willis, B.J. 2001. Lowstand Deltas in the Frontier Formation, Powder River Basin, Wyoming: Implications for sequence stratigraphic models, U.S.A. *American Association of Petroleum Geologists Bulletin*, 85: 261–294.

BICE, K.L. & NORRIS, R.D. 2002. Possible atmospheric CO_2

extremes of the Middle Cretaceous (late Albian-Turonian). *Palaeoceanography*. v.17. doi:10.1029/2002PA000778.

BOULILA, S., DE RAFÉLIS, M., HINNOV, L.A., GARDIN, S., GALBRUN, B. & COLLIN, P. 2010. Orbitally forced climate and sea-level changes in the Paleoceanic Tethyan domain (marl–limestone alternations, Lower Kimmeridgian, SE France). *Palaeogeography Palaeoclimatology Palaeoecology*, 292: 7–70.

BRETT, C.E., MCLAUGHLIN, P.I., CORNELL, S.R. & BAIRD, G.C. 2004. Comparative sequence stratigraphy of two classic Upper Ordovician successions, Trenton Shelf (New York–Ontario) and Lexington Platform (Kentucky–Ohio): implications for eustasy and local tectonism in eastern Laurentia. *Palaeogeography Palaeoclimatology Palaeoecology*, 210: 295–329.

BUCHBINDER, B., BENJAMINI, C. & LIPSON-BENITAH, S. 2000. Sequence development of Late Cenomanian–Turonian carbonate ramps, platforms and basins in Israel. *Cretaceous Research*, 21: 813–843.

CALVER, C.R. 2000. Isotope stratigraphy of the Ediacarian (Neoproterozoic III) of the Adelaide rift complex, Australia and the overprint of water column stratification. PRECAMBRIAN RESEARCH, 100: 121–150.

CARTER, R.M., ABBOTT, S.T., FULTHORPE, C.S., HAYWICK, D.W. & HENDERSON, R.A. 1991. Application of global sea level and sequence stratigraphic models on Southern hemisphere Neogene strata from New Zealand. *International Association of Sedimentologists Special Publication*, 12: 41–65.

CATUNEANU, O. 2006. Principles of Sequence Stratigraphy. Elsevier B.V.

CATUNEANU, O., GALLOWAY, W.E., KENDALL, C.G.ST.C., MIALL, A.D., POSAMENTIER, H.W., & STRASSER, A. 2011. Sequence Stratigraphy: Methodology and Nomenclature. *Newsletters in Stratigraphy*, 44: 173–245.

CATUNEANU, O., ABREU, V., BHATTACHARYA, J.P., BLUM, M.D., DALRYMPLE, R.W., ERIKSSON, P.G., FIELDING, C.R., FISHER, W.L., GALLOWAY, W.E., GIBLING, M.R., GILES, K.A., HOLBROOK, J.M., JORDAN, R., KENDALL, C.G.ST.C., MACURDA, B., MARTINSEN, O.J., MIALL, A.D., NEAL, J.E., NUMMEDAL, D., POMAR, L., POSAMENTIER, H.W., PRATT, B.R., SARG, J.F., SHANLEY, K.W., STEEL, R.J., STRASSER, A., TUCKER, M.E. & WINKER, C. 2009. Towards the standardization of sequence stratigraphy. Earth Science Reviews, 92: 1–33.

CATUNEANU, O., BHATTACHARYA, J. P., BLUM, M. D., DALRYMPLE, R.W., ERIKSSON, P.G., FIELDING, C.R., FISHER, W.L., GALLOWAY, W.E., GIANOLLA, P., GIBLING, M.R., GILES, K.A., HOLBROOK, J.M., JORDAN, R., KENDALL, C.G.ST.C., MACURDA, B., MARTINSEN, O.J., MIALL, A.D., NUMMEDAL, D., POSAMENTIER, H.W., PRATT, B.R., SHANLEY, K.W., STEEL, R. J., STRASSER, A. & TUCKER, M.E., 2010. Sequence stratigraphy: Common ground after three decades of development. *First Break*, 28: 21–34.

CHARI, M. V. N., SAHU, J. N., BANERJEE, B., ZUTSHI, P. L. & CHANDRA, K. 1995. Evolution of the Cauvery Basin, India from subsidence modeling. *Marine and Petroleum Geology*, 12: 667–675.

CHANDRA, P.K. 1991. Sedimentary basins of India. Presidential address of VIII Convention of Indian Geological Congress, 1–31.

CHATTERJEE, S., GOSWAMI, A. & SCOTESE, C. R. 2013. The longest voyage: Tectonic, magmatic, and paleoclimatic evolution of the Indian plate during its northward flight from Gondwana to Asia. *Gondwana Research*, 23: 238–267.

CHIPLONKAR, G.W. 1987. Three decades of invertebrate palaeontology and biostratigraphy of marine Cretaceous rocks of India. Geological Survey of India Special Publication, 11: 305–339.

CINGOLANI, C.A., MANASSERO, M. & ABRE, P. 2003. Coposition, provenance, and tectonic setting of Ordovician siliciclastic rocks in the San Rafael block: Southern extension of the Precordillera crustal fragment, Argentina. *Journal of South American Earth Sciences*, 16: 91–106.

CLOETING, S. 1988. Intraplate stress: A tectonic cause for third order cycles in apparent sealevel? *In*: WILGUS, C.K., HASTINGS, B.S., KENDAL, C.G.ST.C., POSAMENTIER, H.W., ROSS, C.A. & VAN WAGONER, J.C. (Eds), Sea level changes – An integrated approach, 19–29. SEPM Special Publication 42.

COCCIONI, R. & GALEOTTI, S. 2003. The mid-Cenomanian event: prelude to OAE 2. *Palaeogeography Palaeoclimatology Palaeoecology*, 190: 427–440.

DAS, N. 1997. Chemostratigraphy of sedimentary sequences: A review of the state of the art. *Journal of the Geological Society of India*, 49: 621–628.

DUBICKA, Z., PERYT, D. & SZUSZKIEWICZ, M. 2014. Foraminiferal evidence for paleogeographic and paleoenvironmental changes across the Coniacian-Santonian boundary in western Ukrine. *Palaeogeography Palaeoclimatology Palaeoecology*, 401: 43–56.

ELRICK, M. & SCOTT, L.A. 2010. Carbon and oxygen isotope evidence for high-frequency (10^4–10^5 yr) and My-scale glacio-eustasy in Middle Pennsylvanian cyclic carbonates (Gray Mesa Formation), central New Mexico. *Palaeogeography Palaeoclimatology Palaeoecology*, 285: 307–320.

GALE, A.S., HARDENBOL, J., HATHWAY, B., KENNEDY, W.J., YOUNG, J.R. & PHANSALKAR, V. 2002. Global correlation of Cenomanian (Upper Cretaceous) sequences: Evidence for Milankovitch control on sea level. *Geology*, 30: 291–294.

GALE, A.S., VOIGT, S., SAGEMAN, B.B. & KENNEDY, W.J. 2008. Eustatic sea level record for the Cenomanian (Late Cretaceous)—Extension to the Western Interior Basin, USA. *Geology*, 36: 859–862.

GALEOTTI, S., RUSCIADELLI, G., SPROVIERI, M., LANCI, L., GAUDIO, A. & PEKAR, S. 2009. Sea level control on facies architecture in the Cenomanian–Coniacian Apulian margin (Western Tethys): A record of glacio-eustatic fluctuations during the Cretaceous greenhouse? *Palaeogeography Palaeoclimatology Palaeoecology*, 276: 196–205.

GIL, J., GARCÍA-HIDALGO, J.F., SEGURA, M., GARCÍA, A. & CARENAS, B. 2006. Stratigraphic architecture, palaeogeography and sea-level changes of a third order depositional sequence: The late Turonian–early Coniacian in the northern Iberian Ranges and Central System (Spain). *Sedimentary Geology*, 191: 191–225.

Goldhammer, R.K., Dunn, P.A., & Hardie, L.A. 1987. High-frequency glacio-eustatic sea level oscillations with Milankovitch characteristics recorded in Middle Triassic platform carbonates in northern Italy. *American Journal of Science*, 287: 853–892.

Goldhammer R.K, Oswald E.J. & Dunn P.A. 1991. Hierarchy of stratigraphic forcing: Example from Middle Pennsylvanian shelf carbonates of the Paradox basin. *In*: Franseen, E.K., Watney, W.L. & Kendall, C.G.St.C., (Eds.), *Sedimentary modeling*, 361–413. Kansas Geological Survey Bulletin, 233.

Govindhan, A., Ravindran, C.N. & Rangaraju, M.K.R. 1996. Cretaceous stratigraphy and planktonic foraminiferal zonation of Cauvery basin, South India. *In*: Sahni, A. (Ed.), *Cretaceous stratigraphy and palaeoenvironments*, 155–187. Memoirs of Geological Society of India, 37.

Govindan, A., Ananthanarayanan, S. & Vijayalakshmi, K.G. 2000. Cretaceous petroleum system in Cauvery basin, India. *In*: Govindhan, A. (Ed), *Cretaceous stratigraphy - An update*, 365–382. Memoirs of Geological Society of India, 46.

Grammer, G.M., Eberli, G.P. & Van Buchem, F.S.P. 1996. Application of high resolution sequence stratigraphy to evaluate lateral variability in outcrop and subsurface – Desert Creek and Ismay intervals, Paradox basin. *In*: Longman, M. W. & Sonnelfeld, M. D., (Eds.), *Paleozoic systems of the Rocky mountain region, Rocky mountain section*, 235–266. SEPM.

Guha, A.K. 1987. Palaeoecology of some upper Creaceous sediments of India-an approach based on bryozoa. *Geological Survey of India Special Publication*, 11: 419–429.

Guha, A.K. & Senthilnathan, D. 1990. Onychocellids (Bryozoa: Cheilostomata) from the Ariyalur carbonate sediments of south India. *Journal of the Palaeontological Society of India*, 35: 41–51.

Guha, A.K. & Senthilnathan, D. 1996. Bryozoan fauna of the Ariyalur Group (Late Cretaceous) Tamil Nadu and Pondicherry, India. *Palaeontologica Indica*, 49: 2–17.

Gradstein, F.M., Ogg, J.G., Smith, A.G. (Eds.), 2004. A new geologic time scale 2004. Cambridge University Press, Cambridge. 464p.

Haq, B.U. 2014. Cretaceous eustasy revisited. *Global and Planetary Change*, 113: 44–58.

Haq, B.U., Hardenbol, J. & Vail, P.R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235, 1156–1167.

Hays, J.D., Imbrie, J. & Shackleton, N.J. 1976. Variations in the earth's orbit: Pacemaker of the ice ages. *Science*, 194: 1121–1132.

Herrle, J.O., Pross, J., Friedrich, O., Kossler, P. & Hemleben, C. 2003. Forcing mechanisms for mid-Cretaceous black shale formation: evidence from the Upper Aptian and Lower Albian of the Vocontian Basin (SE France). *Palaeogeography Palaeoclimatology Palaeoecology*, 190: 399–426.

Hild, E. & Brumsack, H.J. 1998. Major and minor element geochemistry of Lower Aptian sediments from the NW German basin (core Hoheneggelsen KB 40). *Cretaceous Research*, 19: 615–633.

Hinderer, M. 2012. From gullies to mountain belts: A review of sediment budgets at various scales. *Sedimentary Geology*, 280: 21–59.

Hilgen, F.J., Hinnov, L.A., Aziz, H.A., Abels, H.A., Batenburg, S., Bosmans, J.H.C., de Boer, B., Hüsing, S.K., Kuiper, K.F., Lourens, L.J., Rivera, T., Tuenter, E., Van de Wal, R.S.W., Wotzlaw, J. & Zeeden, C. 2014. Stratigraphic continuity and fragmentary sedimentation: the success of cyclostratigraphy as part of integrated stratigraphy. *Geological Society Special Publication*, 404. doi 10.1144/SP404.12.

Hiscott, R.N. 2001. Depositional sequences controlled by high rates of sediment supply, sea level variations and growth faulting: The Quaternary Baram delta of northwestern Borneo. *Inter. Journal of Marine Geology Geochemistry Geophysics*, 175: 67–102.

Hofmann, P., Ricken, W., Schwark, L. & Leythaeuser, D. 2001. Geochemical signature and related climatic-oceanographic processes for early Albian black shales: Site 417D, North Atlantic Ocean. *Cretaceous Research*, 22: 243–257.

Jafar, S.A. 1996. The evolution of marine Cretaceous basins of India: calibration with nannofossil zones. *In*: Sahni, A. (ed.), *Cretaceous stratigraphy and palaeoenvironments*, 121-134. Memoirs of the Geological Society of India, 37.

Jafar, S.A. & Rai, J. 1989. Discovery of Albian nannoflora from type Dalmiapuram Formation, Cauvery basin, India-Palaeooceanographic remarks. *Current Science*, 58: 358–363.

Kale, A.S. 2011. Comments on 'Sequence surfaces and paleobathymetric trends in Albian to Maastrichtian sediments of Ariyalur area, Cauvery Basin, India' from Nagendra, Kannan, Sen, Gilbert, Bakkiaraj, Reddy, and Jaiprakash. Marine and Petroleum Geology, 2010, 1–8. doi:10.1016/j.marpetgeo.2010.04.002.

Kale, A.S. & Phansalkar, V.G. 1992. Calcareous nannofossils from the Uttatur Group, Trichinopoly District, Tamil Nadu, India. *Journal of the Palaeontological Society of India*, 37: 85–102.

Kale, A.S., Lotfalikani, A. & Phansalkar, V.G. 2000. Calcareous nanofossils from the Uttatur group of Trichinopoly Cretaceous, South India. *In*: Govindan, A. (Ed.), *Cretaceous stratigraphy-an update*, 213–227. Memoirs of the Geological Society of India, 46.

Kampschulte, A., Bruckschen, P. & Strauss, H. 2001. The sulphur isotope composition of trace sulphates in Carboniferous brachiopods: Implications for coeval seawater correlation with other geochemical cycles and isotope stratigraphy. *Chemical Geology*, 175: 149-173.

Keller, G., Berner, Z., Adatte, T. & Stueben, D. 2004. Cenomanian–Turonian and $\delta^{13}C$, and $\delta^{18}O$, sea level and salinity variations at Pueblo, Colorado. Palaeogeography Palaeoclimatology Palaeoecology 211, 19-43.

Kramar, U., 1997. Advances in energy-dispersive X-ray fluorescence. *Journal of Geochemical Exploration*, 58: 73–80.

KULPECZ, A.A., MILLER, K.G., BROWNING, J.V., EDWARDS, L.E., POWARS, D.S., MCLAUGHLIN, P.P., JR., HARRIS, A.D., & FEIGENSON, M.D. 2009. Postimpact deposition in the Chesapeake Bay impact structure: Variations in eustasy, compaction, sediment supply, and passive-aggressive tectonism. *In*: Gohn, G.S., KOEBERL, C., MILLER, K.G., & REIMOLD, W.U. (eds.,) *The ICDP-USGS Deep Drilling Project in the Chesapeake Bay Impact Structure: Results from the Eyreville Core Holes*, 813–839. Geological Society of America Special Paper, 458.

LAL, N.K, SIAWAL, A. & KAUL, A.K. 2009. *Evolution of East Coast of India-A Plate Tectonic Reconstruction. Journal of the Geological Society of India*, 73: 249–260.

MONGELLI, G., CULLERS, R.L. & MUELHEISEN, S. 1996. Geochemistry of Late Cretaceous-Oligocene shales form the Varicolori Formation, Southern Apennines Italy: implications for mineralogical, grain-size control and provenance. *European Journal of Mineralogy*, 8: 733–754.

MASETTI, D., NERI, C., & BOSELLINI, A. 1991. Deep-water asymmetric cycles and progradation of carbonate platforms governed by high-frequency eustatic oscillations (Triassic of the Dolomites, Italy). *Geology*, 19: 336–339.

MEYERS, P. A. & SIMONEIT, B.R.T. 1989. Global comparisons of organic matter in sediments across the Cretaceous/Tertiary boundary. *Advances in Organic Geochemistry*, 16: 641–648.

MIALL, A.D. 1991. Stratigraphic sequences and their chronostratigraphic correlation. *Journal of Sedimentary Petrology*, 61: 497–505.

MIALL, A.D. 2009. Correlation of Sequences and the Global Eustasy Paradigm: A Review of Current Data. CSPG CSEG CWLS convention, Frontiers + Innovation. Alberta, Canada, 123–126.

MIALL, A.D. & MIALL, C.E. 2001. Sequence stratigraphy as a scientific enterprise: the evolution and persistence of conflicting paradigms. *Earth Science Reviews*, 54: 321–348.

MIDDLEBERG, J., CALVERT, S. & KARLIN, R. 1991. Organic-rich transitional facies in silled basins: response to sea level change. *Geology*, 19: 679–682.

MONTERO-SERRANO, J.C., PALAREA-ALBALADEJO, J., MARTÍN-FERNÁNDEZ, J.A., MARTÍNEZ-SANTANA, M. & GUTIÉRREZ-MARTÍN, J.V. 2010. Sedimentary chemofacies characterization by means of multivariate analysis. *Sedimentary Geology*, 228: 218–228.

MORGAN, W.J. 1981. Hotspot tracks and the opening of the Atlantic and Indian Oceans. *In*: EMILIANI, C. (ed.), *The Sea*, 443-475. Wiley Interscience, New York, 7.

MUNNECKE, A. & WESTPHAL, H. 2004. Shallow water aragonite recorded in bundles of limestone-marl alternations – the Upper Jurassic of SW Germany. *Sedimentary Geology*, 164: 191–202.

MUTTERLOSE, J., BODIN, S. & FÄHNRICH, L. 2014. Strontium-isotope stratigraphy of the Early Cretaceous (Valanginian-Barremian): Implications for Boreal-Tethys correlation and paleoclimate. *Cretaceous Research*, 50: 252–263.

NAJARRO, M., ROSALES, I. & MARTIN-CHIVELET, J. 2010. Major palaeoenvironmental perturbation in an Early Aptian carbonate platform: prelude of the Oceanic anoxic event 1a? Sedimentary Geology, 235 (1): 50–71. doi:10.1016/j.sedgeo.2010.03.011.

NELSON, C.S., HENDRY, C.H. & JARRETT, G.R. 1985. Near-synchroneity of New Zealand Alpine glaciations during the past 750 Kyr. *Nature*, 318: 361–363.

NESBITT, H.W. & YOUNG, G.M. 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, 299: 715–717.

OPPO, D.W. & FAIRBANKS, R.G. 1989. Carbon isotope composition of tropical surface wter during the past 22,000 years. *Paleoceanography*, 4: 333–351.

Oppo, D. W., Fairbanks, R. G. & Gordon, A. L., 1990. Late Pleistocene southern ocean $d^{13}C$ variability. Paleoceanography 5, 43-54.

PASLEY, M., RILEY, G. & NUMMEDAL, D. 1993. Sequence stratigraphic significance of organic matter variations: example from the upper Cretaceous mancos shale of the San Juan basin, New Mexico. *In*: KABZ, B. & PRATT, L. (Eds.), *Source rocks in a sequence stratigraphic framework*, 221–241. AAPG Studies in Geology, 37.

PELLENARD, P., TRAMOY, R., PUCÉAT, E., HURET, E., MARTINEZ, M., BRUNEAU, L. & THIERRY, J. 2014. Carbon cycle and sea-water palaeotemperature evolution at the Middle-Late Jurassic transition, eastern Paris Basin (France). *Marine and Petroleum Geology*, 53: 30–43.

PINTO, L., HERAIL, G., MOINE, B., FONTAN, F., CHARRIER, R. & DUPRE, B. 2004. Using geochemistry to establish the igneous provenances of the Neogene continental sedimentary rocks in the Central Depression and Altiplano, Central Andes. Sedimentary Geology, 166: 157–183.

POWELL, C.MC.A., ROOTS, S.R. & VEEVERS, J.J. 1988. Pre-break up continental extension in east Gondwanaland and the early opening of the Indian Ocean. *Tectonophysics*, 155: 261–283.

PRABHAKAR, K.N. & ZUTSHI, P.L. 1993. Evolution of southern part of Indian east coast basins. *Journal of the Geological Society of India*. 41: 215–230.

RACHOLD, V. & BRUMSACK, H.-J. 2001. Inorganic geochemistry of Albian sediments from the Lower Saxony Basin, NW Germany: Palaeoenvironmental constraints and orbital cycles. *Palaeogeography Palaeoclimatology Palaeoecology*, 174: 121–143.

RAI, R., RAMKUMAR, M. & SUGANTHA, T. 2012. Calcareous nannofossils from the Ottakoil Formation, Cauvery basin, South India: Implications on age, Biostratigraphic correlation and palaeobiogeography. *In*: RAMKUMAR, M. (Ed.). *On the sustenance of Earth's resources*, 109–122. Springer-Verlag, Heidelberg.

RADULOVIĆ, B.V., AYOUB-HANNAA, RADULOVIĆ, V.J. & BANJAC, N.J. 2015 *Sillakkudihynchia* gen. nov. (Rhynchonellida, Brachiopoda) from the Upper Cretaceous (Campanian) of the Cauvery Basin, southern India: Taxonomy, palaeoecology and palaeobiogeography. *Nuer Jahrbuch Geologie und Palaeontologie Abhandlung*, 276, 63–78.

RAJU, D.S.N. & RAVINDRAN, C.N. 1990. Cretaceous sea level changes and transgressive/regressive phases in India – A review. *Proceedings on Cretaceous event stratigraphy and the correlation of Indian non-marine strata, Contributions to Seminar cum Workshop on IGCP-216*, Chandigarh, 38–46.

RAJU, D.S.N., RAVINDRAN, C.N. & KALYANSUNDAR, R. 1993. Cretaceous cycles of sea level changes in Cauvery basin, India – A first revision. *Oil and Natural Gas Corporation Bulletin*, 30: 101–113.

RAMANATHAN, S 1968. Stratigraphy of the Cauvery basin with reference to its oil prospects. *In*: Cretaceous-Tertiary of south India. Memoirs of the Geological Society of India, 2: 153–167.

RAMKUMAR, M. 1996. Evolution of Cauvery basin and tectonic stabilization of parts of south Indian shield – Insights from structural and sedimentologic data. *Journal of the Geological Association and Research Centre,* 4: 1–15.

RAMKUMAR, M. 2007. Dolomitic limestone in the Kallankurichchi Formation (Lower Maastrichtian) Ariyalur Group, South India. *Journal of Earth Science*, 1: 7–21.

RAMKUMAR, M. 2008. Cyclic fine-grained deposits with polymict boulders in Olaipadi member of the Dalmiapuram Formation, Cauvery basin, south India: Plausible causes and sedimentation model. *Journal of Earth Science*, 2: 7–27.

RAMKUMAR, M. 2015. Toward standardization of terminologies and recognition of chemostratigraphy as a formal stratigraphic method. *In*: RAMKUMAR, M., (Ed.), *Chemostratigraphy: Concepts, techniques and applications*. 1–21. Elsevier. http://dx.doi.org/10.1016/B978-0-12-419968-2.00001-7.

RAMKUMAR, M. & CHANDRASEKARAN, V.A. 1996. Megafauna and environmental conditions of Kallankurichchi Formation (Lower Maestrichtian), Ariyalur Group, Tiruchy district, south India. *Journal of the Geological Association and Research Centre*, 4: 38–45.

RAMKUMAR, M., STÜBEN, D. & BERNER, Z. 2004a. Lithostratigraphy, depositional history and sea level changes of the Cauvery basin, South India. *Annales Geologiques de la Peninsule Balkanique*, 65: 1–27.

RAMKUMAR, M., STÜBEN, D., BERNER, Z. & SCHNEIDER, J. 2004b. Geochemical and isotopic anomalies preceding K/T boundary in the Cauvery basin, south India: Implications for the end Cretaceous events. *Current Science*, 87:1738–1747.

RAMKUMAR, M., SUBRAMANIAN, V. & STÜBEN, D. 2005a. Deltaic sedimentation during Cretaceous Period in the Northern Cauvery basin, South India: Facies architecture, depositional history and sequence stratigraphy. *Journal of the Geological Society of India*, 66: 81–94.

RAMKUMAR, M., HARTING, M. & STÜBEN, D. 2005b. Barium anomaly preceding K/T boundary: Plausible causes and implications on end Cretaceous events of K/T sections in Cauvery basin (India), Israel, NE-Mexico and Guatemala. *International Journal of Earth Sciences*, 94: 475–489.

RAMKUMAR, M., STÜBEN, D. & BERNER, Z. 2006. Elemental interrelationships and depositional controls of Barremian-Danian strata of the Cauvery basin, South India: Implications on scales of chemostratigraphic modelling. *Indian Journal of Geochemistry*, 21: 341–367.

RAMKUMAR, M., ANBARASU, K., SUGANTHA, T., JYOTSANA RAI., SATHISH, G. & SURESH, R. 2010a. Occurrences of KTB exposures and dinosaur nesting site near Sendurai, India: An initial report. *International Journal of Physical Sciences*, 22: 573–584.

RAMKUMAR, M., BERNER, Z. & STÜBEN, D. 2010b. Hierarchical delineation and multivariate statistical discrimination of chemozones of the Cauvery Basin, south India: Implications on spatio-temporal scales of stratigraphic correlation. *Petroleum Science*, 7: 435–447.

RAMKUMAR, M., STÜBEN, D., BERNER, Z. & SCHNEIDER, J. 2010c. $^{87}Sr/^{86}Sr$ anomalies in Late Cretaceous-Early Tertiary strata of the Cauvery Basin, south India: Constraints on nature and rate of environmental changes across K-T boundary. *Journal of Earth System Sciences*, 119: 1–17.

RAMKUMAR, M., STÜBEN, D. & BERNER, Z. 2011. Barremian–Danian chemostratigraphic sequences of the Cauvery Basin, India: Implications on scales of stratigraphic correlation. *Gondwana Research*, 19: 291–309.

RAYMO, E., OPPO, D.W. & CURRY, W. 1997. The mid-Pleistocene climate transition: A deepsea carbon isotopic perspective. *Paleoceanography*, 12: 546–559.

ROSER, B.P., COOPER, R.A., NATHAN, S. & TULLOCH, A.J. 1996. Reconnaissance sandstone geochemistry, provenance and tectonic setting of the lower Paleozoic terranes of the West Coast and Nelson, New Zealand. *New Zealand Journal of Geology and Geophysics*, 39: 1–16.

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

RUBAN, D.A. 2015. Mesozoic long-term eustatic cycles and their uncertain hierarchy. *Geoscience Frontiers*, 6: 503–511.

Ruban, D.A., Zorina, S.O., Conrad, C.P. & Afanasieva, N.I. 2012. In quest of Paleocene global-scale transgressions and regressions: constraints from a synthesis of regional trends. *Proceedings of the Geologists' Association*, 123: 7–18.

RUFFEL, A.H. & RAWSON, P.F. 1994. Paleoclimate control on sequence stratigraphic patterns in the Late Jurassic to Mid-Cretaceous, with a case study from eastern England. *Palaeogeography Palaeoclimatology Palaeoecology*, 110: 43–54.

SANDULLI, R. & RASPINI, A. 2004. Regional to global correlation of lower Cretaceous (Hauterivian-Barremian) shallow-water carbonates of the southern Appennines (Italy) and Dinarides (Montenegro), southern Tethyan margin. *Sedimentary Geology*, 65: 117–153.

SARG, J.F. 1988. Carbonate sequence stratigraphy. *In*: Sea level changes – An integrated approach. SEPM Special Publication, 42: 155–181.

SASTRI, V.V., VENKATACHALA, B.S. & NARAYANAN, V. 1981. The evolution of the east coast of India. *Palaeogeography Palaeoclimatology Palaeoecology*, 36: 23–54.

SHARMA, A. & RAJAMANI, V. 2000. Weathering of gneissic rocks in the upper reaches of Cauvery River, south India: implications to neotectonics of the region. *Chemical Geology,* 166: 203–223.

SHARMA, A. & RAJAMANI, V. 2001. Weathering of charnockites and sediment production in the catchment area of the Cauvery River, southern India. Sedimentary Geology, 43: 169–184.

SHETH, H.C. 1999. Flood basalts and large igneous provinces from deep mantle plumes: Fact, fiction, and fallacy. Tectanophysics, 311: 1–29.

SHETH, H.C. & CHANDRASHEKARAM, D. 1997. Plume-rift interaction in the Deccan volcanic province. *Physics of the Earth and Planetary Interior*, 99: 179–187.

SINGH, P. & RAJAMANI, V. 2001. Geochemistry of Kaveri flood plain sediments, southern India. *Journal of Sedimentary Research*, 71: 50–60.

SOREGHAN, G.S. 1997. Walther's law, climate changes and upper Palaeozoic cyclostratigraphy in the ancestral Rocky mountains. *Journal of Sedimentary Resesearch*, 67: 1002–1004.

SPALLETTI, L.A., POIRE, D.G., SCHWARZ, E. & VEIGA, G.D. 2001. Sedimentologic and sequence stratigraphic model of a Neocomian marine carbonate-siliciclastic ramp: Neuquen basin, Argentina. *Journal of the South American Earth Sciences*, 14: 609–624.

SPALLETTI, L.A., QUERALT, I., MATHEOS, S.D., COLOMBO, F. & MAGGI, J. 2008. Sedimentary petrology and geochemistry of siliciclastic rocks from the upper Jurassic Tordillo Formation (Neuque´n Basin, western Argentina): Implications for provenance and tectonic setting. *Journal of the South American Earth Sciences*, 25: 440–463.

Srinivasan, M.S. 1989. Recent advances in Neogene planktonic foraminiferal biostratigraphy, Chemostratigraphy and paleoceanography, Northern Indian Ocean. *Journal of the Palaeontological Society of India*, 34: 1–18.

STEPHENS, N.P. & SUMNER, D.Y. 2003. Late Devonian carbon isotope stratigraphy and sea level fluctuations, Canning Basin, Western Australia. *Palaeogeography Palaeoclimatology Palaeoecology*, 191: 203–219.

STRAUSS, H. 1997. The isotopic composition of sedimentary sulphur through time. *Palaeogeography Palaeoclimatology Palaeoecology,* 132: 97–118.

SUNDARAM, R. & RAO, P.S. 1986. Lithostratigraphy of Cretaceous and Palaeocene rocks of Tiruchirapalli district, Tamil Nadu, South India. *Records of the Geological Survey of India*, 115: 9–23.

SUNDARAM, R., HENDERSON, R.A., AYYASAMI, K. & STILWELL, J.D. 2001. A lithostratigraphic revision and palaeoenvironmental assessment of the Cretaceous System exposed in the onshore Cauvery Basin, southern India. *Cretaceous Research*, 22: 743–762.

STÜBEN, D., KRAMAR, U., BERNER, Z., STINNESBECK, W., KELLER, G. & ADATTE, T. 2002. Trace elements, stable isotopes and clay mineralogy of the Elles II K/T boundary section in Tunisia: Indications for sea level fluctuations and primary productivity. *Palaeogeography Palaeoclimatology Palaeoecology*, 178: 321–345.

TAYLOR, S.R. & MCLENNAN, S.M., 1985. The continental crust; its composition and evolution. *Blackwell, Oxford*, 312 p.

TEWARI, A., HART, M.B. & WATKINSON, M.P. 1996. A revised lithostratigraphic classification of the Cretaceous rocks of the Trichinopoly district, Cauvery basin, Southeast India. *In*: PANDEY, J., AZMI, R.J., BHANDARI A. & DAVE, A. (Eds), Contributions to the XV Indian Colloquium on Micropalaeontology and Stratigraphy. 789–800.

TU, T.T.N., BOCHERENS, H., MARIOTTI, A., BAUDIN, F., PONS, D., BROUTIN, J., DERENNE, S. & LARGEAU, C. 1999. Ecological distribution of Cenomanian terrestrial plants based on $\delta^{13}C/\delta^{12}C$ ratios. *Palaeogeography Palaeoclimatology Palaeoecology*, 145: 79–93.

ULIČNÝ, D., JARVIS, I., GRÖCKE, D.R., ČECH, S., LAURIN, J., OLDE, K., TRABUCHO-ALEXANDRE, J., ŠVÁBENICKÁ, L. & PEDENTCHOUK, N. 2014. A high-resolution carbon-isotope record of the Turonian stage correlated to a siliciclastic basin fill: Implications for mid-Cretaceous sea level change. *Palaeogeography Palaeoclimatology Palaeoecology*, 405: 42–58.

VAIL, P.R., MITCHUM, R.M. & THOMPSON, S. 1977. Seismic stratigraphy and global changes of sea level. Part 4 Global cycles of relative changes of sea level. *In*: Payton, C.E. (Ed.), *Seismic stratigraphy - Applications to hydrocarbon exploration*, 83–97. Memoirs of the American Association of Petroleum Geologists, 26.

VAKARELOV, B.K., BHATTACHARYA, J.P., & NEBRIGIC, D.D. 2006. Importance of high-frequency tectonic sequences during Greenhouse times of Earth history. *Geology*, 34: 797–800.

VAN DER MEER, D.G., ZEEBE, R.E., VAN HINSBERGEN, D.J.J., Sluijs, A., Spakman, W. & TORSWIK, T.H. 2014. Plate tectonic controls on atmospheric CO_2 levels since Triassic. www.pnas.org/cgi/doi/10.1073/pnas.1315657111.

VEIGA, G.D. & SPALLETTI, L.A. 2007. The Upper Jurassic (Kimmeridgian) fluvial–aeolian systems of the southern Neuquén Basin, Argentina. *Gondwana Research*, 11: 286–302.

VEIGA, G.D., HOWELL, J.A. & STÖRMBACK, A. 2005. Anatomy of a mixed marine–non-marine lowstand wedge in a ramp setting. The record of a Barremian–Aptian complex relative sea-level fall in the central Neuquen Basin, Argentina. *In*: VEIGA, G. D., SPALLETTI, L. A., HOWELL, J.A. & SCHWARZ, E. (Eds.), *The Neuquen Basin, Argentina: A Case Study in Sequence Stratigraphy and Basin Dynamics*, 139–162. Geological Society of London Special Publication, 252.

VEIZER, J. 1985. Carbonates and ancient oceans: Isotopic and chemical record on timescales of 10^7 – 10^9 years. *In*: SUNQUIST, E.T. & BROECKER, W.S. (Eds.), *The carbon cycle and* *atmospheric CO_2: Natural variations - Archaen to Present*, 595–601. American Geophysical Union Monograph, 32.

VEIZER, J., BRUCKSCHEN, P., PAWELLEK, F., DIENER, A., PODLAHA, O.G., CARDEN, G.A.F., JASPER, T., KORTE, C., STRAUSS, H., AZMY, K. & ALA, D. 1997. Oxygen isotope evolution of Phanerozoic seawater. *Palaeogeography Palaeoclimatology Palaeoecology*, 132: 59–172.

VEIZER, J., ALA, D. & AZMY, K. 1999. $^{87}Sr/^{86}Sr$, $\delta^{13}C$ and $\delta^{18}O$ evolution of Phanerozoic seawater. *Chemical Geology*, 161: 59–88.

VEIZER, J., GODDERIS, Y. & FRANCOIS, L.M. 2000. Evidence for decoupling of atmospheric CO_2 and global climate during the Phanerozoic eon. Nature, 408: 698–701.

WALLMANN, K. 2001. Controls on the Cretaceous and Cenozoic evolution of seawater composition, atmospheric CO_2 and climate. *Geochimica et Cosmochimica Acta*, 65: 3005–3025.

WARZESKI, E.R., CUNNINGHAM, K.J., GINSBURG, R.N., ANDERSON, J.B. & DING, Z. 1996. A Neogene mixed siliciclastic and carbonate foundation for the Quaternary carbonate shelf, Florida Keys. *Journal of Sedimentary Research*, 66: 788–800.

WATKINSON, M.P., HART, M.B. & JOSHI, A. 2007. Cretaceous tectonostratigraphy and the development of the Cauvery Basin, southeast India. *Petroleum Geoscience*, 13: 181–191.

WHITFORD, D.J., ALLAN, T.L., ANDREW, A.S., CRAVEN, S.J., HAMILTON, P.J., KORSCH, M.J., TROTTER, J.A. & VALENTI, G.L. 1996. Strontium isotope chronostratigraphy and geochemistry of the Darai limestone: Juha 1 X well, Papua New Guinea. Proceedings of III PNG convention. 369–380.

WILLIAMS, D.F., THUNELL, R.C. & TAPPA, E. 1988. Chronology of the Pleistocene oxygen isotope record 0 – 1.88 MY BP. *Palaeogeography Palaeoclimatology Palaeoecology*, 64: 221–240.

Резиме

Распознавање између активне тектонике, фаза мировања и циклуса релативног нивоа мора трећег реда у Каувери басену, јужна Индија

Теорија о секвенционом развоју дефинише седиментни систем који се налази под утицајем четири главне промењиве вредности, а то су тектонско тоњење, глобална еустатичка промена нивоа мора, количина приноса седимената и клима. Узастопна истраживања су показала да поједине седиментне секвенце могу бити повезане са циклусима промена нивоа мора на Миланковићевој скали и то до седмог степена. Ипак, постоје извештаји који документују појављивање седиментних записа типичних за високо фреквентне циклусе који су депоновани под примарном контролом тектонике, мада постоји сумња везана за степен под којим тектонски покрети могу да имитирају високо фреквентне циклусе. Тако да питање које се односи на значај које имају тектоника и колебања нивоа мора на депозиционе образце остаје тамо где је практично и започето када су предложени концепти секвенционе стратиграфије. Такође се поставља и питање основних принципа у примени секвенционе и хемостратиграфије. Тренутно је од кључног значаја указати на проблем разликовања одвојеног утицаја тектонике и релативног колебања нивоа мора у седиментном запису.

Каувери басен се налази у јужном делу Индијског полуострва и садржи готово комплетан стратиграфски запис за интервал барем–даниан. Досадашњим истраживањима издвојено је шест хемозона које су међусобно раздвојене секвенционим границама типа 1 и осталим површима које су корелативне са циклусима трећег реда, који се састоје од високофреквентних циклуса са вероватним интервалима од 10^4 до 10^6 година. Према томе, Каувери басен може да буде место за тестирање утицаја тектонике и варирања нивоа мора.

Стратиграфски запис је резултат егзогеног система који је подређен геолошким условима, колебањима нивоа мора и променама геохемијских реакција између мора, копна и климе. Узимајући у обзир да је геохемија седимената веродостојан показатељ порекла седимената, тектонских и палеоклиматских услова, овај рад покушава да појасни динамику порекла, тектонских односа и промене нивоа мора у Каувери басену, уз покушај да их расчлани помоћу геохемијских метода. Извршено је систематско картирање у размери 1 : 50 000 које је обављено на десет попречних профила на којима је описано и узорковано 308 локалитета. На свакој локацији и уздуж профила забележене су информације о литофацијама, односи на контактима, седиментационе и тектонске структуре и појављивање заједница мега- и ихнофосила. Укључено је дефинисање типских профила, препознавање секвенционих стратиграфских површина (између седам типова површи) и њихово дефинисање у оквиру секвенционих граница. Након тога је извршено повезивање са неким од четири догађаја циклуса базног нивоа, а затим са било којом од три системске групе (условљена регресија, нормална регресија и трансгресија).

Овако развијен секвенциони модел је раније представљен. На основу теренских података начињен је целовит стратиграфски профил баремско-данских творевина што је омогућило избор 157 узорака стена за анализу састава ретких елемената. Од поменутих 157 проба, 70 је издвојено ради даље анализе путем ХРФ за одређивање састава главних елемената. Такође су извршене и петрографска и минералошка анализа на 157 проба, а на 70 извршена је анализа минералног састава глина. Геохемијски подаци су разматрани заједно са страти-

графским варијацијама, затим су приказани на успостављеним дијаграмима разврставања, узимајући у обзир услове површинског распадања што је све заједно потврдило главне геолошке догађаје.

Поређење свих ових података као и публиковани радови дозвољавају да се ове промене објасне пореклом, тектонским условима и колебањем нивоа мора, а такође је интерпретиран и продискутован и релативни утицај различитих процеса. Резултати показују да је депозициони систем Куавери басена био под доминантним утицајем колебања нивоа мора узрокованог климом, упркос значајним периодичним кретањима раседнутих блокова. Неколико раседних тектонских покрета временски се поклапају са секвенционим границама (током барема, апт–алба, конијак–сантона, мастрихт-даниана) и могли су допринети поремећају циклуса нивоа мора.

Подаци изнешени овом приликом подржавају утицај тектонике на развој циклуса трећег реда депозиционог система. Учесталост механичког распадања, занемарљиво хемијско распадање матичних стена на шта указује незрелост текстура, појаве високофреквентних циклуса у баремско-коникачким наслагама које су прошле кроз синдепозиционе тектонске догађаје као и постојаност стабилности средине током периода тектонског мировања (кампан–даниан) заједно потврђују главну улогу климе у колебању релативног нивоа мора. Иако појаве узастопне прераде седимената указују на низак степен тоњења, учесталост незрелости текстура и механичка ерозија могу означавати динамичну природу тектонских процеса и постојање уравнотежене промене еустатичког нивоа мора услед тектонских догађаја.

Б. Р.

Plate 1

Fig. 1. Intensively fractured and weathered nature of the basement rock. All along the basin margin, the basement rocks located in the vicinity of the F1 fault lines (Fig. 1) show such characteristics. Location of the photograph: Near Kalpalayam village north of Uttatur.

Fig. 2. Lithoclastic conglomerates of the Sivaganga Formation containing angular, cobble-bounder sized basement clasts. Note the random orientation and fresh nature of the clasts and the unsorted calcareous matrix with fossil fragments.

Fig. 3. Large (>2 m dia) boulders found embedded in the Olaipadi member. The boulders are of basement rocks (dark grey colored boulder at the bottom right of the photograph) and typical coral reef limestones (light yellowish pink colored boulder at the bottom centre of the photograph) and show angular nature. Angular nature of the clasts suggests little or no significant transportation. Fresh nature of these clasts suggests mechanical erosion, rapid transport, immediate burial and faster rate of deposition. These are embedded in parallel bedded Bouma sequences. The bedding planes of individual Bouma sequences follow the periphery of these large clasts and suggest syndepositional tectonic activity and erosion of basement as well as former marine regions. Location of the photograph: Quarry section located near Tirupattur.

Fig. 4. Field photograph showing large (>10 m dia) angular limestone boulder embedded in the Bouma sequences. Note that the bedding planes of the Bouma sequences follow the boundary surface of the clast signifying syndepositional tectonic event that might have eroded the coral reef located at fault margin en masse and dumped it at the adjacently located deeper regions of the basin wherein typical Bouma sequences were being deposited under the influence of turbidity currents. Location of the photograph: Quarry section located near Tirupattur.

Fig. 5. Close-up view of the coralalgal reef facies limestone boulder found embedded in the Bouma sequences. It is to be noted that these constitute typical reef-core and are not at all found anywhere in the basin, signifying, their development only in the former offshore regions of the paleosea, complete denudation during the syndepositional tectonic movements.

Fig. 6. Erosional and angular unconformity surface contact between the Odiyam sandyclay member (Early Turonian) of the Karai Formation and the Varakuppai member (Santonian) of the Sillakkudi Formation (Santonian) exposed at northwest of Varakuppai Village. The intervening Garudamangalam Formation is entirely either eroded and or missing. The major faulting across Coniacian-Santonian had brought down the previously positive areas under the influence of marine forces and the event was accompanied by intense erosion of continental and former offshore regions alike.

Fig. 7. The major faulting event was associated with the development of major fluvial channels that debouched at the fault margin coastlines of paleosea. The field photograph showing the development of climbing ripples consisting of large angular-subangular basement clasts and lithoclasts of older sedimentary rocks and unsorted granule-very coarse sand matrix. Location of the Photograph: Northwest of Varakuppai Village.

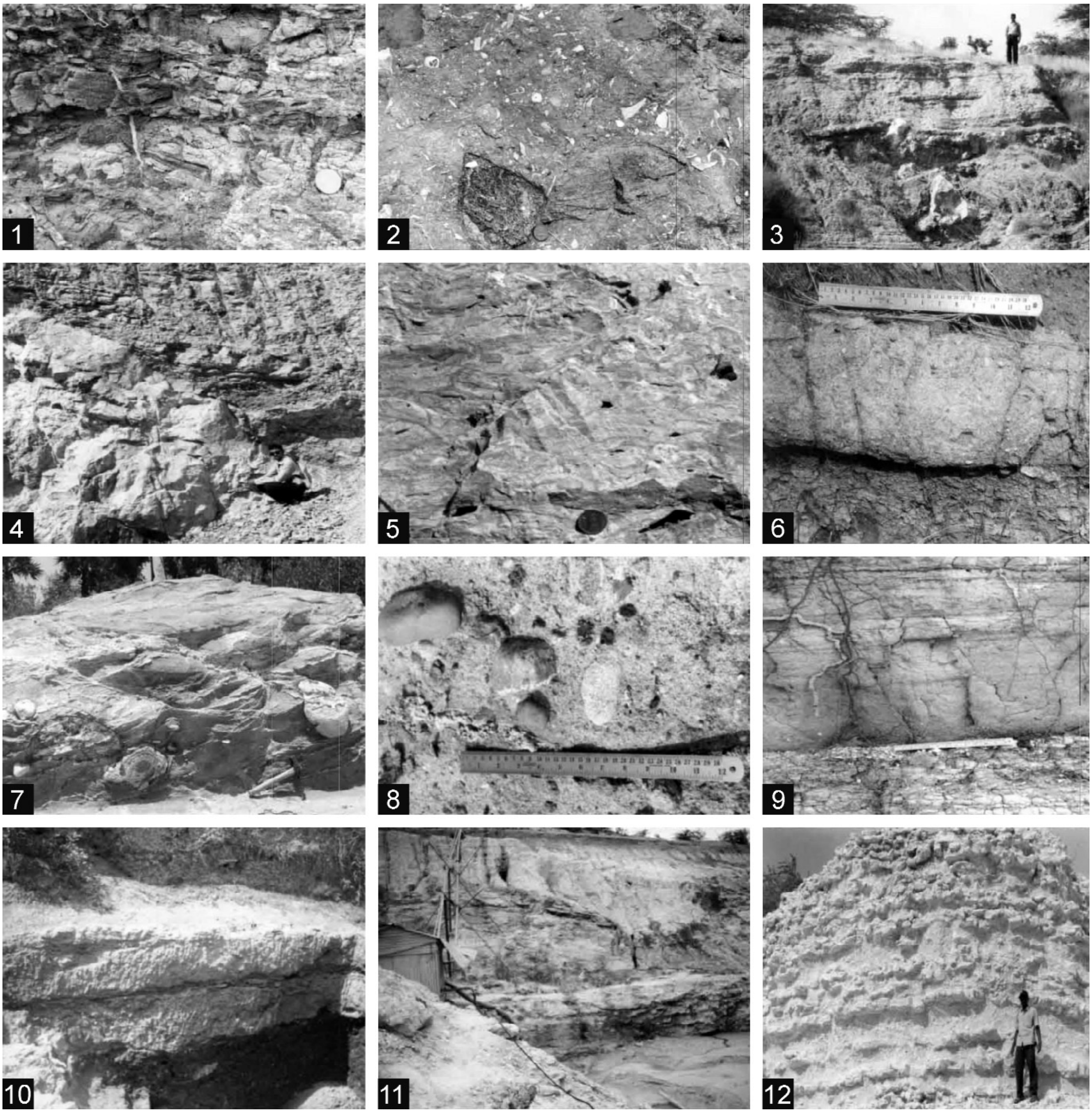
Fig. 8. Close-up view of the previous photograph showing the occurrences of recycled pebble-gravel sized clasts with angular and sub-rounded nature. Many a times, they show reverse grading, suggestive of increase in energy conditions, perhaps associated with syndepositional seismicity (aftershocks?).

Fig. 9. Field photograph showing the erosional offlap contact between Odiyam sandyclay member of the Karai Formation and the Sadurbagam member of the Sillakkudi Formation. The Sadurbagam member was deposited under middle shelf conditions and its occurrence over the Karai Formation signifies, differential depositional topography created by the faulting event and return of sea level fluctuation controlled depositional pattern after major faulting event and fluvial deposition.

Fig. 10. Field photograph showing the erosional contact between Varanavasi member of the Sillakkudi Formation and Kallar member of the Kallankurichchi Formation. In addition, the beds on both the sides show parallel bedding, signifying simple sea level fall and rise across this boundary. Location of the photograph: Kallar river section near Tancem quarry I.

Fig. 11. Field photograph showing conformable offlap between the Srinivasapuram member of the Kallankurichchi Formation and the Kallamedu Formation. Though conformable, the depositional topography might have been variable due to the development of shallow ephemeral river channels that cut through paleosurface and over flown frequently. Location of the photograph: Quarry section located southeast of Kallankurichchi Village.

Fig. 12. Field photograph showing the alternate cyclic development of Marl-Limestone couplets of Periyakurichchi member of Niniyur Formation as a result of high-frequency sea level cycles during Danian. Location of the Photograph: Quarry section located north of Periyakurichchi Village.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ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА ANNALES GÉOLOGIQUES DE LA PÉNINSULE BALKANIQUE	76	47–60	БЕОГРАД, децембар 2015 BELGRADE, December 2015

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Conception to set up a new groundwater monitoring network in Serbia

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Abstract[2]. The Water Framework Directive of the European Union (WFD) adopted in year 2000. outlines number of water policy and management actions, where monitoring is of primary importance. Following WFD principles Serbia adopted new legislation in water sector aiming to conserve or achieve good ecological, chemical and quantitative status of water resources. Serbia, as most of the countries of former Yugoslavia mostly uses groundwater for drinking water supply (over 75%). However, the current situation in monitoring of groundwater quality and quantity is far from satisfactory. Several hundred piezometers for observation of groundwater level under auspices of the Hydrometeorological Service of Serbia are located mostly in alluviums of major rivers, while some 70 piezometers are used by the Serbian Environmental Protection Agency for controlling groundwater quality. Currently only 20% of delineated groundwater bodies are under observation. This paper evaluates current conditions and proposes to expand national monitoring network to cover most of groundwater bodies or their groups, to raise number of observation points to a density of ca. 1 object /200 km^2 and to include as much as possible actual waterworks in this network. Priority in selecting sites for new observation piezometers or springs has to be given to groundwater bodies under threats, either to their water reserves or their water chemical quality. For the former, an assessment of available renewable reserves versus exploitation capacity is needed, while to estimate pressures on water quality, the best way is to compare aquifers' vulnerability against anthropogenic (diffuse and punctual) hazards.

Key words: monitoring, groundwater, „good" status, EU Water Framework Directive, Serbia.

Апстракт. Оквирна директива о водама Европске Уније (ОДВ) усвојена 2000. године, утврђује основне политике и управљања водним ресурсима, при чему је мониторинг вода од примарног значаја. Србија је усвојила основне принципе ОДВ кроз иновирани Закон о водама који промовише циљеве очувања или постизања доброг еколошког, хемијског и квантитативног статуса водних ресурса. Србија, као и већина земаља бивше Југославије, за пиће углавном користи подземне воде (око 75%). Међутим, тренутна ситуација у погледу мониторинга квалитета и квантитета подземних вода далеко је од задовољавајуће. Неколико стотина пијезометара за осматрање нивоа подземних вода под ингеренцијом Хидрометеоролошког завода Србије, налази се углавном у алувијонима већих река, док се око 70 пијезометара користи од стране Агенције за заштиту животне средине Републике Србије за узорковање и контролу квалитета подземних вода. Тренутно се само око 20% од укупног броја издвојених водних тела налази под мониторингом режима квалитета и квантитета подземне воде. Овај прилог даје преглед актуелног стања и садржи предлог проширења националне мреже мониторинга која мора да покрије издвојена тела подземних вода или њихов највећи део, како би се постигла пожељна густина од око 1 објекта на 200 km^2. При томе, у циљу рационализације трошкова, требало би у националну мрежу укључити што је могуће више јавних водовода и других корисника подземних вода. Приоритет у одабиру локације за нове осматрачке пијезометаре или изворе у карсту треба да имају водна тела под притиском на водне ресурсе (интензивна експлоатација), или на квалитет воде (регистрована загађивања или прекомерни садржај појединих компоненти хемијског састава). За оцену притиска на квантитет, потребна је реална процена расположивих обновљивих резерви вода у односу

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на актуелну експлоатацију, док је за процену притиска на квалитет воде најбољи начин да се упореди рањивост конкретних издани у односу на антропогену (дифузну и тачкасту) претњу загађивањем (оцена хазарда).

Кључне речи: мониторинг, подземне воде, „добар“ статус, Оквирна директива ЕУ о водама, Србија.

Introduction

The complex geology of Serbia and adjacent areas has produced hydrogeological heterogeneity and considerable variety in aquifer systems and groundwater distribution. The area is characterized by both, the presence of formations with small groundwater reserve (Paleozoic formations, magmatic and metamorphic rocks, Jurassic and Cretaceous flysch or deeper and thick sedimentary complexes), as well as Mesozoic carbonate rocks, and Tertiary or Quaternary alluvial and terrace deposits which can be very rich in groundwater. Serbia is therefore a relatively rich in groundwater reserves, deposited in different aquifer systems, but unequally distributed along the territory. The major groundwater reserves are accumulated in thick Quaternary and Neogene intergranular aquifers and in karstic aquifers which dominate in south-western and eastern regions of Serbia (STEVANOVIĆ 1995). Alluvial aquifers of large rivers (the Danube, Sava, Velika Morava and Drina) are particularly important and widely used for drinking water supply. Roughly 90% of the population has access to the public water supply, while some 75% of water for public water supply is abstracted from groundwater resources. In some areas, currently tapped resources are unable to quantitatively meet the population's water demand. However, there are other considerable groundwater resources especially in alluvium of large rivers or in karstic aquifers which are still underexploited. Artificial recharge is also not used to a large extent: Only around 1 m^3/s of water is delivered by such sources, which represents less than 5% of the estimated prospect (DIMKIĆ *et al.* 2011).

Most resources deliver a good natural groundwater quality. The main exception is the northern Serbian province of Vojvodina where thick Pleistocene and Neogene sediments of the Pannonian basin formed sub-artesian aquifers. The organic material has been deposited in the natural sediments, and groundwater is frequently loaded with organic substances and ammonia, occasionally, also arsenic or boron.

Although large groundwater consumer Serbia is not properly organizes monitoring of groundwater quality and quantity. Situation is not very different in other countries of former Yugoslavia with exception of those which already become EU members. The obligations of Serbia and steps to be taken to achieve EU standards in environmental sector and particularly requirements of Water Framework Directive (WFD, 60/2000) should definitely include reorganization of current Monitoring network and strengthening of technical capacity of responsible institutions.

History of the existing hydrological network and groundwater monitoring

Systematic groundwater monitoring in Serbia began immediately after World War II. Network of groundwater monitoring stations were set up in 1947. under a decision of the Federal Administration of the Hydrometeorological Service of the Federal People's Republic of Yugoslavia. In 1948, groundwater monitoring was initiated at 41 stations and as early as 1950. the number of stations grew to 233 and then in 1960. to 279. Unfortunately, some of the stations were shut down and abandoned from 1961. and 1990, such that in 1990. there were only 201 piezometers in place. However, after 1990, the Republic Hydrometeorological Service of Serbia (RHMS) placed increasing emphasis on groundwater monitoring. The number of restored and new piezometers grew and doubled by 2014. when the number of monitoring stations was 409 (Fig. 1). Groundwater levels and temperatures had been measured since the very beginning but groundwater sampling for analyses began in 1968. at 35 stations (piezometers). The number of stations has varied since 1969, from as low as 34 to a maximum of 84 (KOCIĆ 2004; NIKOLIĆ *et al.* 2012).

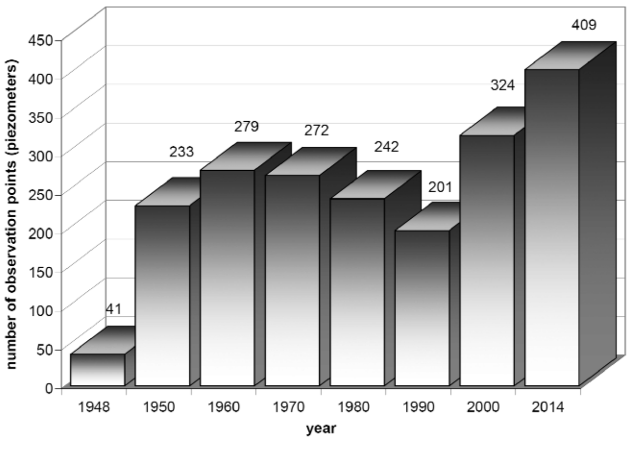

Fig. 1. Number of groundwater monitoring stations in Serbia after WW II.

In spatial terms, the stations have been set up solely in the alluviums of large rivers and at aquifers comprised of Quaternary (Pleistocene) sediments in the Province of Vojvodina. With regard to watersheds, the national network of stations covers the Velika Morava, Zapadna Morava, Južna Morava, Kolubara and Mlava rivers, the District of Mačva and the provinces

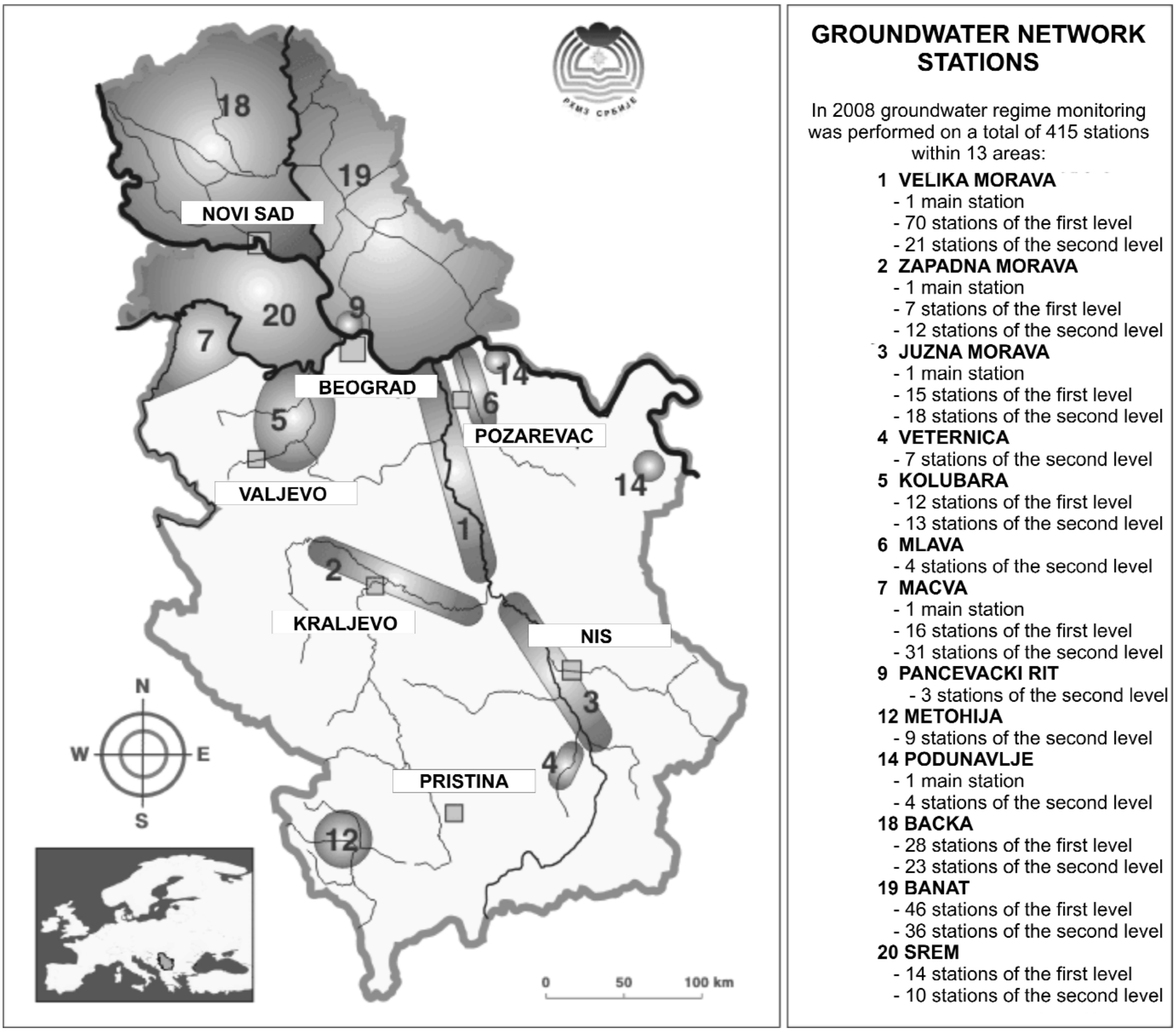

Fig. 2. Network of groundwater monitoring stations of Serbia.

of Kosovo & Metohija and Vojvodina. Figure 2 shows the distribution, along with the numbers and categories of stations.

Apart from monitoring groundwater that occurs in aquifers of the intergranular porosity type, regardless of the significance of the groundwater reserves, very little or no monitoring has been undertaken to date of the other types of aquifers (above all karstic aquifers). For instance, Vrelo Mlave (the source of the Mlava River) was the first karst spring where water level regime monitoring was started in 1949, at the Žagubica Station. Hydrometric surveys to determine the discharge rates of the spring began at that station in 1966, and monitoring and surveys of this spring have continued to the present.

In the mid-1990s, discharge measurements were made at 19 karst springs, but as part of only one or not more than two hydrometric survey campaigns. These springs included among others: Banja Spring (Rakova Bara), Krupaja Spring (Milanovac), Lešje Spring, Petnica Spring, Gradac Spring, Andrić Spring (Ravni), Tolišnica Spring, Gostilje Spring, Vapa Spring, Veliko vrelo (Strmosten) (STEVANOVIĆ *et al.* 2012b). Unfortunately, monitoring of these springs was mostly cancelled in period 2004–2006.

Out of RHMS programme, monitoring of groundwater is also undertaken at city level, and source level (waterworks), as well as in a portion of riparian lands of the Danube, Sava, and Tisa rivers which are within the backwater zone of the Djerdap dam (*Iron Gate Dam* constructed at Danube). The late Monitoring programme was put in place in 1977, to record the effects of the Danube's impoundment on the groundwater regime, to assess the effectiveness of drainage systems (new, reconstructed and non-reconstructed), to improve their operating modes, and to determine the need for and undertake timely interventions to protect the area. More than 700 piezometers were monitored during the past decades in order to define the groundwater regime and assess the Djerdap dam backwater impact on riparian lands (Dimkić *et al*. 2011).

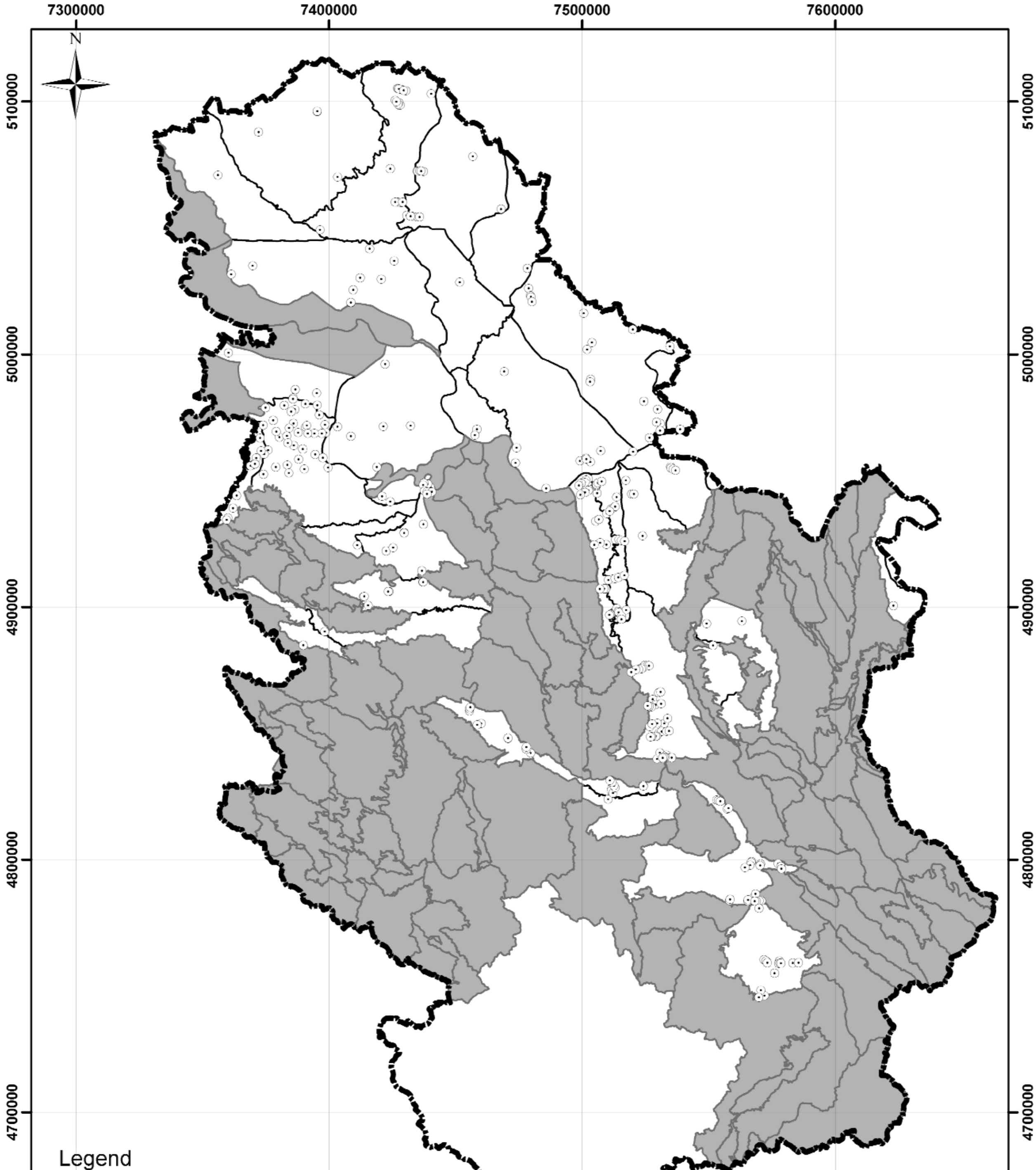

Fig. 3. Distribution of piezometers in groundwater bodies of Serbia.

EU Water Framework Directive and Serbia's implementation tasks

In October 2000, the European Parliament and the Council of the European Union adopted the Water Framework Directive (WFD, 2000/60/EC). In this directive, the European Union modified its previous approaches to recommend control of only heavy and specific pollutants such as nitrates, and established a new long-term strategy in the water sector. The WFD is founded upon the management of water resources at a river basin level. It identifies the conditions that are expected to ensure the implementation of sustainable water use and water protection, while its ultimate goal is to achieve "good status" of all natural water resources, or to ensure good chemical and ecological status of ground, and surface waters, respectively. The main EU objectives set forth in the WFD are:

- Comprehensive protection of all water resources;
- Good status of all water resources;
- Integrated river basin management;
- "Combined approach";
- Appropriate water pricing; and
- Public participation.

Serbia made its initial strides towards WFD implementation in 2003. within the scope of the International Commission for the Protection of the Danube River (ICPDR, 2009). Serbia took part in the preparation of the 2004 Roof Report for the Danube River Basin (DIMKIĆ *et al.* 2005). and generated a preliminary National Report at the beginning of 2005. Since then, in order to harmonize the country's water management policies with WFD requirements and objectives, Serbia enacted a series of laws and implementing legislation, including: *the Water Law* (Official Gazette of the Republic of Serbia 30/10), *the Law on Meteorological and Hydrological Activities* (OG 88/2010), *the Regulation on the Designation of Surface Water and Groundwater Bodies* (OG 96/2010) and *the Regulation on Ecological and Chemical Status Parameters of Surface Water Resources and Chemical and Quantitative Status Parameters of Groundwater Resources* (OG 74/10).

The WFD outlines the water strategy action that needs to be taken, where monitoring is of primary importance (STEVANOVIĆ & VUČETIĆ 2006, QUEVAUVILLER 2008). Serbia adopted *the Regulation on the Designation of Surface Water and Groundwater Bodies* in order to conserve or achieve good ecological, chemical and quantitative status of groundwater resources. A body of groundwater designated within a geological formation was taken as the basis for groundwater monitoring, or the smallest unit for monitoring network planning (UNITED KINGDOM TECHNICAL ADVISORY GROUP 2005a). All designated groundwater bodies (GWBs) have been classified as intergranular, karstic or fractured groundwater bodies. Following detailed analyses and several delineation stages, the initial number of GWBs of 208 (ĐURIĆ *et al.* 2004), was ultimately reduced to 153 (OG 96/2010). This was the first step towards WFD implementation concerning groundwater management.

Spatial distribution of monitoring objects – piezometers on delineated GWBs is shown on figure 3. The list of GWBs with established monitoring is presented in Table 1. It can be concluded that only 34 out of 153 or around 20% of all GWBs, have continual observation of groundwater table. The figures 4a and 4b present percentage of GWBs with number of observation points per 100 km^2. As an example 9% of GWBs has 5 or more observation points per 100 km^2. In contrast, 13 GWBs or 38% has between 0.5 to 0.177 piezometers per 100 km^2. This is equal to density of 1 object per 200 km^2 and 500 km^2, respectively (Fig. 5).

The figure 6 shows positions of the springs which were included in the observation by RHMS for certain period of time.

The next important step in implementation of WFD was GWB characterization, which allowed for the integration into groups of GWBs. The characterization included the determination/description and quantification of geological and hydrogeological conditions, particularly the geometry of the GWBs, the nature of the aquifer roof and floor, the rate of water exchange, and the dependence of terrestrial ecosystems on infiltrated or discharged groundwater (UNITED KINGDOM TECHNICAL ADVISORY GROUP 2005b). The focus was on chemical quality pressures–diffuse and point sources of pollution, as well as quantity pressures–abstraction rates and artificial recharge, if any (STEVANOVIĆ 2011). The WFD introduced *surveillance monitoring* and *operational monitoring*, depending on the nature of groundwater pressures. Operational monitoring requires a higher monitoring frequency and surveying of specific components, critical to water quality.

In the WFD, the groundwater level is the main parameter that defines the quantitative status. There is no exact limit, but it needs to ensure that long-term use will not threaten the available groundwater resource, that the environmental objectives of associated surface water bodies will be achieved and that there will be no threat to terrestrial ecosystems. Given that there was some doubt as to what over-exploitation means and when it occurs (CUSTODIO 1992; BURKE & MOENCH 2000), it was necessary to stay within relative categories. The problem with determining the chemical status is that maximum permissible concentrations have not been defined, except for a few parameters. To achieve objectives, if good status cannot be restored or attained, then the chemical status must be at least that which existed before applicable legislation was adopted, or before its implementation began.

RHMS has transferred its duties related to groundwater quality monitoring by means of piezometers to

Table 1. Groundwater bodies under systematic observation and actual number of piezometers.

No	Groundwater body - GWB	Area F (km^2)	Number N*	Number N**	N* / F	N** / F
1	2	3	4	5	6	7
1	Severozapadna Bačka - top aquifer	1232.43	5	1	246	1232
2	Telečka - top aquifer	2643.55	11	3	240	881
3	Gornja Tisa - top aquifer	1772.02	30	4	59	443
4	Severni Banat - top aquifer	1545.78	19	3	81	515
5	Srednja Bačka - top aquifer	2068.06	16	3	129	689
6	Donja Tisa - top aquifer	1099.78	5	1	220	1100
7	Srednji Banat - top aquifer	1013.72	3	0	338	
8	Jugozapadni Banat - top aquifer	2228.19	16	2	139	1114
9	Vršačke planine	257.63	2	1	129	258
10	Jugoistočni Banat - top aquifer	2298.93	25	3	92	766
11	Beograd right bank of Sava	179.68	7	2	26	90
12	Pančevački rit	413.74	4	1	103	414
13	Negotin Kladovo - alluvium	462.86	4	1	116	463
14	Kličevac	604.28	4	1	151	604
15	Kostolac	1005.37	4		251	
16	Kučaj i Beljanica	726.52	2	2	363	363
17	Velika Morava alluvium left bank	468.26	27	3	17	156
18	Velika Morava alluvium right bank	429.31	28	3	15	143
19	Levač	718.98	2	1	359	719
20	Velika Morava Neogene - south	1321.17	38	3	35	440
21	Kučaj - west	288.06	1	1	288	288
22	Južna Morava Neogene - north	1153.38	21	3	55	384
23	Leskovac - Neogene	914.31	22	2	42	457
24	Rasina	497.41	1	1	497	497
25	Zapadna Morava - alluvium	588.04	21	3	28	196
26	Mačva Basic water bearing layer	763.41	40	3	19	254
27	Kolubara - Neogene	656.57	10	4	66	164
28	Valjevo	542.81	6	2	90	271
29	Lelić - karst	306.83	1	1	307	307
30	Ljig	565.82	1	1	566	566
31	Lozničko polje	243.88	11	2	22	122
32	Povlen	322.37	1	1	322	322
33	Zapadni Srem - Pliocene	1172.92	11	2	107	586
34	Istočni Srem - Pliocene	2248.99	10	1	225	2249
	Total	32755.06	409	34		

Note:
*- total number of piezometers for groundwater table observation
**- total number of piezometers for groundwater quality observation

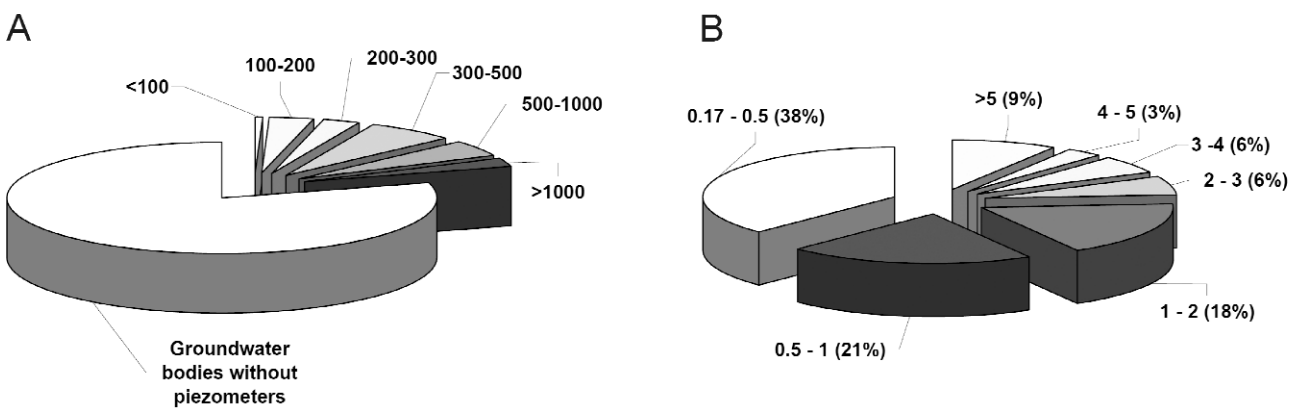

Fig. 4. **a,** Distribution of GWBs without or with piezometers and density (1 object per X km^2); **b,** Percentage of GWBs with number of piezometers per 100 km^2.

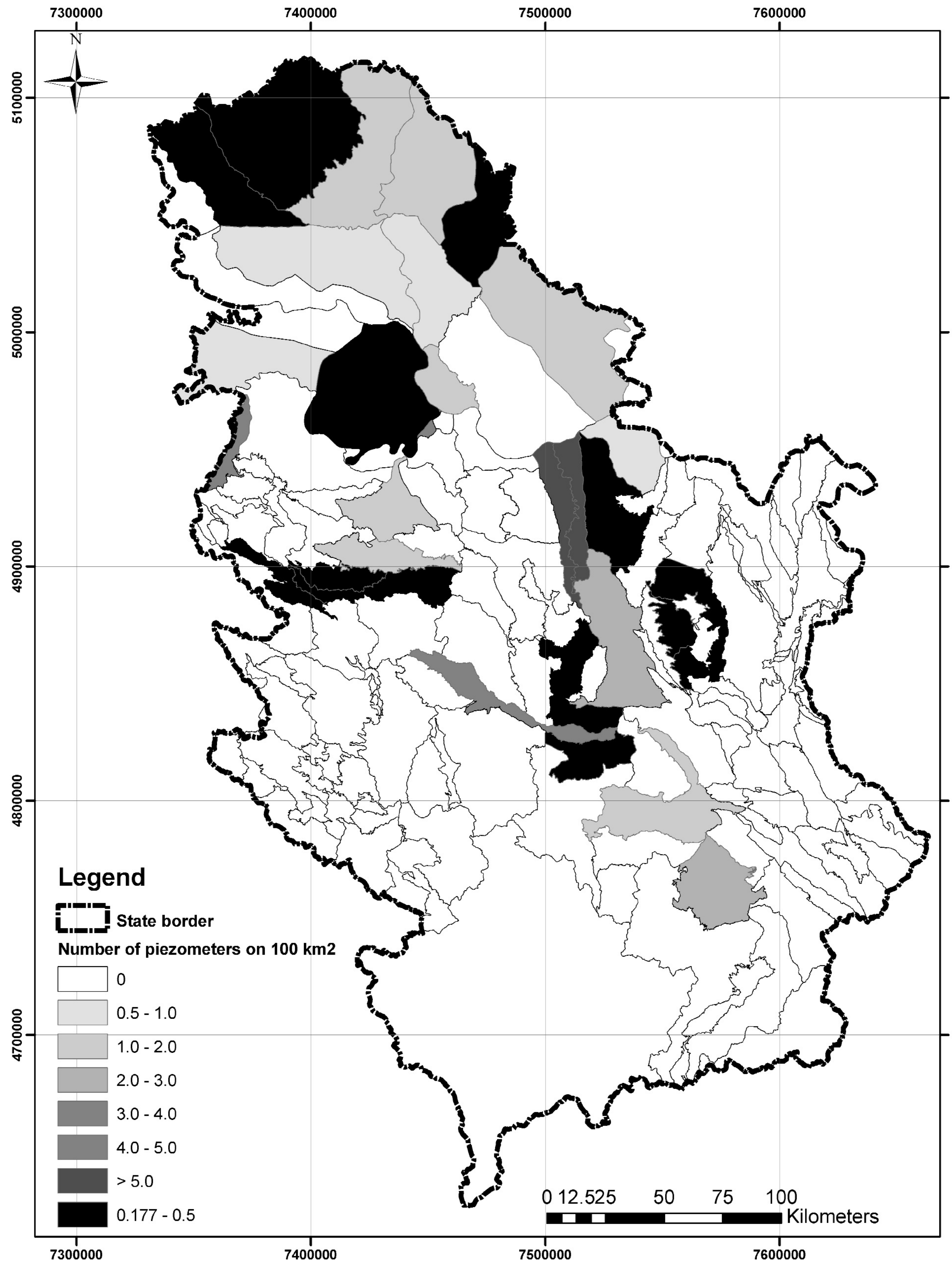

Fig. 5. Groundwater bodies which posses some monitoring boreholes (piezometers) and their density per 100 km^2.

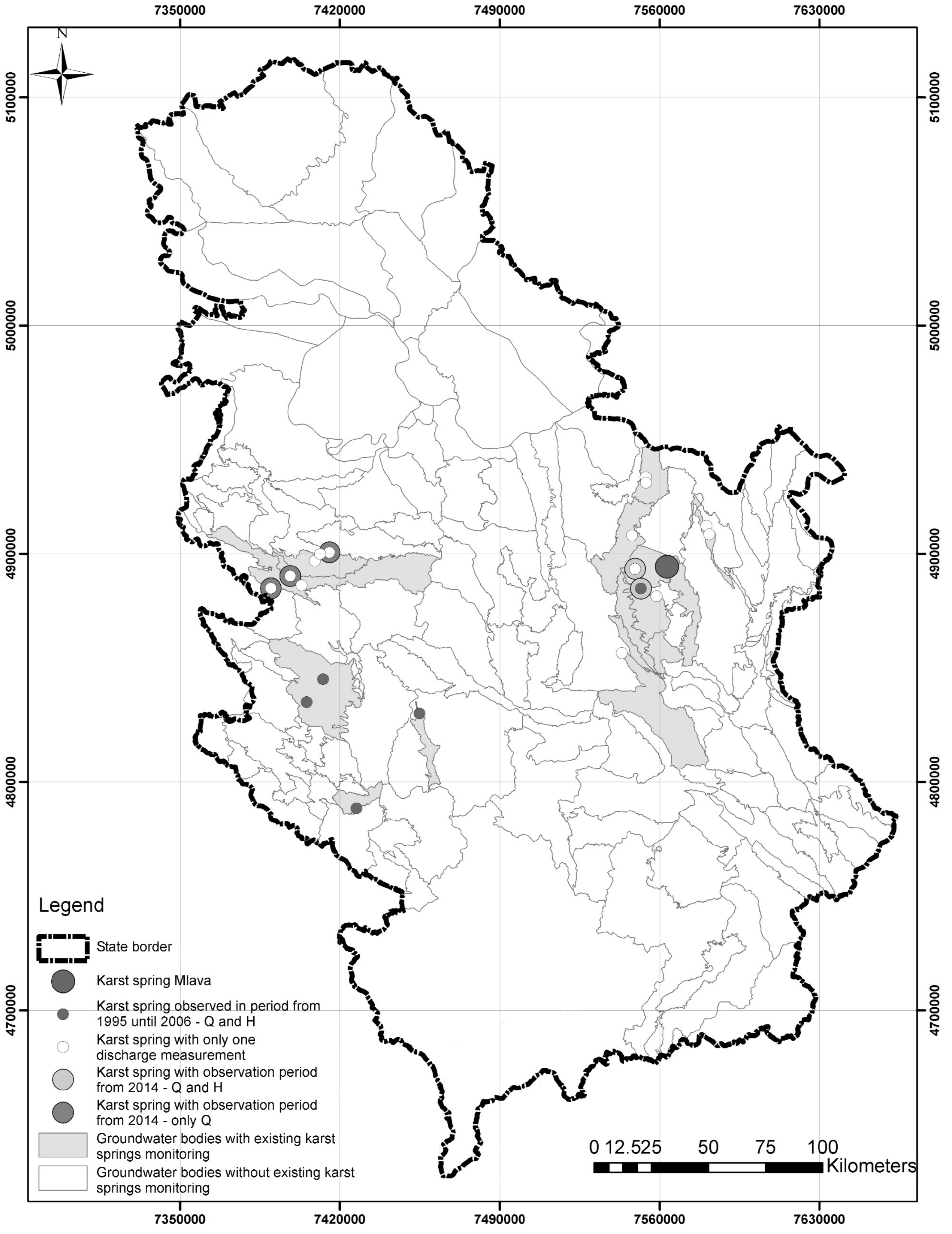

Fig. 6. Groundwater bodies in which some karstic springs were temporarily observed by RHMS.

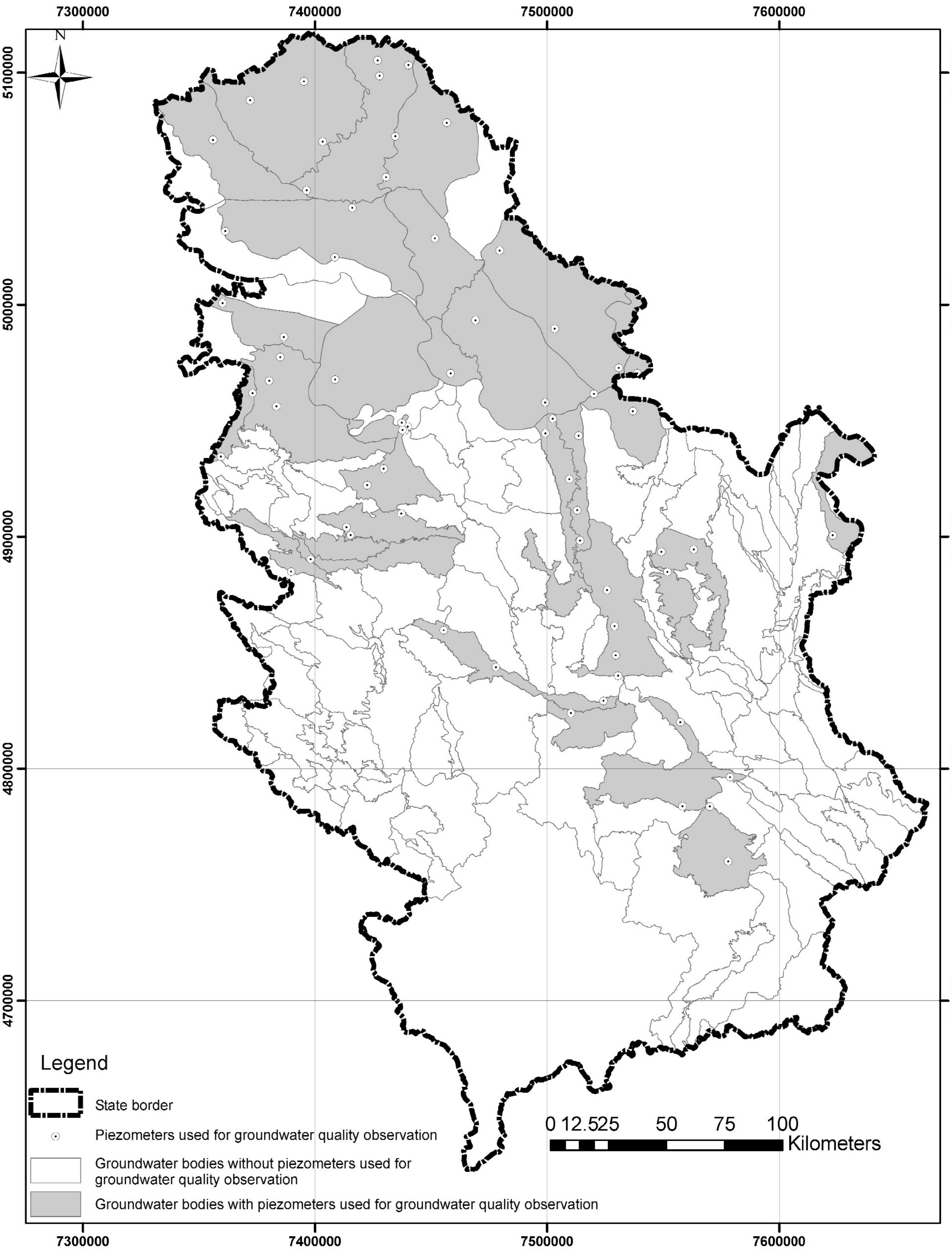

Fig. 7. Distribution of piezometers used for groundwater quality observation.

the Serbian Environmental Protection Agency (SEPA). In 2013. this network included 70 piezometers, while analyses comprise the determination of 66 physical, chemical and biological parameters. SEPA has been reporting to the public via its website and also to the European Environment Information and Observation Network (EIONET). Spatial distribution of piezometers which are used for groundwatwer quality observation, is shown on figure 7.

Criteria and conditions for Serbia's new groundwater monitoring network

In most of European countries, the density of water quality monitoring networks is lower than that of the networks that monitor groundwater level fluctuations. The main reasons lie in operating expenses (costly analyses) and the feasibility of collecting information from other entities (water users) in an organized manner. The network density is also a result of numerous other factors, such as the size of the country, assessed aquifer vulnerability to pollution, and population density. The effect of population density is, for example, apparent in Finland and the Netherlands. In sparsely populated Finland there are only 0.02 monitoring stations per 100km^2, while in the densely populated Netherlands, where groundwater is the main drinking water resource, there is one monitoring station on average per 10km^2 (STEVANOVIĆ 2011).

Monitoring of groundwater quality and quantity is a highly complex task and an obligation according to the WFD. However, considerable financial resources are needed to implement the WFD (FOSTER & MCDONALD 2014). For Example, Austria spends about 2 million € every year and Hungary as much as 4 million € solely on routine groundwater regime monitoring. Countries are also allowed to specify lower objectives for certain groundwater bodies, as needed, if the achievement of good status is not possible without major spending. Consequently, if an efficient approach is followed and if, for example, the obligations of water supply operators and other users are regulated, the water regime database can be substantially enlarged (STEVANOVIĆ 2011).

A number of strategic hydrogeological projects implemented from 2007 to 2001, including "*Groundwater Monitoring*" (GRUPA AUTORA 2010) have been major contributors to the improved knowledge of groundwater resources and the initial steps towards the establishment of a new monitoring network (STEVANOVIĆ *et al.* 2012a; MILANOVIĆ *et al.* 2014). One GWB has been selected per aquifer type and experts from the University of Belgrade-Faculty of Mining and Geology, the Jaroslav Černi Institute for the Development of Water Resources and the Serbian Geological Survey were commissioned to implement pilot monitoring projects following WFD principles. Unfortunately, funding ceased in the final stages of the projects, such that the proposal of a new monitoring network has been postponed.

Given Serbia's circumstances (size, complex geology, hydrogeological conditions), it is believed that at least one groundwater monitoring station per 200 km^2 is needed. This means a total of 400–500 objects in function. This number is close to the existing number of monitoring stations, at least with regard to groundwater quantity, but the way they are currently deployed is inadequate. Only the so-called "top aquifers" (i.e. alluviums of the largest rivers) are monitored. Systematic monitoring has to be the basis for proper GWB characterization and protection from potential polluters and accidental pollution.

Finally, a new monitoring network has to be gradually built. The target for its completion should be the year 2027. In order to get feasible and non-expensive network the existing waterworks and companies that got concessions for water extraction, must be obliged to fulfill their obligations to regularly observe discharges, water tables and chemistry of tapped springs and wells and to deliver this data to responsible authorities. As such, the number of regularly observed water points would increase along with network density. However, certain number of new boreholes would be required as many of GWBs do not have any intakes. In addition to, for objective assessment some piezometers have to be located outside radius of extraction wells used by waterworks.

As set up of monitoring network will rise in stages, prioritization in selection of monitoring sites should be given to GWBs under already recognized pressures. In term of pressure to groundwater quantity, an assessment of available renewable reserves versus exploitation capacity would be needed for each of GWB. When pressures to groundwater quality are considered, the best way for realistic assessment would be to compare aquifers' vulnerability against anthropogenic (diffuse and punctual) hazards. In Serbia, the aquifer vulnerability map in scale 1:500,000 has already been completed under above-mentioned project "*Groundwater Monitoring*" (Fig. 8).

For regional analysis of diffuse hazards the *Corine Land Cover Map* (EEA, 2006) can be very useful, while SEPA's data on pollutants and their distribution and loads can be used for an assessment of punctual (point) pressure.

Conclusion

Consistent WFD implementation and the setting up of a new groundwater monitoring network in Serbia are extremely important for improving knowledge about groundwater resources and their active protection. As an EU member-candidate, Serbia declared its commitment to the WFD back in 2003, but primarily a lack of funds and still unregulated water user obliga-

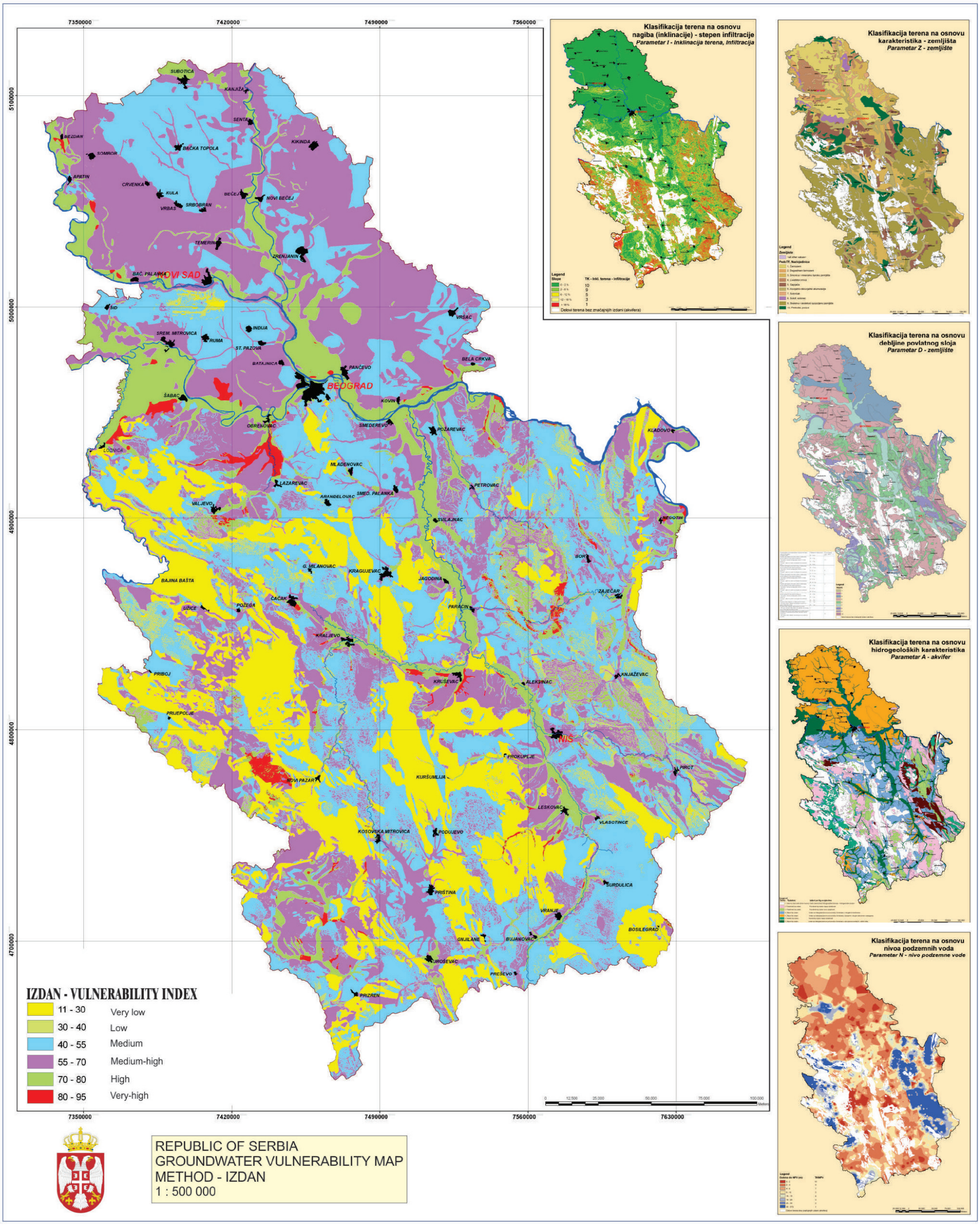

Fig. 8. Groundwater Vulnerability Map of Serbia (MILANOVIĆ *et al*. 2010).

tions have lead to an unsatisfactory state of affairs in the monitoring of groundwater resources, which for the most part support drinking water supplies and are used by some 75% of Serbia's population.

Despite the fact that groundwater level regimes are monitored by more than 400 special-purpose piezometers in Serbia, nearly all of them have been deployed in the same type of alluvial aquifer, where groundwater levels are largely a reflection of river stages (which are also monitored). This is certainly a departure from hydrogeological "logic" and from the preferred approach to national groundwater monitoring, which needs to include all types of aquifers. As such, phreatic ("top") aquifers in Serbia's geological circumstances need to include aquifers in mountainous regions (e.g. karst aquifers are found in more than 30% of western and eastern Serbia), which have virtually not been monitored to date. Consequently, RHMS's concern for aquifers in the alluviums of large rivers, evident from the facts on the ground, needs to be (re)defined. The best solution would be to entrust the setting up of a monitoring service for other types of aquifers and the monitoring task itself to the Serbian Geological Survey. Strictly applied regulations to waterworks and concessionaires to measure and provide data on groundwater quantity and quality would relax needed investment in operation and maintenance of the new Monitoring network.

A new and efficient monitoring network, which covers all, or most of GWBs and all major tapped aquifers (not only alluvial, as at present), determined on the basis of hydrogeological exploration, and systematic groundwater quality and quantity data collection with active involvement of water users, are both national needs and obligations. Proposal is to reach density of 1 observation object / 200km^2 is also given. It took in consideration complex geology, hydrogeological settings, historical data, but also economic situation in the "transition" country. The scope and extent of monitoring, and the frequency of measurements and analyses, depend on the hydrogeological setting and the aquifer regime. In dynamic environments such as karst, monitoring will certainly be more frequent than, for instance, in the case of artesian aquifers in lowland river basins.

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References

BURKE, J.J. & MOENCH, H.M. 2000. *Groundwater and society: Resources, tensions and opportunities*. Spec ed. of DESA and ISET, UN public. ST/ESA/265, 170 pp. New York.

CUSTODIO, E. 1992. Hydrogeological and hydrochemical aspects of aquifer overexploitation. *Selected Papers of IAH*, Hydrogeology,3: 3–27. Verlag Heinz Heise, Hannover.

DIMKIĆ, M., MARJANOVIĆ, N., MILOVANOVIĆ, M., VARGA, S. & MILOJKOVIĆ, S. 2005. Serbian Water Sector Development Strategy (in Serbian). *In:* DIMKIĆ M. & MILOVANOVIĆ M. (eds.), *Management of Water Resources in Serbia*, 1–27, Institute for the Development of Water Resources Jaroslav Černi, Belgrade.

DIMKIĆ, M., STEVANOVIĆ, Z. & DJURIĆ, D., 2011. Progress and improvement of the status of groundwater in Serbia, *Proceedings of IWA Specialist Groundwater Conference*, Keynote Paper, 81–101, Belgrade.

ĐURIĆ, D., JOSIPOVIĆ, J., ZOGOVIĆ, D., KOMATINA, M., STEVANOVIĆ, Z., ĐOKIĆ, I. & LUKIĆ, V. 2004. *ICPDR Roof Report for 2004*. Institute „J. Černi", Ministry of Agriculture, Forestry and Water Management of Serbia, Belgrade.

EUROPEAN COMMISSION, 2007. *WFD CIS Guidance Document No. 15. Common Implementation Strategy for the Water Framework Directive (2000/60/EC)* Guidance on Groundwater Monitoring, Directorate General Environment of the European Commission, Brussels, Belgium.

EUROPEAN ENVIRONMENT AGENCY, EEA, 2006. CORINE Land Use Map. *www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster*

FOSTER, S. & MCDONALD, A. 2014. The 'water security' dialogue: why it needs to be better informed about groundwater. *Hydrogeology Journal,* November 2014, 22 (7): 1489–1492.

GRUPA AUTORA 2010. *Projekat „Monitoring podzemnih vodnih resursa Srbije, izveštaj za 2010"*, Fond stručne dokumentacije Departmana za hidrogeologiju Rudarsko-Geološkog fakulteta Univerziteta u Beogradu, Instituta za vodoprivredu „Jaroslav Černi", Geološkog instituta Srbije, Beograd.

ICPDR, 2009. *Danube River Basin Management Plan,* Vienna, www.icpdr.org

KOCIĆ, V. 2004. Državna mreža stanica podzemnih voda, stanje i perspektive, *Zbornik radova savetovanja „Dan voda"*, Beograd.

MILANOVIĆ, S., STEVANOVIĆ, Z., ĐURIĆ, D., PETROVIĆ, T. & MILOVANOVIĆ, M. 2010. Regionalni pristup izradi karte ugroženosti podzemnih voda Srbije – nova metoda "IZDAN" (Regional approach in creating groundwater vulnerability map of Serbia – a new method „IZDAN"). *Proceedings of XV Geological Congress of Serbia*, 585–590, Beograd.

MILANOVIĆ, S., STEVANOVIĆ, Z., VASIĆ, LJ. & RISTIĆ-VAKANJAC, V., 2014. 3D Modeling and monitoring of karst system as a base for its evaluation and utilization – A case study from eastern Serbia, *Environmental Earth Science*, 71 (2): 525–532

NIKOLIĆ, I., KOCIĆ, V. & RISTIĆ VAKANJAC, V., 2012. Monitoring podzemnih voda u državnoj mreži stanica Srbije, *Zbornik radova 14 Srpskog simpozijuma o hidrogeologiji sa međunarodnim učešćem*, 45–50, Zlatibor.

QUEVAUVILLER, P. 2008. Integrated management principles for groundwater in the EU-WFD context. RSC, 473–493, London.

STEVANOVIĆ, Z., 1995. Vodni mineralni resursi litosfere Srbije. *In:* STEVANOVIĆ, Z (ed.) *Vodni mineralni resursi litosfere Srbije*. Posebno izdanje IHG RGF, 3–30, Beograd.

STEVANOVIĆ, Z. & VUČETIĆ, LJ. 2006. Podzemne vode u propisima Evropske Unije. *Zbornik radova medjunarodne konferencije "Vode - potencijali i valorizacija",* 45–50, Budva.

STEVANOVIĆ, Z. 2011. *Menadžment podzemnih vodnih resursa*, Rudarsko-Geološki fakultet Univerziteta u Beogradu, 340 pp. Beograd.

STEVANOVIĆ, Z., RISTIĆ VAKANJAC V. & MILANOVIĆ S. (eds.) 2012a. CCWaterS – Climate changes and impacts on water supply. University of Belgrade – Faculty of Mining and Geology, 552 pp. Belgrade.

STEVANOVIĆ, Z., RISTIĆ VAKANJAC V., MILANOVIĆ S., VASIĆ LJ. & PETROVIĆ B. 2012b. Značaj monitoringa podzemnih voda u karstu Srbije, *Zbornik radova simpozijuma „Zaštita karsta 2011"*, 21–28, Bela Palanka.

UNITED KINGDOM TECHNICAL ADVISORY GROUP, 2005a. *Approach to Delineation of Groundwater Bodies*, Paper by the Working Group on Groundwater, Guidance document no. GW2

UNITED KINGDOM TECHNICAL ADVISORY GROUP, 2005b. *Methodology for Risk Characterization of Ireland's Groundwater*, Paper by the Working Group on Groundwater, Guidance document no. GW8

WATER FRAMEWORK DIRECTIVE WFD, 2000. Official Journal of EU, L 327/1, 2000/60, Brussels

Резиме

Концепт формирања нове мреже за мониторинг подземних вода у Србији

Доношењем Оквирне директиву о водама 2000. године (ОДВ - *Water Framework Directive EU/WFD – 2000/60/EC*) Европска унија успоставила је нову и заједничку, дугорочну политику у домену вода. Основа Директиве је управљање водним ресурсима на нивоу речних сливова, а њом су дефинисани услови који треба да омогуће спровођење политике одрживог коришћења и заштите вода, док је основни циљ довођење свих природних вода у „добро стање", у погледу квантитета и квалитета. Следећи добру праксу чланица ЕУ, и већина земаља нечланица је у своје прописе о водама уградила концепт и решења ове Директиве које су усмерене на очување, заштиту и побољшање квалитета околине у смислу рационалне употребе вода и других природних ресурса. Концепт се базира на предострожности и превентивним акцијама, а које би обезбедиле "добар" статус вода до 2015, или најдаље до 2027. Оквирна директива прописује потребу израде Програма мера, као и Планова управљања речним сливовима. Посебна „Сестра Директива" ЕУ односи се на подземне воде и разматра и прописује услове за обезбеђивање смањења притиска на квантитет (акције за смањење прекомерне експлоатације) и квалитет подземних вода (очувати или успоставити добар хемијски статус).

У складу са захтевима ОДВ, државе су у обавези да формирају или прилагоде своје осматрачке мреже за подземне воде. Организација мониторинга подземних вода, праћење њиховог квалитета и квантитета, представља сложен задатак. ОДВ ЕУ уводи надзорни и оперативни мониторинг зависно од стања притиска на ове ресурсе: Оперативни се спроводи са гушћом фреквенцијом осматрања и праћењем специфичних компоненти, критичних за квалитет воде. Густина мреже је резултат бројних фактора, зависи од величине земље, оцењене угрожености издани од загађивања, интензитета експлоатације, уочених конфликата интереса у коришћењу ресурса, као и густине насељености. На пример, док је у ретко насељеној Финској свега 0.02 осматрачка објекта на 100 km^2, у густо насељеној Холандији где су подземне воде основни ресурс воде за пиће, просечно је на сваких 10 km^2 лоциран по један осматрачки пункт. За примену Директиве у пракси потребна су и значајна финансијска средства. На пр. Аустрија годишње инвестира око 2, а Мађарска чак 4 милиона еура, само за редовна осматрања режима. Државе могу да одреде и она подземна водна тела код којих је потребно поставити ниже циљеве јер је успостављање «доброг» статуса често немогуће без великих финансијских улагања.

У Србији стање у погледу мониторинга подземних вода није задовољавајуће. Иако се још 1947. године отпочело са праћењем режима подземних вода, а већ 1960. године било формирано чак 279 станица, у периоду од 1961. до данас, број осматрачких пијезометара је у константном опадању (сл. 1). Просторно посматрано станице су формиране искључиво у алувијонима већих река и изданима формираним у оквиру квартарних наслага у Војводини (сл. 2). На пијезометрима Основне мреже углавном се осматрају нивои подземних вода и температура вода, што је задатак Хидрометеоролошког завода Србије (РХМЗ), док се на око 70 пијезометра прати квалитет воде што је у обавези Агенције за животну средину (САЖС) која врши и извештавање према Европској агенцији за животну средину (EIONET). Иако је било више покушаја да се у националну мрежу укључе и јаки карстни извори, до данас се осматрања врше једино на Врелу Млаве у источној Србији.

Како би се стање у погледу мониторинга побољшало и вршило испуњавање обавеза према ОДВ у Србији је учињено неколико корака.

Измењени су законски прописи и донет нови Закон о водама (2010), извршене су делинеације и прелиминарне анализе водних тела подземних вода (ПВТ) као основних јединица за планирање осматрачке мреже, а у припреми су и планови управљања речним сливовима.

Након спроведених детаљних анализа као и више фаза рада на делинеацији, утврђен је број од 153 ПВТ у Србији (сл. 3). Други важан корак је тзв. карактеризација водних тела, која подразумева одређивање – опис и квантификацију геолошких, хидрогеолошких услова терена, посебно геометрије водног тела, карактера повлате и подине, брзине водозамене, зависности еко система на површини терена од инфилтрираних или истеклих подземних вода. Посебно се разматрају притисци на хемијски квалитет – дифузни и концентрисани извори загађивања, као и притисци на квантитет – обим експлоатације, и уколико постоји и вештачко прихрањивање.

Анализа указује да је у 2015. години само на нешто више од 20% ПВТ успостављена одговарајућа осматрачка мрежа. Тачније, само на 34 од укупно 153 издвојена водна тела постоје пијезометри за праћење нивоа подземних вода. Девет ПВТ има 5 или више осматрачких објеката на 100 km^2 (сл.4). Укупно 13 водних тела (или 38%) има 0.5 до 0.177 пијезометра на 100 km^2 што би дакле одговарало густини од једног објекта на 200 km^2, односно 500 km^2 површине територије (сл. 5,6).

Који су неопходни кораци за проширење мреже и како је погустити? Први услов за испуњавање ове обавезе у процесу даљег придруживања ЕУ (област *Животна средина*) је обезбеђивање средстава за рад РХМЗ и САЖС како би повећали број објеката (сл.7), спровели истраживачки мониторинг и успоставили потребну фреквенцију осматрања параметара квантитета и квалитета подземних вода. Такође, стриктним спровођењем већ прописаних обавеза постојећим водоводима или другим корисницима да врше осматрања и податке достављају недлежним службама, може се обезбедити значајан фонд допунских података о режиму вода.

У нашим условима (површина територије, комплексна геологија, хидрогеолошки услови) сматра се да би био потребан најмање један успостављени осматрачки пункт за праћење подземних вода на сваких 200 km^2. То би значило да је потребан број од око 400–500 пунктова осматрања. Број јесте приближан садашњем, бар када је у питању режим квантитета, али је концентрација објеката потпуно неадекватна и прате се само тзв. „прве издани“, заправо алувијони највећих речних токова. Континуирани мониторинг треба да буде основа да се свако ПВТ адекватно окарактерише и да се заштити од могућих потенцијалних и екцесних загађивача.

Нова мрежа се може и поступно развијати како би до 2027. године била приближно комплетирана. Приоритете за нове објекте би требало дефинисати на бази утврђених притисака који се могу оценити на следећи начин:

Притисци на квантитет. Најбољи начин за ову оцену је утврђивање односа експлоатисаних количина у односу на обновљиве (природно и вештачки) резерве подземних вода. Практични проблем може бити недостатак података о режиму издашности или осцилација нивоа, као и непоузданост података експлоатације. Билансне методе су најподесније за оцену величине обновљивих ресурса.

Притисци на квалитет. Треба да буду базирани на односу природне рањивости издани и ПВТ са једне стране, и с друге стране хазарду проистеклом из присуства дифузних и пунктуелних загађивача. Резултат треба да буде израда карата ризика (према дифузним и пунктуелним загађивачима) и она треба да садржи класификацију нивоа ризика (самим тим и притисака) услед антропогених активности. Регионалне карте рањивости издани су незаменљива подлога ових оцена (за територију Србије ову карту у размери 1:500,000 је израдила група аутора тзв. Стратешких пројеката реализованих у периоду 2007–2011, сл.8), док за карту дифузног хазарда корисно може послужити *Corine land cover map* израђена од стране Европске агенције за заштиту животне средине.

Подземне воде у Србији, као уосталом на целом простору бивше СФРЈ, су основни извор снабдевања пијаћом водом становништва (преко 75%). Стога постоје и посебне обавезе државе и њених институција, као и стручних и научних капацитета у погледу њихове превентивне и систематске заштите, обезбеђивања алтернативних изворишта и регулације постојећих у циљу повећања њиховог капацитета, а у условима све већих притисака изазваних антропогеним активностима и климатским променама. За испуњење ових циљева, први и основни услов је постојање података прикупљених ситематским мониторингом квантитета и квалитета подземних вода.

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Hydrogeothermal characteristics of groundwater from Ribarska Banja spa, central Serbia

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Abstract. Ribarska Banja spa is one of the most popular balneotherapy and recreation centers in Serbia. It features several thermal groundwater sources whose temperatures range from 26 to 54 °C. The mineral content of these waters is low and their composition is of the SO_4-Na or HCO_3-Na type. Thermal water exploration has been conducted in the general area for many years, to assess the hydrogeothermal potential in order to extract larger amounts of thermal water for multiple uses. The hydrogeothermal system of Ribarska Banja spa was defined based on a synthesis of the results of comprehensive structural geology, geophysical, hydrogeological, hydrochemical and geothermal research. The primary groundwater reservoir of the hydrogeothermal system is comprised of tectonic zones (systems of faults and fractures) within Cretaceous-Paleogene metamorphosed and non-metamorphosed rocks. The overlying hydrogeological and temperature barrier is made up of a series of low metamorphosed rocks (chlorite, chlorite-sericite schists, gabbros, etc.), highly metamorphosed rocks (gneisses) and Neogene clay and sand sediments. The system is recharged by infiltration of atmospheric precipitation and surface water at the highest elevations of Mt. Jastrebac. Investigations have also shown that the system's heat source is younger granitoide intrusion spreading northwest of Ribarska Banja spa. Based on the quartz geothermometers, expected reservoir temperatures are in the range of 85–97 °C that can be expected at a depth of 1.87 km. Total energy usage at Ribarska Banja spa is 31 TJ/y with thermal capacity of 1.65 MWt and utilization factor of 0.58. Geothermal gradient is 0,051 °C/m, while heat flow density is 163.5 mW/m^2.

Key words: Thermal water, Hydrogeothermal system, Hydrogeothermal resources, Hydrogeothermal exploration, Ribarska Banja spa.

Апстракт: Рибарска Бања је једна од најпопуларнијих балнеолошко-рекреативних центара у Србији. У бањи постоји више појава истицања термалних вода са температурама у опсегу од 26 до 54 °C. Ове воде имају малу минерализацију, док су по хемијском саставу SO_4-Na или HCO_3-Na. Истраживање термалних вода у овом подручју извођена су дуги низ година, са циљем да се дефинише хидрогеотермална потенцијалност подручја и да се захвате веће количине термалних вода за вишенаменско коришћење. Хидрогеотермални систем Рибарске Бање је дефинисан на основу синтезе резултата комплексних структурно-геолошких, геофизичких, хидрогеолошких, хидрохемијских и геотермалних истраживања. Примарни резервоар хидрогеотермалног система представљају тектонске зоне (системи раседа и пукотина) у оквиру кредно-палеогених метаморфисаних и неметаморфисаних стена. Повлатну хидрогеолошку и температурну баријеру чине пакет нискометаморфних стена (хлоритски, хлоритско-серицитски шкриљци, габрови и друге стене), високометаморфних стена (гнајсеви) и неогени глиновито-песковити седименти. Прихрањивање система одвија се инфилтрацијом атмосферских и површинских вода на највишим котама планине Јастрепца. Истраживања су такође показала да извор топлоте геотермалног система је млађи гранитоидни интрузив који се пружа северозападно од Рибарске Бање. На основу кварцних геотермометара, очекивана температура резервоара је у опсегу од 85 до 97 ºC и може се очекивати на дубини од 1,87 km. Укупна енергија искоришћења Рибарске Бање је 31 TJ/y са термалним капацитетом од 1,65 MWt и фактором искоришћења од 0.58. Геотермални градијент је 0,051 °C/m, док је густина топлотног тока 163,5 mW/m^2.

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Кључне речи: термалне воде хидрогеотермални систем, хидрогеотермална истраживања, Рибарска Бања.

Introduction

Ribarska Banja spa is located in central Serbia, on the northeastern slopes of Mt. Jastrebac.

Thermal water wells, featuring water temperatures in the range from 26 to 54 °C, as well as thermal spa facilities, are situated in the Ribarska River valley, some 3 km from the village of Ribare. Intensive research of thermal waters starting in the late seventies (MILOVANOVIĆ 1978; MILOVANOVIĆ 1980; MILOVANOVIĆ 1992; MILOJEVIĆ 2004; ŠPADIJER *et al.* 2005; ŽIVANOVIĆ & ATANACKOVIĆ 2013)

The geology of the terrain was found to be highly complex and posed a major challenge for geologists (RAKIĆ *et al*. 1976; KRSTIĆ *et al.* 1980; SPAHIĆ 2006). Hydrogeological research was faced with a number of problems as it was difficult to identify the rocks and determine the rupture structures of the terrain. Drilling yielded considerable amounts of water from metamorphic rocks, characterized by increased temperatures suggesting the existence of a complex hydrogeothermal system. It was originally assumed that the system was recharged at higher altitudes of Mt. Jastrebac and that its granitoid was the cause of the elevated temperature groundwater regime at Ribarska Banja spa (MILOVANOVIĆ 1980; MILOVANOVIĆ 1992). However, recent research (ŠPADIJER *et al.* 2005; ŽIVANOVIĆ & ATANACKOVIĆ 2013), like as stable isotope analyses and chemical tests of the water samples collected from wells allowed insight into the individual contributors to the formation of the hydrogeothermal system of Ribarska Banja spa, from the source of recharge to the point of discharge.

Structural geology of the area

Geological characteristics. Due to the presence of different lithostratigraphic units and their highly complicated internal and external tectonic relationships, the zone of formation and discharge of the thermal waters of Ribarska Banja spa is characterized by an extremely complex geology. It features two large lithostratigraphic units, inversely positioned and in tectonic contact. The lower part is comprised of Upper Cretaceous and Cretaceous-Paleogene low metamorphosed rocks, overlain by pulled-over and highly metamorphosed crystalline schists (Fig. 1, Fig. 2). The Mt. Jastrebac Paleogene granitoid is emplaced in the Mesozoic-Paleogene metamorphic complex (RAKIĆ *et al.* 1976; SPAHIĆ 2006; MAROVIĆ *et al.* 2007).

The crystalline bedrocks comprised of two large rock complexes: gneisses and "green schists". The gneisses (G) are exposed in an intermittent and irregular series running in the NW-SE direction, beginning at the Village of Srndalje. They have been classified as belonging to the Proterozoic Eon (UROŠEVIĆ 1929) and are in tectonic contact with underlying green schists. To the east and northeast of Ribarska Banja spa, the gneisses are overlain by Miocene clastic sediments.

"Green schists" associated with a low-to-medium metamorphosed volcanogenic sediment formation and distinct petrographic member changes are quite extensive in the Ribarska Banja spa area. Their age was determined by the discovery of Upper Cretaceous (Upper Cretaceous-Paleogene) palynomorphs in phyllites, sericite schists and calc-schists at several locations (SPAHIĆ 2006). These schists can be grouped into three units: lower, upper and middle. The lower and middle units of metamorphic rocks are inversely positioned relative to the upper unit.

The lower unit is comprised of epidote-actinolite, epidote-chlorite and chlorite schists (Sepak) and metagabbros (ν). This unit was probably a result of gabbro rocks metamorphosing and formations of metamorphosed spilite-keratophyre association, accompanied by intensive carbonitization and serpentinization. The colors are light grayish-green to dark green.

The middle unit is made up of sericite, quartz-sericite, sericite-chlorite and quartz-muscovite schists (Sseco), calcschists and marbles (Sca). The rocks belonging to this formation are found north of Banjski Potok, in the direction of Srndalje, and their age was determined based on numerous palynomorphs as Upper Cretaceous. The middle unit features calcschist sand marbles (Sca) in the form of tectonically relocated and transported belts, along with different types of sericite schists.

The highest level of the green schists, the so-called Đulica member (K, Pg), is exposed west of Ribarska Banja spa (SPAHIĆ 2006). It is comprised of phyllites, metamorphosed sandstones, metasiltstones, and nonmetamorphosed rocks (conglomerates and sandstones). These sediments were determined by exploration drilling at Ribarska Banja spa.

The Mt. Jastrebac granitoid (δγ) is located west of Ribarska Banja spa. It was created by the intrusion of a granodiorite pluton into Upper Cretaceous and Paleogene sediments, forming a periclinal dome. It is largely a homogeneous magmatic body, in places crisscrossed by veins of aplite, pegmatite, granodiorite porphyrite and latite.

Miocene sediments (M) are comprised of yellowish, semi-consolidated sandstones, sands, sandy clays and conglomerates. Quaternary sediments are found downstream from Ribarska Banja spa, in the Ribarska River alluvium, where they are comprised of gravel, sand and clay deposits (al).

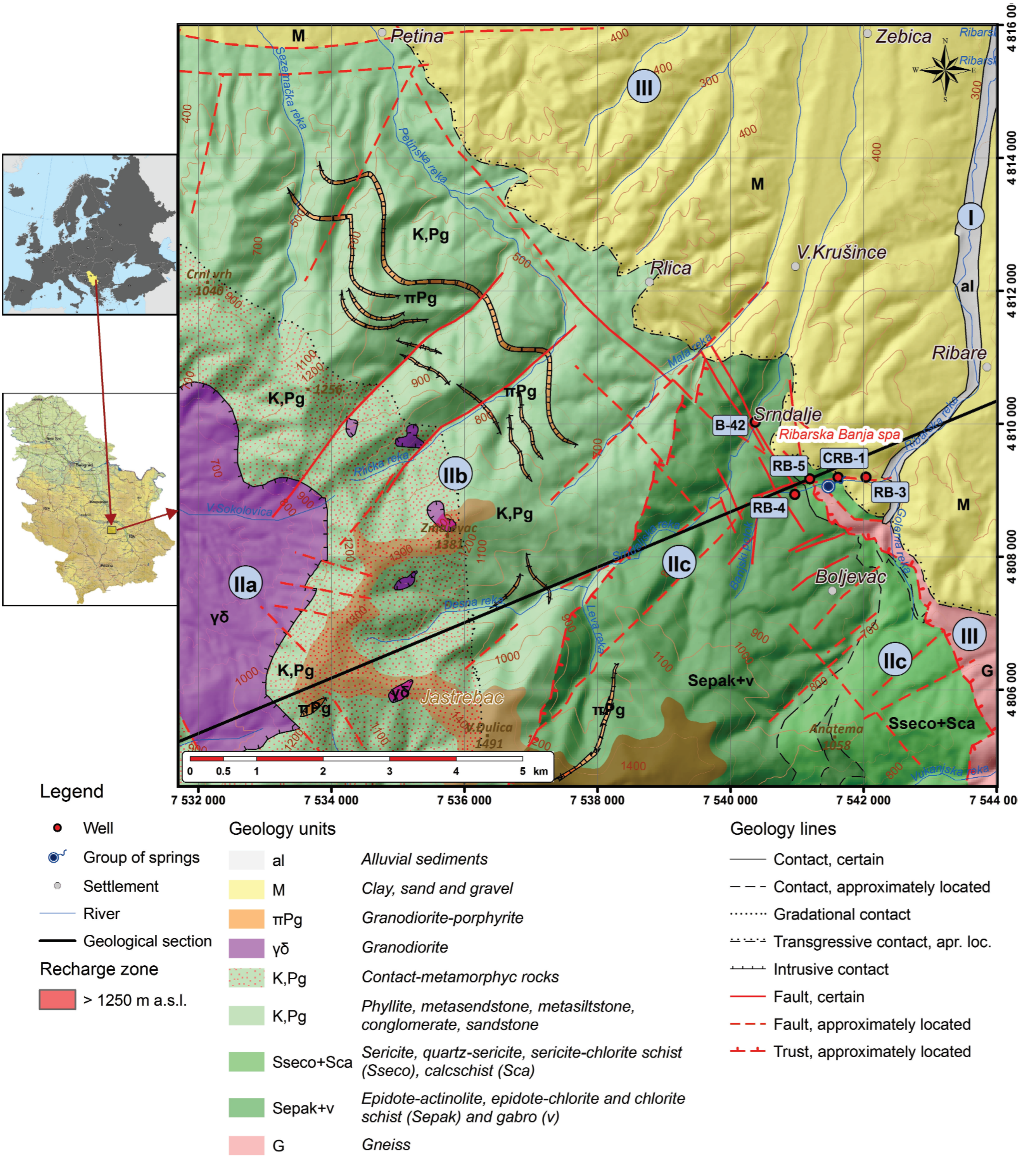

Fig. 1. Geological map of Ribarska Banja spa, according to SPAHIĆ (2006), RAKIĆ *et al.* (1969), KRSTIĆ *et al.* (1974), modified. Legend of hydrogeological units: **I,** alluvial aquifer; **IIa,** fissured aquifer formed in granite rocks; **IIb,** fissured aquifer formed in K,Pg unit; **IIc,** fissured aquifer formed in metamorphic rocks (Sseco+Sca and Sepak+v); **III,** low permeable rocks (Gneiss and Miocene sediments)

Tectonic assemblage. Based on numerous data about the basic elements of the assemblage (foliations, fractures, faults), which has been examined extensively to gain insight into the tectonic relationships, three distinct structural units can be recognized: lower, middle and upper structural floors. The lower structural floor is made up of Cretaceous (Cretaceous-Paleogene) metamorphosed rocks and Proterozoic gneisses, while the upper structural floor is comprised of Neogene and Quaternary sediments. The lower and middle floors are inversely positioned to each other (ŠPADIJER *et al.* 2005; SPAHIĆ 2006; MAROVIĆ *et al.* 2007).

The faults system has been studied in general, with regard to the entire region, because it was determined that these structures intersected all the structural floors. Statistical data processing revealed two distinct directions of the faults: NW–SE and ENE–WSW (ŠPADIJER *et al.* 2005; SPAHIĆ 2006).

The second fault system (ENE–WSW) is detected in the valley of stream of Banjski Potok (Banja Creek). This is a highly complex dislocation zone, marked in places by two or three faults and a crushing belt that is several meters wide. The microlocations of the thermal wells are found along this zone. The positions of the faults have been well documented by geophysical investigations, which show that the tectonic surfaces dip steeply (70–80°) from the breakout zone to the north-northeast. The fault zone was reached in wells CRB-1 and RB-2. This zone is associated with thermal water discharges (ŠPADIJER *et al.* 2005; ŽIVANOVIĆ *et al.* 2010).

Hydrogeology

The presence of diverse petrographic types, intensive tectonic and magmatic activity and the existence of rocks and sediments of varying degrees of porosity have resulted in the formation of the alluvial and fractured types of aquifers in the area of Ribarska Banja spa. Additionally, terrains poor in aquifers were identified as a separate hydrogeological unit.

The alluvial aquifer is found in loose sand-gravel deposits of the stream of Banjski Potok, with large schist and granitoid blocks whose thickness is less than 3.0 m. The groundwater levels are in direct hydraulic connection with surface water. The small areal extent and small thickness of the alluvial deposits prevents accumulation of significant groundwater reserves in this aquifer.

Fractured aquifers were formed within the rocks of the Upper Cretaceous-Paleogene metamorphosed complex and the Mt. Jastrebac granitoid. The lithological composition and the intensity of fracturing of the rock complex have led to the identification of three aquifer subtypes in the Ribarska Banja spa area (Fig. 2): fractured aquifer in granitoid rocks (IIa), fractured aquifer in the upper unit of semi-metamorphosed and non-metamorphosed clastic rocks (IIb), and fractured aquifer in the lower and middle units of metamorphosed Upper Cretaceous-Paleogene rocks (IIc).

The fractured aquifer within the upper unit of semi-metamorphosed and non-metamorphosed clastic rocks (IIb) features good hydrogeological properties. This aquifer is recharged along the edges of the Mt. Jastrebac granitoid, through infiltration of surface water and water from atmospheric precipitation (Fig. 2). A system of faults causes part of these waters to circulate towards Ribarska Banja spa, and to be heat-

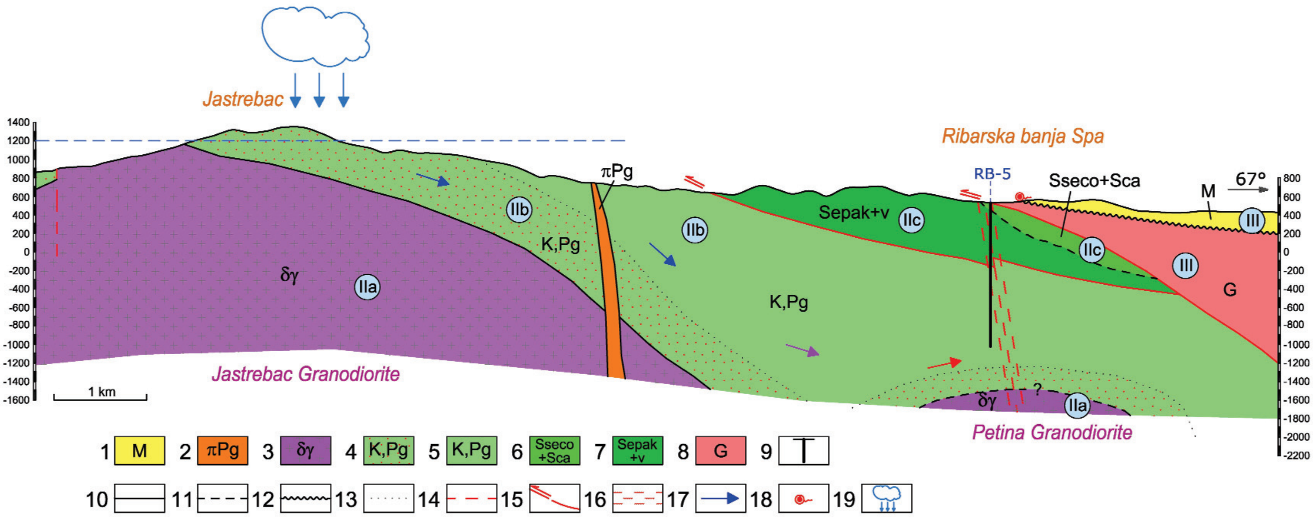

Fig. 2. Geological and hydrogeological section. Legend: **1,** Miocene sediments (clay, sand and gravel); **2,** Granodiorite-porphytite; **3,** Granodiorite; **4,** Contact-metamorphic Cretaceous-Neogene rocks; **5,** Cretaceous-Neogene rocks (phyllite, metasendstone, metasiltstone, conglomerate, sandstone); **6,** Sericite, quartz-sericite, sericite-chlorite schist (Sseco), calcschist and marble (Sca); **7,** Epidote-actinolite, epidote-chlorite and chlorite schists (Sepak) and gabbro (v); **8,** Gneiss; **9,** Well; **10,** Contact, certain; **11**, Contact, approximately located; **12,** Transgressive contact; **13,** Gradational contact; **14,** Fault, approximately located; **15,** Trust; **16,** Fault zone; **17,** Groundwater direction; **18,** Thermal spring; **19**, Recharge area. Hydrogeological units: **IIa,** fissured aquifer formed in granite rocks; **IIb,** fissured aquifer formed in K,Pg unit; **IIc,** fissured aquifer formed in metamorphic rocks (Sseco+Sca and Sepak+v); **III,** low permeable rocks.

ed along the way. The part of the aquifer below the local base of erosion (the stream of Banjski Potok) was previously drained via thermal springs featuring temperatures up to 38 °C. These springs were active until wells were drilled and these wells now drain the aquifer.

Fractured aquifers formed in granitoid rocks (IIa) and those formed in the lower and middle units of metamorphosed Upper Cretaceous-Paleogene rocks (IIc) feature poorer hydrogeological properties than those of the upper unit. Groundwater occurs at shallow levels of these rocks and the fracture porosity, and thus the water-bearing capacity, decreases with depth. Generally speaking, relative to the groundwater in the fractured aquifer of the upper unit (IIb), the granitoid rocks (IIa) constitute an underlying barrier while lower and middle units (IIc) constitute a barrier for the upward movement of groundwater whose temperature is generally elevated.

Low permeable rocks are comprised of Precambrian gneisses and Miocene sediments, spreading east and northeast of Ribarska Banja spa. The gneisses tend to be highly fractured and degraded near the ground surface, and may locally feature aquifers poor in groundwater. At some places, these aquifers are discharged via springs whose yield is less than 0.01 l/s. They often dry out during longer summer periods. In general, based on its hydrogeological properties, this rock complex is a barrier to the flow of groundwater from fractured or alluvial aquifers, and may be classified as impermeable or semi-permeable terrains.

In the vicinity of Ribarska Banja spa, Miocene sediments are mostly composed of clays with low water-bearing potential. Still, further east of the study area, exploratory drilling revealed artesian groundwater in the Miocene complex.

Hydrogeothermal resources of Ribarska Banja spa

According to the data available from previous research (Leko *et al.* 1922; Protić 1995) thermal waters in Ribarska Banja spa were previously discharged naturally via a series of springs distributed along the stream of Banjski Potok, until the year 1969. The yield of these springs varied (0.05–1.5 l/s), as did the water temperature (16–38 °C). The main, hypsometrically lowest spring featured a water temperature of about 38 °C. The total yield of all thermal springs was some 2 l/s, which was insufficient for the needs of the "Special Hospital". This led to the drilling of several exploratory boreholes/production wells, from which thermal water has been exploited since 1970.

Boreholes are drilled in the zone of thermal water discharge along the route of one of the gravity faults (Živanović *et al.* 2010): RB-1 was 100 m deep (later replaced by well RB-5), RB-2 was 125 m deep and RB-3 was 278 m deep. All featured thermal water, pressures of 0.45, 2.75 and 3.2 bar, outflow capacities of 2.0, 9.0 and 7.0 l/s and exit water temperatures of 21 °C, 32 °C and 27 °C, respectively. Well CRB-1 was drilled nearby borehole RB-2, with a water temperature between 38 and 42 °C. The artesian flow of the well was 15 l/s and the initial water temperature was 41 °C. Once the exploitation of the well started in 1971, all the small springs in the stream of Banjski Potok valley dried out. Exploratory borehole RB-4 was drilled to a depth of 852 m. Water from this well is 41.5 °C. The well is used to fill the pools of the new Thermal Spa Center. Deepest well in the Ribarska Banja spa is RB-5 which was drilled at the location of the former shallow borehole RB-1, to a depth of 1543 m. Initial artesian flow was 10 l/s, featuring a water temperature of 54 °C and hydrostatic pressure of 5.85 bars.

Hydrodynamic research during the period from 2003 to 2013 included exploratory/production wells CRB-1, RB-3, RB-4 and RB-5 (Table 1). It should be noted that the thermal waters of RB-4 and RB-5 are in direct hydraulic contact. The table shows the artesian flows when all wells are operating.

Table 1. Hydrogeothermal resources of Ribarska Banja spa based on hydrodynamic tests conducted from 2003 to 2009 (Živanović & Atanacković 2013).

Well	Depth (m)	Max outflow capacity (l/s)	Temperature (°C)
CRB-1	163	9.5	38.7
RB-3	278	5.5	26.0
RB-4	852	3.3	41.5
RB-5	1543	9.2	54.0
		27.5	

Utilization of thermal water

All the four wells are in service: CRB-1 is used to fill balneotherapy pools, RB-3 and RB-4 to fill the pool of the new Thermal Spa Center, and RB-5 to heat the entire resort.

At its maximum capacity of 9.2 l/s, the heat energy of RB-5 is 0.89 MWt (for a temperature reduction by ΔT=23 °C). At the average annual rate of discharge of 5.8 l/s, 17.60 TJ/y is utilized. The utilization factor is 0.63. Similar utilization factors are calculated for other exploitation wells (Table 2). Total energy utilization at Ribarska Banja spa is 31.42 TJ/y, while the thermal power at current outlet temperatures is estimated to be 1.65 MWt. This amount of heat replaces 750.45 tons of oil equivalent, or 1072 tons of coal equivalent. The relatively high outlet temperature and relatively low utilization (capacity) factor indicate that the thermal water potential is not completely

Table 2. Utilization of geothermal energy for direct heat. Applied equations: Capacity (MWt) = Max. flow rate (l/s) x [inlet temp. (°C) - outlet temperature (°C)] x 0.004184; Energy use (TJ/y) = Ave. flow rate (l/s) x [inlet temp. (°C) - outlet temperature (°C)] x 0.1319; Capacity factor = [Annual energy use (TJ/y) x 0.03171] / Capacity (MWt)

Well	T (°C)		Flow rate (l/s)		Capacity (Mwt)	Energy use (TJ/y)	Capacity Factor
	Inlet	Outlet	Maximum	Average			
CRB-1	38.7	28.0	9.5	6.0	0.43	8.47	0.63
RB-5	54.0	31.0	9.2	5.8	0.89	17.60	0.63
RB-4	41.5	25.0	3.3	1.4	0.23	3.05	0.42
RB-3	26.0	21.0	5.5	3.5	0.12	2.31	0.64
Sum/Avr					**1.65**	**31.42**	**0.58**

exploited and that additional geothermal energy usage can be achieved by cascaded water utilization.

Water temperature to 54 °C, can be used for ponds, soil heating, melting snow, the production of alcohol, food, for greenhouses, for manufacturing furniture, cleaning wool and metal.

Methods

Chemical analyses of thermal waters sampled from wells RB-4, RB-5 and CRB-1 were performed in 2011 at the Federal Institute for Geosciences and Natural Resources (BGR) laboratory in Hannover. The samples were stored in polyethylene terephthalate (PET) bottles (0.5 L) with PET caps, filled completely. Chemical analyses were performed in the laboratories of the Federal Institute for Geosciences and Natural Resources (BGR) in Hannover. The following techniques were used for the analyses: ICP-AES inductively coupled plasma atomic emission spectroscopy (Ca, K, Mg, Na, SiO_2), IC ion chromatography (Cl, F, SO_4), titration (HCO_3).

Well RB-3 was not available for sampling, so data from analysis performed at the Institute of Chemistry, Technology and Metallurgy (IHTM) laboratory in Belgrade in 2004. UV-VIS spectrophotometry was applied for SO_4, volumetric method for HCO_3, CO_3 and Cl, while AAS spectrophotometer was used for cations. For all samples, pH and temperature were determined in the field, and electroconductivity (EC) was determined by conductometric method. Results of chemical analysis are shown in Table 3.

Geothermometer calculations were made to assess rock temperatures within the reservoir. Silicon and cation geothermometers were used for the four deep wells: RB-3, RB-4, RB-5 and CRB-1 (Table 4).

Stable isotopes ^{2}H and ^{18}O were determined at the Technical University in Dresden on a mass spectrometer in 2011 (Table 5). V-SMOW2 and SLAP2 standards were applied.

RAD7 instrument was used for determining ^{222}Rn concentrations in the water samples. The activity concentrations of ^{226}Ra in the thermal water samples were also measured by the gamma-spectroscopy method and the results are shown in Table 5 (NIKOLOV *et al.* 2014).

Results and discussion

Hydrogeochemical properties of thermal waters. The thermal water samples at Ribarska Banja spa were found to be alkaline with a low EC (Table 3). According concentration of anion, it is apparent that the SO_4 and HCO_3 concentrations were roughly the same (in % eq), but that the deep wells (RB-4 and RB-5) featured higher SO_4 than HCO_3 concentrations, while HCO_3 was dominant over SO_4 in well CRB-1 and RB-3. Obviously at greater depths there are considerable inputs of SO_4, while closer to the surface HCO_3 dominates. Sulfur is widely distributed in reduced form as metallic sulfides (HEM 1985). Pyrite (FeS_2)

Table 3. Chemical analyses and stable isotopes of thermal water samples.

Sample	pH	EC (μS/cm)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	SO_4 (mg/l)	Cl (mg/l)	SiO_2 (mg/l)	F (mg/l)
RB-4	9.1	417.0	88.5	1.5	1.9	0.03	111.0	6.0	92.9	1.78	43.6	2.05
RB-5	9.2	426.0	88.4	1.5	2.0	0.01	97.0	8.0	95.8	1.78	43.4	2.04
CRB-1	8.4	424.0	82.0	2.0	8.67	1.7	149.0	3.0	73.8	2.64	38.6	1.49
RB-3	8.0	360.0	72.5	1.6	18.4	4.0	165.0	3.6	65.1	10.7	35.0	

was found in a wide area around Ribarska Banja spa, which explains the high concentration of SO_4 in the groundwater there. Additionally, the cooler water samples were richer in Ca and Mg than those collected from the deep wells.

High concentrations of fluoride indicate the groundwater circulation through joints and faults in metamorphic and igneous rocks (PETROVIĆ *et al*. 2012). The geological source of fluoride in groundwater is related to the mineral composition of fluorite, fluoroapatite, cryolite, amphibolites and micas (DANGIĆ & PROTIĆ 1995; CHAE *et al.* 2007).

The chemical composition of Ribarska Banja spa water, make this water healing. Water is used in balneotherapy as a treatment aid for locomotor system disorders and conditions (such as rheumatism, bone and joint injuries, bone fractures and bone and joint surgery).

Solute geothermometry. The geothermometers applied (Table 4) indicated that higher temperatures may be expected in the geothermal reservoir than those detected to date in the deep wells. Chalcedony geothermometers suggested that the temperatures within the system were from 55 to 67 °C, closely matching the temperatures measured inside the well. Such temperatures were also indicated by the Na-K geothermometer (according to ARNÓRSSON *et al.* 1983). Temperatures calculated by Na-K geothermometers are not acceptable in this case because of the higher pH values and the groundwater temperatures below 100 °C. Results obtained by Na-K-Ca geothermometers are also not acceptable because of low compound of Ca and groundwater temperature. Significant temperature difference between shallower (CRB-1, RB-3) and deeper boreholes (RB-4 and RB-5) indicates the inflow of colder waters rich with Ca in the shallow boreholes.

It is generally believed that chalcedony, cristobalite and amorphous silica can control the solubility of silicon at low temperatures (FOURNIER 1977), although this is not always the case. All quartz geothermometers showed roughly the same temperatures (from 85 °C to 97 °C), regardless of the applied method. The reliability of quartz geothermometers is generally the highest at temperatures from 120 to 250 °C (ARNÓRSSON 2000), although if water has been in contact with rocks over a long period, quartz may control the solubility of silicates at temperatures below 100 °C (CHELNOKOV 2004). According to these geothermometers, the highest temperature was expected in wells RB-5 and RB-4 (about 95 to 97 °C).

Isotopic properties of thermal waters ($\delta^{18}O$, δ^2H, ^{222}Rn, ^{226}Ra). The isotopic composition were determined as between δ^2H = –77.12‰ and –77.43‰, and $\delta^{18}O$= –10.85‰ and –11.01‰ (Table 5). Stable isotopes were used to determine the recharge of water. The stable isotope values of the wells at Ribarska Banja spa were distributed along the global meteoric water line, GMWL (CRAIG 1961), indicating recharge by atmospheric precipitation (Fig. 3).

Based on isotope values for geothermal water of Serbian Crystalline Core (PETROVIĆ PANTIĆ 2014), recharge zone of Ribarska Banja spa thermal water is defined above 1000 m a.s.l. The highest peak of Mt. Jastrebac-Đulica is at 1492 m a.s.l., suggesting that the geothermal system of Ribarska Banja spa is

Table 4. Determination of aquifer temperature by geothermometers (index q-quartz, ch-chalcedony). **a)** SiO_2 geothermometer (FOURNIER 1977); **b)** SiO_2 geothermometer (FOURNIER 1977); **c)** SiO_2 geothermometer (FOURNIER & POTTER 1982); **d)** SiO_2 geothermometer (FOURNIER & POTTER 1982); **e)** SiO_2 geothermometer (ARNORSSON *et al.* 1983); **f)** SiO_2 geothermometer (FOURNIER 1977); **g)** Na-K geothermometer (GIGGENBACH 1988); **h)** Na-K geothermometer (NIEVA & NIEVA 1987); **i)** Na-K geothermometer (FOURNIER 1979); **j)** Na-K geothermometer (ARNORSSON *et al.* 1983); **k)** Na-K-Ca geothermometer (FOURNIER & TRUESDELL 1973);

Well	T (°C)	T_q^a (°C)	T_q^b (°C)	T_q^c (°C)	T_q^d (°C)	T_{ch}^c (°C)	T_{ch}^f (°C)	T_{Na-K}^g (°C)	T_{Na-K}^h (°C)	T_{Na-K}^i (°C)	T_{Na-K}^j (°C)	$T_{Na-K-Ca}^k$ (°C)
CRB-1	38.7	90.1	92.4	90.6	91.0	61.4	59.4	140.2	108.9	119.9	84.9	62.7
RB-3	26.0	85.9	88.7	86.4	86.8	57.2	54.9	134.9	103.6	114.5	79.0	41.4
RB-4	41.5	95.5	97.1	95.9	96.2	66.8	65.1	121.6	90.3	100.8	64.4	86.6
RB-5	54.0	95.3	96.9	95.8	96.0	66.6	64.9	121.7	90.4	100.9	64.5	85.5

Table 5. Content of $\delta^{18}O$, δ^2H, ^{222}Rn, ^{226}Ra in Ribarska Banja spa water.

Sample	**$\delta^{18}O$ (‰)**	**δ^2H (‰)**	**Activity concentration of ^{222}Rn (Bq/L)**	**Activity concentration of ^{226}Ra (Bq/L)**
RB-4	–10.99	–77.33	42 ± 7	0.32 ± 0.19
RB-5	–11.01	–77.43	54 ± 8	0.48 ± 0.18
CRB-1	–10.85	–77.12	104 ± 15	0.26 ± 0.08

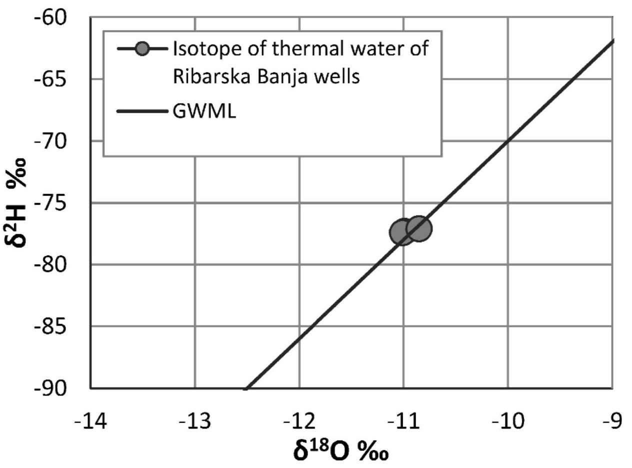

Fig. 3. The ^{2}H versus ^{18}O diagram for thermal water of Ribarska Banja spa (wells RB-4, RB-5 and CRB-1). Global world meteoric line GWML (CRAIG 1961).

recharged on Mt. Jastrebac within K–Pg contact metamorphic rocks. This is also confirmed by the low concentrations of ^{18}O and ^{2}H because low isotope concentrations are related to waters recharging in the winter months at high attitudes (HADŽIŠEHOVIĆ *et al.* 1995; KEBEDE *et al.* 2005).

Water from shallow well CRB-1 in Ribarska Banja spa has the highest concentration of ^{222}Rn, and the lowest concentration of ^{226}Ra. Opposite of this sample is sample from well RB-5 with the highest Ra and the lowest ^{222}Rn. ^{222}Rn is appear in fault and this is a reason why their concentration is highest from CRB-1 which is from fault zone in schist. High concentration of ^{222}Rn could indicate an active fault zone, as well known that area of Ribarska Banja spa is marked with neotectonic movement.

Geothermal potentiality. Based on temperature log at borehole RB-5 (H=1178 m), temperature gradient is 0,051 °C/m. The heat flow density is 163.5 mW/m^2 (PETROVIĆ PANTIĆ 2014) and heat conductivity of schist has been found to be 3.21 W/mK (MILIVOJEVIĆ & PERIĆ 1990). A significant geothermal potential of Ribarska Banja spa is indicated by the average value of geothermal gradient in the world ranging 0.025 to 0.03 °C/m (DICKSON & FANELLI 2004) and average Earth heat flow density of 91.6 mW/m^2 (DAVIES & DAVIES 2010).

At the area of Ribarska Banja spa 36 boreholes (from 20 to 100 m) were drilled (MILOVANOVIĆ 1978) in order to define thermal properties of rocks (PEROVIĆ *et al.* 1978) as well as the geothermal gradient and heat flow density of the wider area.

The map of heat flow density (Fig. 4) shows that the highest values of heat flow are observed south of the spa. The resulting value of the density of heat flow in the well RB-5 of 163.5 mW/m^2 corresponds to the density of heat flow in the area of the spa defined by interpolation of values from boreholes up to 100 m.

The depth of thermal water circulation can be determined based on the temperature at which groundwater is circulating (defined using geothermometers) and the geothermal gradient determined for a given area (ALLEN *et al.* 2006). Reliability of this method depends on selected geothermometers and reliability of temperature log.

The value of the geothermal gradient of 51 °C/km for Ribarska Banja spa is determined in the borehole RB-5. The temperature of 95.3 °C calculated on the basis of quartz geothermometers can be expected at the depth of 1.87 km. Borehole RB-5 is drilled to 1543 m, with a registered maximum temperature of about 80 °C, and therefore the depth of the thermal waters circulation of 1.87 km is quite realistic.

Hydrogeothermal system of Ribarska Banja spa. The Mt. Jastrebac granitoid has generally been identified in the literature as the heat source of the geothermal system of Ribarska Banja spa (MILOVANOVIĆ 1980). The reason for this is the location of the granitoid relative to the locations of the thermal springs, such that the hydrogeothermal system of Ribarska Banja spa is often referred to as the Mt. Jastrebac hydrogeothermal system. Based on K/Ar analyses, the granitoid was found to be of an Eocene age of 37 million years (ČERVENJAK *et al.* 1963). Numerous occurrences of vein rocks in the extended area of Mt. Jastrebac are indicative of the granitoid beneath sedimentary strata.

Geomagnetic investigations conducted in the Petina area northwest of Ribarska Banja spa have detected a large geomagnetic anomaly of an elliptical shape. The anomaly was caused by a granitoid intrusion at a depth of about 2000 m, below Upper Cretaceous-Paleogene and Neogene sediments. This intrusion was emplaced in the Post-Paleogene period, or in the final stage of magmatism (VUKAŠINOVIĆ 2005). As this is a young granitoid and given that overlying sediments prevent heat dissipation, it was assumed that the intrusive body was the heat source of the geothermal water. This assumption has been supported by negative values of gravitational anomalies (MILOJEVIĆ 2004) from Petina to Ribarska Banja spa, as a result of deposition of the tectonically fractured granitoid in a trench or, more likely, of undetected apophyses that may be part of the Mt. Jastrebac granitoid.

In magmatic areas, heat is most often transferred through contact-metamorphosed rocks or hard magmatic rocks. Based on the measured heat conductivity of 3.87 W/m°C (PEROVIĆ *et al.* 1978), contact-metamorphosed Upper Cretaceous rocks are the best heat conductors. In addition to this function, the complex also serves as a reservoir, such that thermal groundwater is stored within the faults and fractures of contact-metamorphosed rocks, from where they circulate to Ribarska Banja spa. Considerable amounts of water were found to be present in these fractures and faults. Water temperatures at the point of discharge measured

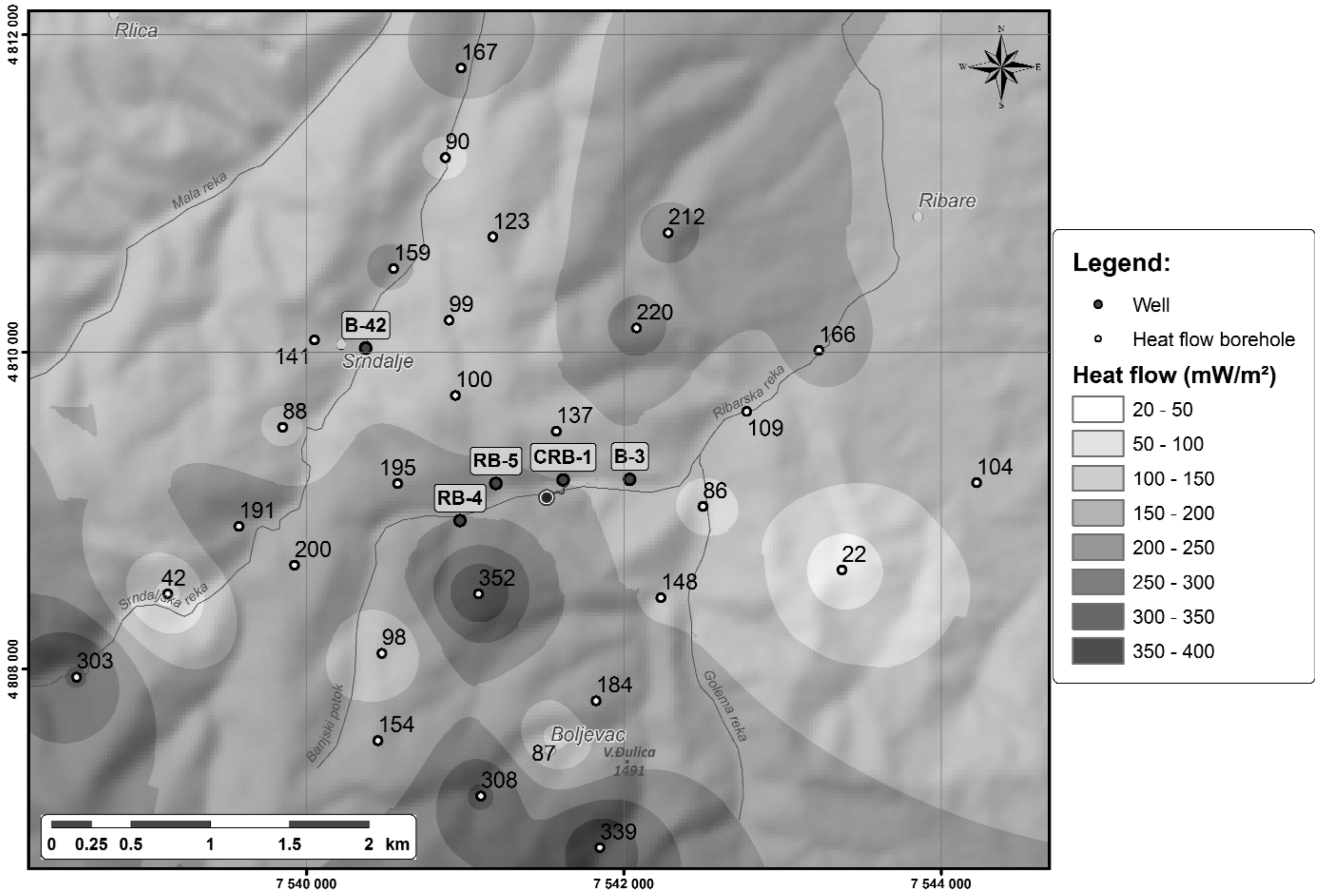

Fig. 4. Interpolated heat flow density map created using Inverse Distance Weighting (IDW) method (according to MILOVANOVIĆ 1978).

from 26 to 54 °C, while inside the reservoir, according to quartz geothermometer are expected to be up to 97 °C.

The overlying and lateral barriers of the hydrogeothermal system of Ribarska Banja spa are comprised of Lower and Middle Cretaceous-Paleogene rocks and gneisses. The heat conductivity of these rocks has been found to range from 2.14 to 3.18 W/mK (PEROVIĆ *et al.* 1978).

Based on research conducted to date, the main features of the hydrogeothermal system of Ribarska Banja spa may be defined as follows (Fig. 2):

- The system is recharged at Mt. Jastrebac, within K-Pg sediments, through precipitation infiltration;
- Contact-metamorphosed Upper Cretaceous rocks are good heat conductions of this system;
- Tectonic zones/systems of faults and fractures within the Upper Cretaceous contact-metamorphosed rocks are the reservoirs of the system;
- Lower and Middle Cretaceous-Paleogene rocks, gneisses and Neogene sediments constitute the system's hydrogeologic and temperature barrier;
- A granitoid intrusion at Petina, emplaced in the final stage of magmatism, is the heat source.

Conclusion

The hydrogeothermal system of Ribarska Banja spa was defined on the basis of structural geology, geophysical, geothermal, hydrogeological, hydrodynamic and hydrochemical research conducted in the narrow and extended zones of thermal water discharges. The research project reported in this paper has shown that the heat source is a younger granitoid intrusion in the Petina area, emplaced in the final stage of magmatism. The recharge zone is at high altitudes of Mt. Jastrebac, made up of Upper Cretaceous-Paleogene clastic rocks. Waters originating from atmospheric precipitation and small surface streams are infiltrated and circulate to Ribarska Banja spa along faults perpendicular to this rock complex. The upper hydrogeological and temperature barrier is comprised of metamorphosed rocks dominated by chlorite and chlorite-sericite schists, gneisses and overlying Neogene formations.

The resources of the hydrogeothermal system of Ribarska Banja spa amount to 27.5 l/s. Based on their chemical composition, these are oligomineral waters, where Na is the dominant cation. With regard to the anion composition, waters closer to the surface are of the HCO_3 type and with increasing depth they become

SO_4-HCO_3. In addition to balneotherapy and recreation, the quantity and quality of the hydrogeothermal resources can support heating of thermal spa facilities. Current energy utilization is 31 TJ/y, but estimated thermal capacity of 1.65 MWt and energy utilization factor of 0.58 indicates that additional geothermal energy can be used. Expected reservoir temperatures of about 97 ºC, can be expected at a depth of 1.87 km. Geothermal gradient is 0.051 ºC/m, while heat flow density is 163.5 mW/m^2.

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References

ALLEN, D.M., GRASBY, S.E. & VOORMEIJ, D.A. 2006. Determining the circulation depth of thermal springs in the southern Rocks Mountaiun Trench, south-eastern British Columbia, Canada using geothermometry and borehole temperature logs. *Hydrogeological Journal 14:*159–172.

ARNÓRSSON, S., GUNNLAUGSSON, E., & SVAVARSSON, H. 1983. The chemistry of geothermal waters in Iceland III, Chemical geothermometry in geothermal investigations, *Geochimica et Cosmochimica Acta, 47*: 567–577.

ARNÓRSSON, S. (Ed.) 2000. *Isotopic and chemical techniques in geothermal exploration, development and use. Sampling methods, data handling, interpretation.* 351 pp. International Atomic Energy Agency, Vienna.

CHAE, G.T., YUN, S.T., MAYER, B., KIM, K.H., KIM, S.Y., KWON, J.S., KIM, K. & KOH, Y.K. 2007. Fluorine geochemistry in bedrock groundwater of South Korea. *Science of the Total Environment,* 385 (1–3): 272–283.

CHELNOKOV, G. 2004. Interpretation of geothermal fluid composition from Mendeleec volcano, Kunashir, Russsia, *The United Nation University Geothermal Training Programme*, Report, 5: 57–82. ISBN: 9979-68-65-9.

CRAIG, H. 1961. Isotopic variations in meteoric waters, *Science*, 133: 1702–1703.

ČERVENJAK, Z., FERARA, G. & TONGIORGI, E. 1963. Age Determination of Some Yugoslav Granites and Granodiorites by the Rubidium-Strontium Method, *Nature*, 197: 893.

DANGIĆ, A. & PROTIĆ, D. 1995. Geochemistry of mineral and thermal water of Serbia: content and distribution of fluorine. *Bulletin of Geoinstitute*, 31: 315–323 (in Serbian, English summary).

DAVIES, J. H. & DAVIES, D. R. 2010. Earth´s surface heat flux. *Solid Earth 1*: 5–24 .

DICKSON, M.H. & FANELLI, M. 2004. What is Geothermal Energy? Istituto di Geoscienze e Georisorse, Pisa, Italy http://www.geothermal-energy.org/, 13.6.2012.

FOURNIER, R.O. 1977. Chemical Geothermometers and Mixing Models for Geothermal Systems, *Geothermics*, 5 (1–4): 41–50.

FOURNIER, R.O. & POTTER, R.W. 1982. A revised and expanded silica (quartz) geothermometer, *Geothermal Resources Council Bulletin,* 11: 3–9.

FOURNIER, R.O. 1979. A revised equation for Na-K geothermometer. *Geothermal Resources Council Transactions,* 3: 221–224.

FOURNIER, R.O. & TRUESDELL, A.H. 1973. An empirical Na-K-Ca geothermometer for natural waters. *Geochimica et Cosmochimica Acta,* 37: 1255–1275.

GIGGENBACH, W. F. Geothermal solute equilibria, 1988. Derivation of Na-K-Mg-Ca geoindicators, *Geochimica et Cosmochimica Acta,* 52: 2749–2765.

HADŽIŠEHOVIĆ, M., DANGIĆ, A, MILJEVIĆ, N, ŠIPKA, V. & GOLOBOČANIN, D. 1995. Geothermal-water characteristics in the Surdulica aquifer, *Ground Water,* 33 (1): 112–123.

HEM, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. *United States Geological Survey Water Supply Paper,* Second Edition. 2254: 129 pp.

KEBEDE, S., TRAVI, Y., ALEMAYEHU, T. & AYENEW, T. 2005. Groundwater recharge, circulation and geochemical evolution in the source region of the Blue Nile River, Ethiopia, Applied Geochemistry 20: 1658–1676.

KRSTIĆ, B., RAKIĆ,B.,VESELINOVIĆ, M.,DOLIĆ, D., RAKIĆ, M., ANĐELKOVIĆ, J. & BRANKOVIĆ, V. 1974. *Basic geological map of the SFR Yugoslavia, Sheet Aleksinac 1:100.000*. *Savezni geološki zavod*. Beograd.

KRSTIĆ, B., VESELINOVIĆ, M., DIVLJAN, M., & RAKIĆ, M. 1980. *Explanatory booklet of the basic geological map of the SFR Yugoslavia, Sheet Aleksinac 1:100.000*. 59 pp. Savezni geološki zavod, Belgrade (in Serbian, English and Russian summaries).

LEKO, M.T., ŠČERBAKOV, A. & JOKSIMOVIĆ, H., 1922. Healing waters and climate in the Kingdom of Serbs, Croats and Slovenes. *Ministry of Public Health*. 26 pp. Belgrade (in Serbian).

MAROVIĆ, M., ĐOKOVIĆ, I., TOLJIĆ, M., SPAHIĆ, D. & MILIVOJEVIĆ, J., 2007. Extensional Unfroofing of the Veliki Jastrebac Dome (Serbia), *Geološki anali Balkanskoga poluostrva*, 68: 21–27.

MILIVOJEVIĆ, M. & PERIĆ, M. 1990. *Geothermal potentiality of Serbia Excluding Autonomous Provinces*. 380 pp. Faculty of Mining and Geology, University of Belgrade (In Serbian).

MILOJEVIĆ, M. 2004. *Report on the study data analysis results of the regional geophysical investigations of the wider area of Ribarska Banja spa*. 8 pp. Geo-explorer, Belgrade (in Serbian).

MILOVANOVIĆ, B. 1978. *Report on basic geothermics exploration of Ribarska Banja spa area.* 21 pp. Zavod za geološka, hidrogeološka, geofizička i geotehnička istraživanja, Belgrade (in Serbian).

MILOVANOVIĆ, B. 1980. Some aspects of the methodology and the results of geothermic research on the example of Ribarska Banja spa in Serbia, *Proceedings 6. Yugoslavian symposium on engineering geology and hydrogeology,* Portorož, Slovenia, 1: 363–373 (in Serbian).

MILOVANOVIĆ, B. 1992. *Assessment of geothermal resources on the territory of Serbia south of the Sava and Danube River with a special focus on the most promising localities*. 26 pp. Geozavod HIG Belgrade and NIS-Naftagas, Novi Sad, Serbia (in Serbian).

NIEVA, D. & NIEVA, R. 1987. Developments in geothermal energy in Mexico. XII. A cationic composition geothermometer for prospection of geothermal resources. *Heat Recovery Systems & CHP*. *7*: 243–258.

NIKOLOV, J., TODOROVIĆ, N., BIKIT, I., PETROVIĆ PANTIĆ, T., FORKAPIĆ, S., MRĐA, D. & BIKIT, K. 2014. Radon in thermal waters in south-east part of Serbia, *Radiation Protection Dosimetry,* 160 (1–3): 239–243.

PEROVIĆ, N., ŽIVOTIĆ, S., MAGLIĆ, K. & MILOVANOVIĆ, B. 1978. Thermal properties of samples of rocks from geothermal sites in SR Serbia, *Thermics*, *3*, (in Serbian).

PETROVIĆ, T., ZLOKOLICA-MANDIĆ, M., VELJKOVIĆ, N., PAPIĆ, P., & STOJKOVIĆ, J. 2012. Chapter 19. Geochemistry of Bottled Water in Serbia. *In*: F.F. QUERCIA & D. VIDOJEVIC (eds.), Clean Soil and Safe Water, NATO Science for Peace and Security Series C: Environmental Security, 17: 247-266.

PETROVIĆ PANTIĆ, T. 2014. *Hydrogeothermal resources of Serbian Crystalline Core.* Unpublished PhD dissertation 199 pp. Faculty of Mining and Geology, University of Belgrade. (in Serbian).

PROTIĆ, D. 1995. *Serbian mineral and thermal waters*. Geoinstitute special editions, 17: 269 pp. Belgrade (in Serbian).

RAKIĆ, M., HADŽI-VUKOVIĆ, M., KALENIĆ, M., MARKOVIĆ, V. & MILOVANOVIĆ, LJ. 1969. *Basic geological map of the SFR Yugoslavia, Sheet Kruševac 1:100.000*. Savezni geološki zavod, Belgrade.

RAKIĆ, M.O., HADŽI-VUKOVIĆ, M., DIMITRIJEVIĆ, M., KALENIĆ, M. & MARKOVIĆ, V. 1976. *Explanatory booklet of the basic geological map of the SFR Yugoslavia, Sheet Kruševac 1:100.000.* 64 pp. Savezni geološki zavod, Belgrade (in Serbian, English and Russian summaries).

SPAHIĆ, D. 2006. *Geology of eastern part of Veliki Jastrebac.* Unpublished M.Sc. thesis, 70 pp. Faculty of Mining and Geology, University of Belgrade (in Serbian).

ŠPADIJER, S., ĐOKOVIĆ, I., MAROVIĆ, M., MILOJEVIĆ, M., TOLJIĆ M. & ŽIVANOVIĆ, V. 2005. *Study on performed hydrogeological investigations of the Ribarska Banja spa thermal waters conducted in 2004*. 46 pp. Faculty of Mining and Geology, Belgrade (in Serbian).

ŽIVANOVIĆ, V., DRAGIŠIĆ, V., KRMPOTIĆ, M., TADIĆ, D. & ATANACKOVIĆ, N., 2010. Hydrogeothermal Resources of Ribarska Banja spa. *Proceedings of II Spa congress with international participation*, 149–160. Vrnjačka Banja.

ŽIVANOVIĆ, V. & ATANACKOVIĆ N., 2013. *Study on reserves of Ribarska Banja spa thermomineral waters, Faculty of Mining and Geology*, 105 pp. Belgrade (in Serbian).

UROŠEVIĆ, S. 1929. Jastrebac. Geologic and petrographic study of granite and crystalline schists, *Glas Srpske kraljevske akademije nauka,* 137:(65), 1–52 (in Serbian).

VUKAŠINOVIĆ, S. 2005. *Anomalous magnetic field and geological composition of the Republic of Serbia*. 247 pp. Geoinstitut, Belgrade, (in Serbian).

Резиме

Хидрогеотермалне карактеристике подземних вода Рибарске Бање, централна Србија

Рибарска Бања се налази у централном делу Србије, на северо-источним падинама Великог Јастребца. У геолошкој грађи терена доминирају зелени шкриљци. Западно од Рибарске Бање утиснут је Јастребачки гранитоид, док се северо-источно пружају миоценски седименти. У хидрогеолошком погледу издвајају се следеће издани: алувијална и пукотинска. Највеће количине вода добијене су из пукотинске издани формиране у горњем пакету слабо метаморфисаних стена кластичног карактера.

У бањи тренутно постоје четири бушотине (од 163 до 1543 m) из којих се експлоатишу подземне воде, максималаног капацитета 27,5 l/s, температуре од 26 до 54 °C. Применом кварцних геотермометара, очекивана температура резервоара подземних вода је у опсегу од 85 до 97 °C и та температура се може очекивати на дубини од 1,87 km. По хемијском саставу воде су маломинерализоване, алкалне, SO_4-Na или HCO_3-Na са повишеним садржајем флуора. У раду су примењене и изотопске анализе. На основу изотопа δ^2H и $\delta^{18}O$ прихрањивање подземних вода се врши падавинама и отапањем снежног покривача на висинама изнад 1000 м.н.в, што одговара планини Велики Јастребац. Највиша концентрација ^{222}Rn одређена је у води из бушотине ЦРБ-1 где је вода захваћена из раседне зоне.

Проучавањем геотермалног потенцијала Рибарске Бање, само у бушотини РБ-5, добијена вредност геотермалног градијента износи 0,051 °C/m, док је густина топлотног тока 163,5 mW/m^2. У раду је дефинисан хидрогеотермални систем Рибарске Бање, тако са су дати следећи елементи система:

- прихрањивање се врши на планини Јастребац, у оквиру K-Pg седимената, инфилтрацијом атмосферских вода;
- добри проводници топлоте у систему су контактно-метаморфне стене горње креде;
- тектонске зоне, системи раседа и пукотина у оквиру контактно-метаморфних стена горње креде представљају резервоаре система;

- баријеру система (хидрогеолошку и температурну) представљају стене доњег и средњег кредно-палеогеног комплекса, гнајсеви и неогени седименти;
- извор топлоте представља гранитоидни интрузив код Петине (северо-западно од бање), утиснут у последњој фази магматизма.

Термалне воде се вишенаменски користе, за пуњење базена, за загревање објеката, као санитарна топла вода. Укупна енергија искоришћења Рибарске Бање је 31,42 TJ/y са термалним капацитетом од 1,65 MWt и фактором искоришћења од 0,58.

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Clogging of water supply wells in alluvial aquifers by mineral incrustations, central Serbia

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Abstract. The formation of incrustations on public water supply well screens reduces their performance considerably. The incrustations increase hydraulic losses, reduce the capacity of the well and screen, affect the quality of the pumped water and increase maintenance costs. In alluvial environments, the most common deposits are iron and manganese hydroxides. However, the rates of formation, compositions and levels of crystallization vary, depending on the geochemical characteristics of the alluvial environment, the microbiological characteristics of the groundwater and the abstraction method. Samples of 15 incrustations were collected from wells that tap shallow alluvial aquifers and were found to be dominated by iron. XRD analyses detected low-crystalline ferrihydrite and manganese hydroxide in the samples collected from the water supply source at Trnovče (Velika Morava alluvial). The incrustations from the Belgrade Groundwater Source revealed the presence of ferrihydrite and a substantial amount of goethite α-FeOOH. Apart from goethite, greigite (Fe_3S_4) was detected in three samples, while one sample additionally contained bernalite $Fe(OH)_3$ and monoclinic sulfur S_8. Among carbonates, only siderite was detected. Iron oxidizing bacteria generally catalyze deposition processes in wells, while sulfate reducing bacteria (SRB) play a role in the biogenic formation of greigite. Determining the nature of the deposited material allows better selection of rehabilitation chemicals and procedure.

Key words: alluvial aquifers, water supply wells, mineral incrustations, bacteria, central Serbia.

Апстракт. Формирање инкрустација на филтерским конструкцијама бунара смањује њихове перформансе. Створени талози повећавају хидрауличке губитке, смањују капацитет бунара, погоршавају квалитет експлоатисане воде и повећавају трошкове одржавања водозахвата. У бунарима који захватају подземне воде алувијалних издани најчешће се јављају талози гвожђа и мангана. Ипак, брзина формирања, састав и степен кристалинитета талога, зависе од геохемијских карактеристика средине, микробиолошких карактеристика и методе захватања воде. За потребе истраживања анализирано је 15 узорака инкрустација узетих из бунара који каптирају плитке алувијалне издани. Ренгенска дифракција показала је доминантно учешће ферихидрита и хидроксида мангана ниског степена кристалинитета у узорцима талога са изворишта Трновче (алувијон Велике Мораве). Инкрустације из бунара са хоризонталним дреновима Београдског изворишта подземних вода осим ферихидрита садрже значајне количине гетита α-FeOOH. У три узорка осим гетита, доказано је присуство грејгита (Fe_3S_4), док је један узорак садржао поред ових минерала берналит ($Fe(OH)_3$) и моноклинични сумпор S_8. Од карбонатних минерала детектован је сидерит. Гвожђе оксидишуће бактерије катализују процесе формирања талога у бунарима, док сулфато-редукујуће бактерије (СРБ) имају улогу у биогеном формирању грејгита. Одређивање минералошког састава бунарских талога и начина њиховог формирања кључно је за бољи одабир поступака и средстава за физичко-хемијске регенерације бунара.

Кључне речи: алувијалне издани, бунари, инкрустације, бактерије, централна Србија.

Introduction

Alluvial environments are collectors of groundwater, which is often used for the public water supply. In Serbia, around 70% of the water supply comes from groundwater of which over 50 % comes from alluvial aquifers (Dimkić *et al.* 2007a). However, groundwater abstraction is often hindered by well clogging. It is well-

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known that the formation of well incrustations leads to numerous adverse consequences, such as declining well capacity over time, reduction in conveyance capacity of the well screens and growing hydraulic losses.

The aim of this paper is to indicate the different mineralogical incrustations formed on screen slots of shallow wells taps different redox environments. The given results could improve well rehabilitation techniques and help in decision making for using appropriate chemicals depending on incrustation type.

Because of the adverse impact on groundwater abstraction, incrustation has been studied with regard to the iron oxidation rate and the formation of oxy(hydroxides) on screen slots by APPLIN & ZHAO 1989; WALTER 1997, HOUBEN 2006, HOUBEN & TRESKATIS 2007, MAJKIĆ 2013, while van BEEK 2011 examined declining well capacity as a result of mechanical clogging. Incrustations of screen slots are most often formed when the screens are positioned such that they tap different vertical geochemical zones (HOUBEN 2006, MAJKIĆ-DURSUN *et al.* 2012).

Most aquifers feature hydrochemical zonality. In alluvial aquifers, for instance, the amount of dissolved oxygen tends to decrease along the flow from the river to the aquifer, but also in the vertical direction, from the ground surface to the depth of groundwater. Being a strong oxidant, oxygen is generally used for oxidizing organic substances, but it is also expended in mineral weathering. The deeper and more distant the well is from the river, the tapped groundwater becomes an increasingly reducing. In neutral media (pH =7), redox zones can be identified according to the following descending sequence (JURGENS *et al.* 2009):

As the redox potential decreases, the following re-

$$O_2 \rightarrow NO_3^- \rightarrow Mn^{4+} \rightarrow Fe^{3+} \rightarrow SO_4^{2-} \rightarrow CO_2$$

duction reactions will take place: transformation of nitrate into nitrogen, reduction of manganese(IV), reduction of Fe(III), transformation of sulfate into hydrogen sulfide and, at a very low redox potential, methanogenesis (MCMAHON & CHAPELLE 2008, JURGENS *et al.* 2009).

Iron, as the fourth major constituent of the Earth's crust, plays an enormous role in biogeochemical reactions (STRAUB *et al.* 2001, RODEN *et al.* 2004, FORTIN & LONGLEY 2005, DIMKIĆ *et al.* 2011). Under reduction conditions, iron travels underground as dissolved Fe(II). In the presence of oxygen, in media exhibiting close-to-neutral pH value, iron rapidly oxidizes into insoluble Fe(III), producing iron oxy(hydroxides) and oxides (DAVIDSON & SEED 1983, STUMM & MORGAN 1996, HOUBEN 2003, MAJKIĆ 2013). The transformation of soluble Fe(II) into insoluble Fe-oxy(hydroxide) requires mixing of oxygen-containing water with reducing water carrying dissolved iron ions (van BEEK *et al.* 2010). Mixing of groundwater from different geochemical zones can also be a result of permanent drawdown in the near-well region, due to over-exploitation (APPLIN & ZHAO 1989, LARROQUE & FRANCESCHI 2011, MAJKIĆ 2013). Increasing pH levels and the release of CO_2 also affect the rate of iron oxidation (DAVIDSON & SEED 1983).

Oxidation of Mn(II) requires a higher oxidation potential (0.6–1.2 V) than the oxidation of Fe(II) (0.0–0.5 V) (HOUBEN & TRESKATIS 2007). The deposition of manganese is much slower than that of iron; the process is accelerated at high pH values (pH > 8) (MARTIN 2005). Sulfates can be reduced in the groundwater of shallow alluvial sediments, which CHAPELLE *et al.* (2009) associate with a possibly high reaction rate between Fe(II) and H_2S, producing insoluble iron sulfides (FeS).

The role of bacteria in the formation of incrustations can be very important in terms of catalyzing reaction rates and forming biofilm, as well as from the perspective of the biogenic origins of minerals (SMITH & TUOVINEN 1985, CULLIMORE 1999, LOVLEY 2000, EHRILCH 2002, FRANKEL & BAZYLINSKI 2003, EMERSON & WEISS 2004).

In order to study well clogging, two different alluvial sources were selected in the present research. Long-term groundwater chemistry monitoring had been undertaken at these water supply sources and the results of microbiological analyses revealed incrustations on well screens. The Water Supply Source Trnovče (Fig 1.) was chosen as an example of extremely rapid clogging and formation of considerable incrustations on well screens and well pump discharge pipes (MAJKIĆ-DURSUN *et al.* 2012, MAJKIĆ 2013). The Belgrade Groundwater Source (Fig 1.) was selected because of its importance for the public water supply of Serbia's capital. The wells at this source tap the alluvium of the Sava River, while those at Trnovče tap the alluvium of the Velika Morava River.

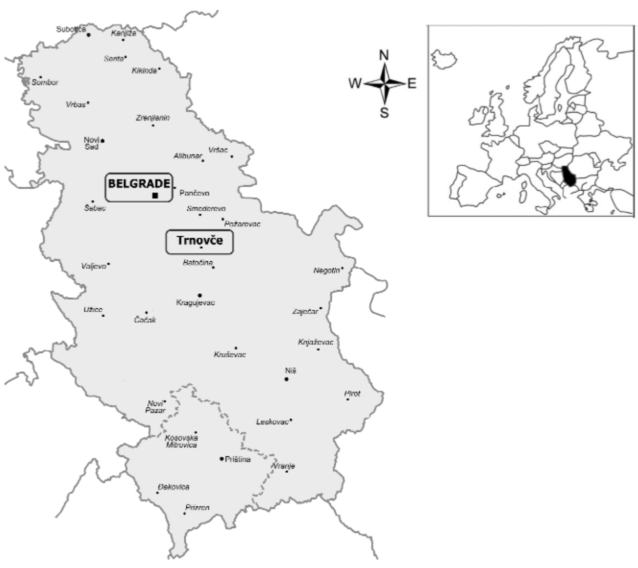

Fig. 1. Sampling sites: water supply sources Trnovče and Belgrade.

Study Areas

At the location of Trnovče Water Supply Source the aquifer is comprised of alluvial sediments, whose total thickness is about 15 m. The part of the aquifer from which groundwater is extracted is predominantly represented by sandy gravels (Fig. 2.). The average thickness of these sandy-gravels in the Trnovče area is about 10 m, but the thickness of saturated part of aquifer is usually smaller (MAJKIĆ-DURSUN *et al.* 2012). The sandy-gravel sequence is covered by fine-grain sediments, generally sandy and dusty clays, dusty sands and sandy clays whose thickness ranges from 5 to 6 m (Fig. 2.). Aquifer floor is made from Neogene clays. The thickness of water saturated part of the aquifer varies during the year, but generally groundwater pumping levels are felt into zone of well screens (MAJKIĆ-DURSUN *et al.* 2012, MAJKIĆ, 2013) (Table 1).

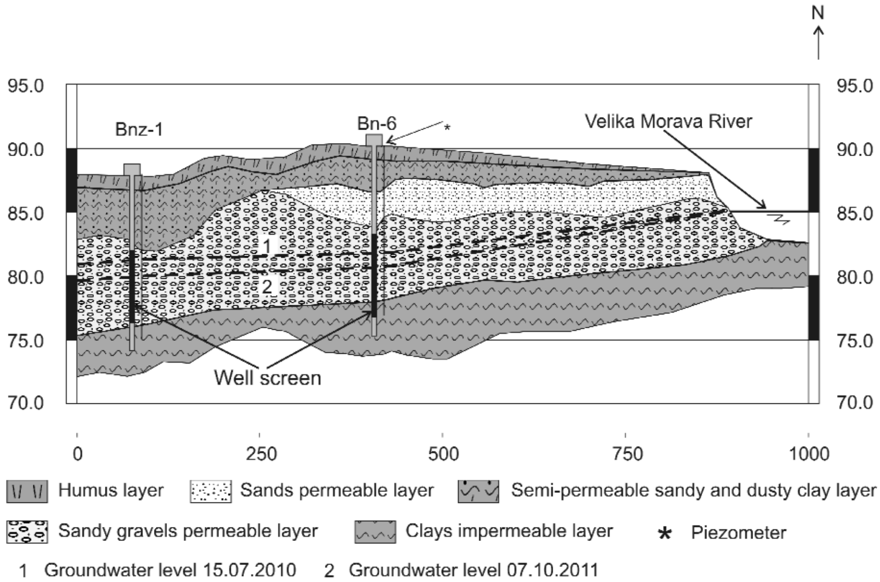

Fig. 2. Simplified hydrogeological cross section from tube well Bnz-1 to Bn-6

Table 1. General data for selected tube wells at the Trnovče groundwater source. BT-16 was drilled in 2007. n.a., not available.

Tube well	Depth (m)	Screen position (m a.s.l)	Pump position (m a.s.l)	Distance from the river (m)	$Q_{av.2002}$/ $Q_{av.2012}$ Q (L/s)	*Eh* aver. (mV)
BT-16	15.3	83.12–78.62	77.1	645	-/n.a.	89
Bn-9G	16.0	80.88–76.62	76.0	520	11.2/6.5	229
Bn-8a	15.0	82.50–76.50	78.5	1080	9.2/5.3	n.a
Bn-6	14.5	83.00–77.00	76.5	470	9.9/5.0	175
Bn-5	15.1	82.55–75.15	76.9	350	9.0/3.0	234
Bnz-1	13.6	82.16–76.16	76.2	780	20.0/5.1	162

Six tube wells (BT-16, Bn-9G, Bn-8a, Bn-6, Bn-5 and Bnz-1) were selected at Trnovče groundwater source for well deposits analysis.

General data for each selected tube well from Trnovče groundwater source are given in Table 1.

The Belgrade Groundwater Source is comprised of 99 radial wells and about 50 tube wells, located along the Sava's bank upstream from its confluence with the Danube. The Sava River alluvial was developed through several sedimentation cycles and sequences: sandy gravel, sands of various grain sizes, and silty and clayey sediments. The thickness of the Quaternary strata is up to 25 m. DIMKIĆ & PUŠIĆ (2014) distinguish, two cross-sectional zones, with regard to the grain sizes of the sediments. According to those authors, Lower zone is consisting of coarse-grain sediments (Fig 3) in which radial well laterals are installed (Table 2). Grain sizes of Lower zone rang from medium-grain sand to fine-grain gravel. These sediments occasionally feature clay, sandy clay and silt interbeds and lenses: while the Upper zone is consisting of fine-grain sediments, with poorer filtration properties (Fig. 3).

General data for selected radial wells from Belgrade groundwater source are given in Table 2.

The radial wells are situated adjacent to the river, and some well laterals are below the riverbed, most of the groundwater that flows to the wells is partly from the wider zone of the alluvial aquifer, and partly from the deeper aquifer. The main redox characteristic of this source is a relatively low Eh, generally below 150 mV (Table 2).

Table 2. General data for selected radial wells from Belgrade groundwater source (*radial well RB-7 set laterals in two positions).

Radial well	Well depth (m)	Lateral position (m a.s.l)	Total lateral number/ Number of active laterals	Pumping water level (in 2014) (m a.s.l)	$Q_{inital}/Q_{well2014}$ (L/s)	*Eh* aver. (mV)
RB-42	25.7	50.5	8/3	55.59	110.0/12.5	85
RB-46	23.6	52.4	8/5	58.03	116.0/16.8	75
RB-48	32.0	45.5	8/6	53.87	135.0/23.0	80
RB-3m	23.2	53.0	8/4	59.16	185.0/44.0	100
RB-3	27.6	48.5	11/1	53.21	225.0/ 5.2	120
RB-4	25.3	50.4	8/8	58.05	318.0/105.0	160
RB-7*	24.5	(I) 50.5 (II) 51.3	10/6	55.20	196.0/18.0	100
RB-69	18.6	58.2	8/3	63.18	100.0/6.3	100
RB-83	24.0	53.0	8/7	56.25	100.0/41.0	110

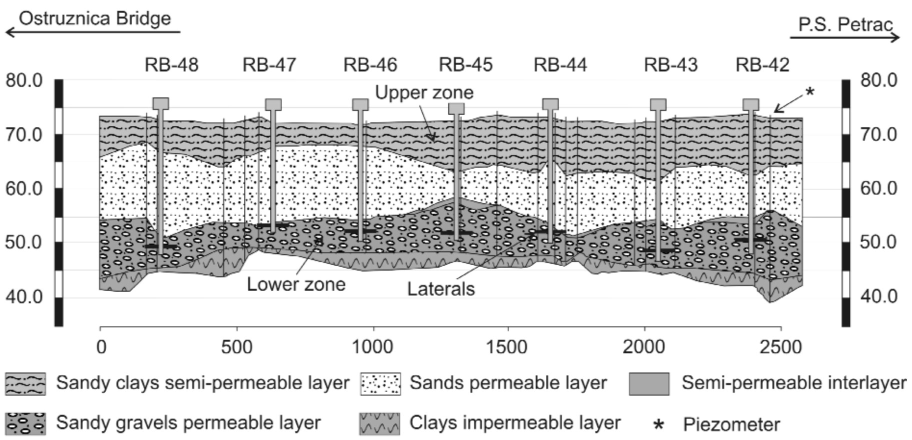

Fig. 3. Simplified hydrogeological cross-section from radial well RB-48 to RB-42 (Belgrade groundwater source - the Sava River right waterside; sector Surčin).

Materials and methods

Samples of 15 incrustations, collected from wells that tap shallow alluvial aquifers, were analyzed for the purposes of this research, following special-purpose groundwater chemistry monitoring from 2006 to 2013 at Belgrade and 2008–2013 at Trnovče groundwater source. The results of groundwater chemical monitoring were used to define the predominant redox processes, applying the chemical criteria proposed by MCMAHON & CHAPELLE (2008), JURGENS *et al.* (2009) and chemical and microbiological criteria proposed by MAJKIĆ (2013). The redox categories and prevailing redox processes were identified using the input data and the threshold values established in the *Workbook for identifying redox processes* (JURGENS *et al.* 2009). The criterion for the selection of wells whose incrustations were to be tested was the existence of different oxidation-reduction categories based on the outcomes of groundwater chemical analyses. According to JURGENS *et al.* (2009) and MAJKIĆ (2013), groundwater samples are often mixture of multiple layers of an aquifer, and that mixing in well bore can produce chemistry results that suggest multiple redox condition. Commercial Biological Activity Reaction tests (BART) were used for microbiological analyses of groundwater. During investigation four different BART tests were applied: IRB BART (for Iron-related bacteria), SRB BART (for Sulfate–reducing bacteria), HAB BART (for Heterotrophic aerobic bacteria) and SLIME BART (for Slime forming bacteria). Six wells were selected at Trnovče groundwater source (BT-16, Bn-9G, Bn-8a, Bn-6, Bn-5 and Bnz-1), where the redox category was determined to be mixed oxic-anoxic (mixture of oxygen and iron-reducing groundwater O_2-Fe(III)). At Belgrade groundwater source, the selected wells included six radial wells (RB-7, RB-42, RB-4, RB-83, RB-69, RB-3), whose redox category was anoxic (iron-reducing groundwater), and three wells that fell into the mixed anoxic category (wells RB -3m, RB-46 and RB-48), defined as iron and sulfate-reducing groundwater (Fe(III)-SO_4).

Prior to sampling, the wells were visually inspected with an underwater (GeoVISION Deluxe) camera.

Incrustations from the radial well laterals at Belgrade were sampled by specially-trained divers, who removed the incrustations from the inside of the laterals. At Trnovče, incrustations were sampled from tube wells during the course of mechanical regeneration, prior to applying chemicals.

The samples were placed in sterile jars and refrigerated to prevent oxidation. The samples were dried at a temperature of 60°C (CORRNEL & SCWERTMANN 1996), or 37°C if the samples contained manganese. For analytical purposes, the samples were ground into powder in an agate mortar.

X-ray powder diffraction (XRPD) analyses of the samples were conducted using a Philips PW-1710 automated diffractometer (equipped with a diffracted beam curved graphite monochromator and a Xe-filled proportional counter), including a Cu-tube operated at 40 kV and 30 mA. Data were collected in the 2θ-range between 4–80°, with a counting time of 0.25 s per step and a step size of 0.02° 2θ. A fixed 2° divergence and 0.2 mm receiving slits were used.

The morphological characteristics were determined and the semi-quantitative chemical analyses of the incrustations performed applying the SEM-EDS technique (SEM model: JEOL JSM – 6610LV). The same instrument was used to photograph the bacteria. The powdered samples were sputter coated with 24-carat gold. The limit of detection for the semi-quantitative analyses was 0.1wt. %. The main shortfall of this method was the high spectrum baseline, which rendered the determination of micro-components in the sample rather difficult.

Results

The outcomes of the present study of the geochemical compositions of the incrustations (Table 3) showed that ferrihydrite, low-crystallinity iron-oxy(hydroxide) and, to a lesser extent, manganese hydroxides were precipitated in the mixed oxic-anoxic redox environment where the redox process was defined as O_2-Fe(III) reduction. Ferrihydrite ($Fe_5HO_8 \cdot 4H_2O$) is often referred to in the literature as “amorphous iron hydroxide”, although the crystallographic order of this mineral is low (CORNELL & SCHWERTMANN 2003). Ferrihydrite is generally the most common mineral phase of recent iron incrustations (MAJKIĆ 2013). The proportion of the ferrihydrite mass in the analyzed incrustations was between 625.9 to 762.2 g/kg, while that of $Mn(OH)_2$ was 2.67 g/kg to 212.8 g/kg. No $Mn(OH)_2$ deposits were found in the samples collected from anoxic environments (Fig. 4).

Low-crystallinity iron oxy(hydroxides) are considered the dominant sorbents of dissolved metals in groundwater, given their large specific surface and surface capacity due to the existence of a large number of OH^- groups, such that low-crystallinity Fe-oxy(hydroxides) are chemically more reactive than crystallized Fe-oxides (TADESSE 1997). The results from this investigation also showed that phosphates adsorb very well on ferrihydrite, while the proportion by weight decreased in incrustations where goethite was detected in conjunction with iron sulfides (Table 3).

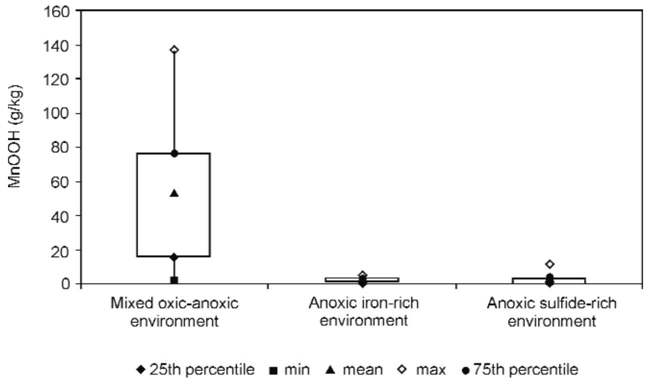

Fig. 4. Box-plot of low-crystallinity $Mn(OH)_2$ proportions of incrustations in different geochemical environments.

A scanning microscope detected two species of iron-related bacteria: *Galionella ferruginea* and *Leptothrix* sp. in samples (Figs. 5 and 6). In all the samples collected from wells in mixed oxic-anoxic environment, the bacteria were coated with a thick layer of Fe-oxy(hydroxide) (Fig 5). According to RODEN *et al.* (2004), Fe(II) oxidizing bacteria dwell in microaerobic environments, with lower oxygen concentrations. FORTIN & LANGLEY (2005) explained that the metabolic activity of acidophilous and neutrophilous iron bacteria under oxic conditions causes the oxidation of Fe(II) into Fe(III) and the creation of biogenic iron oxides as extracellular deposits on the walls of bacterial cells. This layer has multiple roles (FRENKEL & BAZYLINSKI 2003). HANERT (1992) concluded that the

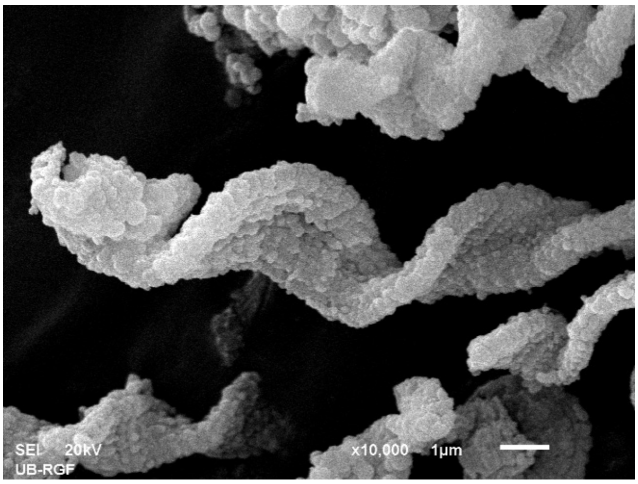

Fig. 5. Scanning electron image of IRB *Gallionella ferruginea* with biogenic mineral coatings on their cells in incrustations of a water well in a mixed oxic-anoxic environment.

Table 3. Selected geochemical parameters of water well incrustations (analyses performed using EDS). *Oxygen determined by stoichiometry. LLD, low limit detection.

Sample	Water supply source	SiO_2 (wt%)	Al_2O_3 (wt%)	Fe_2O_3 (wt%)	MnO (wt%)	CaO (wt%)	P_2O_5 (wt%)	S (mg/kg)	As (mg/kg)	Ba (mg/kg)	Sn (mg/kg)	Sb (mg/kg)
BT-16	Trnovče	8.6	0.2	69.3	0.3	7.2	12.3	56.7	73.3	383.3	166.7	120.0
Bn-9G		6.9	0.3	72.8	7.7	5.7	4.4	73.3	336.7	483.3	146.7	320.0
Bn-8a		5.6	0.3	72.8	5.4	6.3	7.9	46.7	288.0	366.7	293.3	220.0
Bn-6		9.0	0.4	76.2	1.5	4.9	7.2	<LLD	573.0	306.7	<LLD	83.3
Bn-5		5.3	0.4	62.6	21.3	4.3	4.3	<LLD	507.0	586.7	156.7	<LLD
Bnz-1		6.5	0.4	65.1	13.6	4.3	6.6	<LLD	<LLD	186.7	146.7	336.7
RB-48	Belgrade	5.7	1.0	75.9	0.0	1.3	0.4	15313.3	80.0	<LLD	<LLD	73.3
RB-46		29.1	3.6	53.5	0.0	1.4	0.1	9656.7	61.8	<LLD	<LLD	<LLD
RB-3m		3.8	0.6	79.1	0.0	2.2	2.7	10853.3	<LLD	80.0	<LLD	73.3
RB-42		54.8	6.4	18.1	1.8	12.2	0.0	963.3	<LLD	113.3	393.3	186.7
RB-7		7.3	0.4	77.4	0.2	5.7	7.8	53.3	166.7	<LLD	<LLD	<LLD
RB-4		10.9	0.2	79.3	0.1	3.8	4.3	<LLD	256.7	306.7	<LLD	86.7
RB-83		4.1	0.3	67.2	0.2	9.3	16.3	<LLD	345.0	300.0	<LLD	405.0
RB-69		17.6	4.4	51.9	0.4	10.8	10.4	350.0	104.0	375.0	110.0	235.0
RB-3		43.5	5.1	33.9	0.7	8.7	4.5	<LLD	<LLD	<LLD	<LLD	<LLD

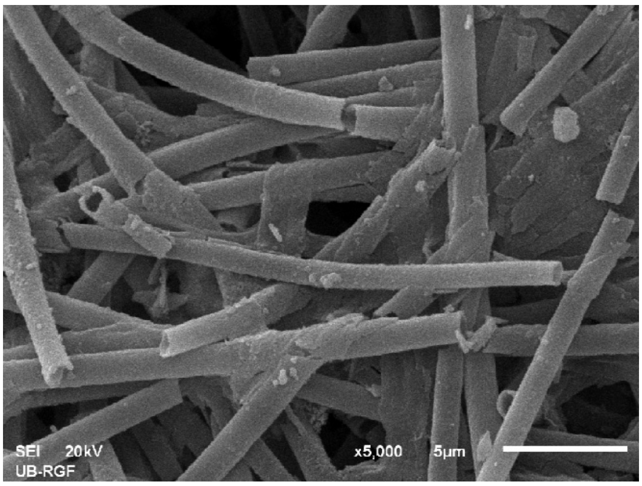

Fig. 6. Scanning electron image of IRB *Leptothrix* sp. without biogenic mineral coatings on their cells in incrustations of a water well in a anoxic environment (well RB-69, Belgrade).

coats become the cores for future mineralization (i.e. they continue to accumulate Fe- oxy(hydroxides)).

In anoxic environments, the formation of incrustations on well screens is slower than in mixed oxic-anoxic environment. The results of XRD analyses of incrustations sampled from anoxic iron-rich environments showed the presence of better crystallized forms like goethite α-FeOOH. The re-crystallization of low-crystalline ferrihydrite into thermodynamically stable goethite depends on several factors: increasing pH (SCHWERTMANN & MURAD 1983), temperature (DAS *et al.* 2011), the presence of inhibitors like phosphates (GALVEZ *et al.* 1999, WANG *et al.* 2013), silicates (CORNELL & SCWERTMANN 2003), and organic substances (CORNELL & SCWERTMANN 1979), as well as on the concentrations of adsorbed bivalent metals (MARTINEZ and MCBRIGE 1998). Previously adsorbed anions and cations might be released during the re-crystallization process. The occurrence of siderite $Fe(CO)_3$ was noted in incrustations sampled from wells that tap anoxic groundwater at Belgrade groundwater source. The presence of siderite can also be associated with the bioreduction of ferrihydrite (MORTIMER & COLEMAN 1997, FREDRICKSON *et al.* 1998) (Fig. 7). The simultaneous presence of Fe oxides, carbonates and sulfides could be indicative of a change in redox conditions during incrustation, or of the presence of different micro-environments in well laterals.

Anoxic S-rich environments are characterized by parallel Fe(III)-SO_4 reduction processes. Such conditions were noted in three of the studied wells at Belgrade groundwater source. The proportions of sulfur in the incrustations on radial well laterals were from 9.66 to 15.3 wt %. In the incrustation sample from well RB-48, XRD diffraction revealed the presence of greigite Fe_3S_4, bernalite $Fe(OH)_3$, sulfur S_8 and goethite α-FeOOH. The scanning electron microscopy of the incrustation sample is shown in Fig. 8, while Fig. 9 shows the results of XRD analysis. The

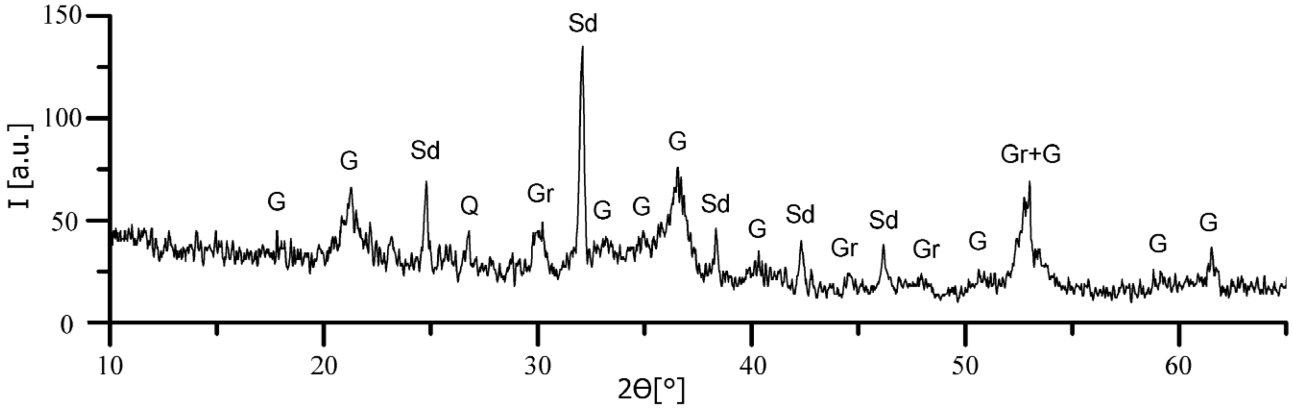

Fig. 7. XRD pattern of incrustation from well RB-3m (Belgrade groundwater source). Legend: **Sd**, siderite ($Fe(CO)_3$); **Q,** quartz (SiO_2); **G,** goethite (α-FeOOH); **Gr,** greigite (Fe_3S_4).

occurrence of elemental sulfur in the incrustation sampled from well RB-48 is attributable to sulfide oxidation by means of ferrihydrite and goethite, where elemental sulfur is the end product of oxidation (Poulton *et al.* 2004). Elemental sulfur can also be reduced to sulfide by most sulfate-reducing bacteria (Madigan *et al.* 2009). Greigite is a tiospinel of iron, a sulfur analog of magnetite, whose general formula is Fe_3S_4. This metastable mineral can occur biogenically, through the activity of *Desulfovibrio desulfuricans* in the presence of iron salts (Rickard & Luther 2007), or magnetotactic bacteria, including anaerobic sulfate-reducing bacteria, which can synthesize greigite (Mann *at al.* 1990, Postfai *et al.* 1998). In Germany, Houben & Treskatis (2007) attributed the formation of greigite and the occurrence of sulfur in well incrustations to bacterial activity. The microbiological analyses of the groundwater samples collected from the above-mentioned well revealed the presence of sulfate-reducing bacteria (SRB), but their species could not be identified by the BART method applied.

Bernalite $Fe(OH)_3$, detected in a sample collected from well RB-48 (Fig. 8), occurred as a pseudo-octahedral to pseudo-cubic crystal. Fernano and Suranganee (2009) associate the occurrence of bernalite with acidic sulfate soils that contain iron sulfides. It is rare and its presence in well incrustations should be studied in detail with regard to site-specific micro-environmental conditions.

Quartz SiO_2 and clay minerals were found in the analyzed samples, as products of the natural environment. Their proportion was higher at Belgrade (3.8–54.8 wt%) than at Trnovče (5.6–9 wt%) as a result of corrosion processes on old laterals.

Discussion

The decline in water well capacity at the Belgrade Groundwater Source was initially caused by draw-

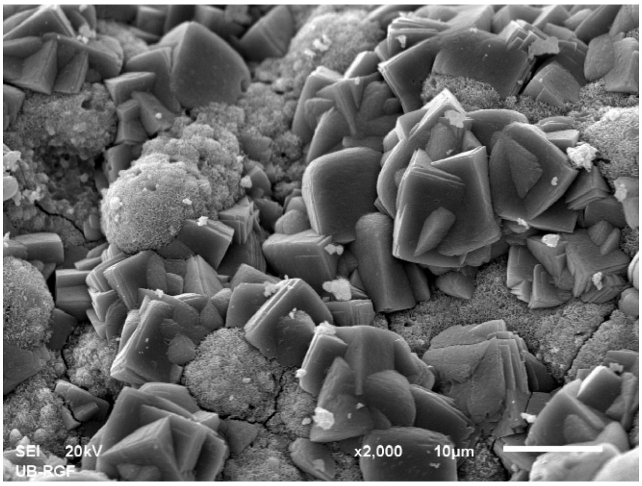

Fig. 8. Scanning electron image of incrustation from well RB-48 (Belgrade groundwater source). Image of bernalite ($Fe(OH)_3$) associate with greigite (Fe_3S_4).

down, then by riverbed colmation and finally by well ageing and ruination (Dimkić *et al.* 2007b). During the initial period of service (1956 to 1965), the wells relied on dynamic groundwater reserves to a large extent. This period was characterized by high groundwater levels but there were initial signs of decline. In the second period (1965 to 1986), colmation of the Sava riverbed and well aging due to clogging of radial well laterals resulted in a declining capacity of the source. At that time, the decreasing well capacity was offset by the construction of new wells and physical (and to a lesser extent chemical) regeneration of laterals. Very low groundwater levels were typical of that period. Static groundwater reserves were increasingly being used. The third period (1985 to 2012) was characterized by very low spending for maintenance and development of the source. This was a result of the crisis in Serbia in the 1990s and a lack of funding. As the wells aged and failed, the capacity of the entire source decreased

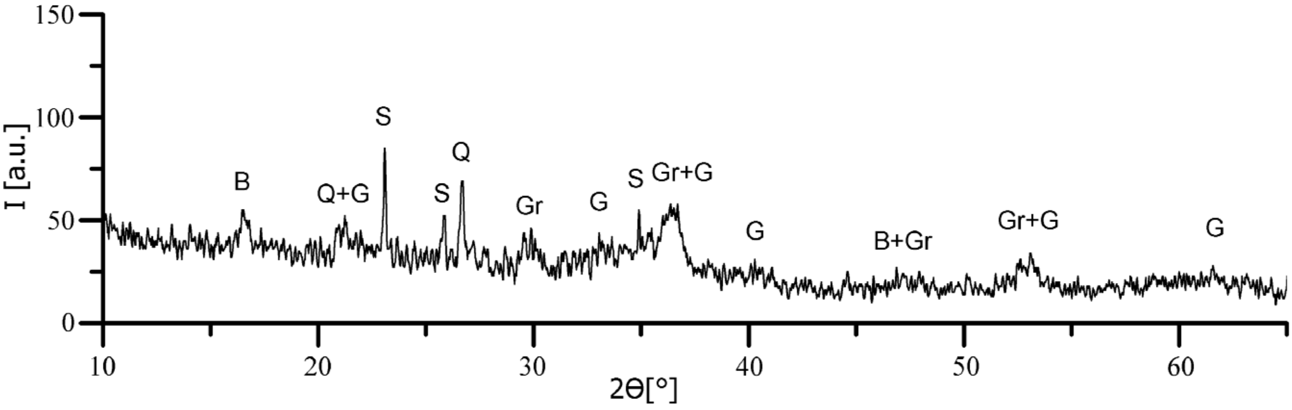

Fig. 9. XRD pattern of incrustation from well RB-48 (Belgrade groundwater source). Legend: **G**, goethite (α-FeOOH); **B,** bernalite ($Fe(OH)_3$); **Q,** quartz (SiO_2); **S,** sulfur (S_8); **Gr,** greigite (Fe_3S_4).

(DIMKIĆ *et al.* 2007b). In the Table 2, are shown data for decreasing capacity of selected radial wells. At Belgrade, physical regeneration has been the method of choice for years, using WOMA pumps with directional nozzles at a pressure of 30–60 bars.

Until the year 1998, the water supply source at Trnovče operated five wells, whose total capacity was 60 l/s. Today, there are 20 tube wells, whose average yield is about 5 l/s per well (Table 1). Available data on well capacity variation at Trnovče over the past ten years indicate that well yield is gradually declining (Table 1) and that post-regeneration capacity is far below the initial capacity (MAJKIĆ-DURSUN *et al.* 2012). Camera inspection was undertaken before and after regeneration in 2011 at Trnovče, to monitor the effectiveness of regeneration (MAJKIĆ 2013). The footage and the post-regeneration groundwater level and discharge monitoring data revealed only short-term effects (several months).

Mineral and chemical analyses showed that iron incrustations of different crystallinity levels were dominant at both water supply sources. Their total proportion by weight ranged from 18.1 to 79.3%. The average was 63.7. The state of disequilibrium was caused by mixing of reduced iron–containing groundwater with oxygenated groundwater (mixed oxic-anoxic groundwater category), while the well was in service. In such environments, incrustations comprised of ferrihydrite ($Fe_5HO_8{\cdot}4H_2O$) and low-crystallinity $Mn(OH)_2$ are common and were typical of the source at Trnovče, while anoxic environments revealed goethite (α-FeOOH), siderite $Fe(CO)_3$, greigite (Fe_3S_4), bernalite $Fe(OH)_3$ and quartz (SiO_2). Iron sulfide minerals were detected in samples collected from anoxic S-rich geochemical settings.

The crystallinity level was higher in samples collected from wells where the time interval between two regenerations was longer than two years.

Minerals like quartz and clay occurred as products of the media passively incorporated into the well deposits. Their amounts were the greatest in the wells affected by both clogging and corrosion processes (wells RB-42 and RB-46). Studies have shown that bacteria play an important role in the formation of incrustations, especially *Gallionella ferruginea* and *Leptothrix* sp.

The regenerations carried out at Trnovče were effective only in the short term. The application of hydrochloric acid and citric acid as inhibitor were not sufficient to sanitize the near-well region, resulting in a reduced life of the well. At Belgrade, mechanical regeneration of radial wells tended to sanitize only a part of the lateral, leading to a reduction in the conveyance capacity of the lateral and eventual sealing. High-crystallinity incrustations are rather difficult to remove, so the study of the rate of re-crystallization of ferrihydrite to goethite is of major importance in assessing the proper time interval to the next regeneration.

Apart from scientific significance, the occurrence and re-crystallization of mineral deposits is also important in economic terms. The reduction in solubility and hardening of incrustations determine the method and cost of regeneration. Mineral and chemical analyses of the composition of the incrustation are also important for proper selection of chemical agents that will enhance the effectiveness of regeneration. Given the cost of regeneration, prior analyzing of the incrustations will enable considerable savings and extend the time interval between two regenerations.

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References

APPLIN, K.R. & ZHAO, N.1989. The kinetics of Fe(II) oxidation and well screen encrustration. *Ground Water*, 27 (4): 168–174.

VAN BEEK, K., BREEDVELD, R., TAS, M. & KOLLEN, R. 2010. Prevention of Wellbore Clogging by Intermittent Abstraction. *Groundwater Monitoring & Remediation*, 30:81–89. doi: 10.1111/j.1745-6592.2010.01307.x

VAN BEEK, C.G.E.M. 2011. *Cause and prevention of clogging of wells abstracting groundwater from unconsolidated aquifers*. 192 pp. IWA Publishing, London.

CHAPELLE, F.H., BRADLEY, P.M., THOMAS, M.A. & MCMAHON, P.B. 2009. Distinguishing iron-reducing from sulfate-reducing conditions. *Ground Water,* 47 (2): 300–305.

CORNELL, R.M. & SCHWERTMANN, U. 1979. Influence of organic anions on the crystallization of ferrihydrite, *Clays and Clay Minerals,* 27 (6): 402–410.

CORNELL, R.M. & SCHWERTMANN, U. 2003. *The iron oxides: structure, properties, reactions, occurrences, and uses.* 2nd, Completely rev. and extended edition. 664 pp. Weinheim. Wiley-VCH.

CULLIMORE, D.R. 1999. *Microbiology of well biofouling.* 456 pp. CRC Press Boca Raton, USA.

DAVIDSON, W. & SEED, G. 1983. The kinetics of the oxidation of ferrous iron in synthetic and natural waters, *Geochimica et Cosmochimica Acta*, 47: 67–79.

DAS, S., HENDRY, M.J. & ESSILFIE-DUGHAN, J. 2011. Transformation of two-line ferrihydrite to goethite and hematite as a function of pH and temperature. *Environmental Science & Technology*, 45 (1): 268–75.

DIMKIĆ, M., STEVANOVIĆ, Z. & ĐURIĆ, D. 2007a. Utilization, Protection and Status of Groundwater in Serbia. *Proceedings Groundwater management in the Danube river basin and other large river basins*. Regional IWA Conference. Belgrade, 7 p.

DIMKIĆ, M., TAUŠANOVIĆ, V., PUŠIĆ, M., BORELI-ZDRAVKOVIĆ, DJ., DJURIĆ, D., SLIMAK, T., PETKOVIĆ, A., OBRADOVIĆ, V. & BABIĆ, R. 2007b. Belgrade groundwater source, condition and possible development directions. *Water Practice and Technology,* 2 (3). doi 10.2166/wpt.2007.059

DIMKIĆ, M., PUŠIĆ, M., MAJKIĆ-DURSUN B. & OBRADOVIĆ, V. 2011. Certain Implications of Oxic Conditions in Alluvial Groundwater, *Water resources and Management*, 1 (2): 27–43.

DIMKIĆ, M., PUŠIĆ, M. 2014. Correlation Between Entrance Velocities, Increase in Local Hydraulic Resistances and Redox Potential of Alluvial Groundwater Sources, *Water resources and Management*, 4 (4): 3–23.

EHRLICH, H.L. 2002. Geomicrobiology of iron. *In*: EHRLICH, H.L. (ed.), *Geomicrobiology*, 345–428. Marcel Dekker, Inc. New York, NY.

EMERSON D. & WEISS, J.V. 2004. Bacterial iron oxidation in circumneutral freshwater habitats: findings from the field and the laboratory. *Geomicrobiology Journal,* 21: 405–414.

FERNANDO, G.W.A.R. & SURANGANEE, R.K.N. 2009. Development of acid sulphate soils in Nilwala flood protection area, Matara, Sri Lanka. *Journal of geological Society of Sri Lanka*, 13: 71–82.

FORTIN, T.D. & Langley, S. 2005. Formation and occurrence of biogenic iron-rich minerals. *Earth-Science Reviews,* 72: 1–19.

FRANKEL, R. & BAZYLINSKI, D.A. 2003. Biologically Induced Mineralization by Bacteria. *Reviews in Mineralogy and Geochemistry*, 54: 95–114.

FREDRICKSON, J.K., ZACHARA, J.M, KENNEDY, D.W., LI, S-M. & HINMAN, N.W. 1998. Biogenic iron mineralization accompanying the dissimilatory reduction of hydrous ferric oxide by a groundwater bacterium. *Geochimica et Cosmochimica Acta,* 62: 3239–3257.

GALVEZ, N., BARRON, V. & TORRENT, J. 1999. Effects of phosphate on the crystallization of hematite, goethite and lepidocrocite from ferrihydrite, *Clays and Clay Mineralogy,* 47 (3): 304–311.

HANERT, H.H. 1992. The Genus *Gallionella*. *In*: BALOWS, A.,TRÜPER, G.H., DWORKIN, M., HARDER, W. & SCHLEIFER, K-H. (Eds.) *The Prokaryotes*, 4082–4088. Springer-Verlag New York, Inc., New York.

HOUBEN, G.J. 2003. Iron oxide incrustations in wells. Part 1: genesis, mineralogy and geochemistry. *Applied Geochemistry*, 18: 927–939.

HOUBEN, G.J. 2006. The influence of well hydraulics on the spatial distribution of well incrustations. *Ground Water,* 44 (5): 668–675.

HOUBEN, G. & TRESKATIS, C. 2007. *Water Well Rehabilitation and Reconstruction*. 391 pp, McGraw Hill, New York.

JURGENS, B.C., MCMAHON, P.B., CHAPELLE, F.H. & EBERTS, S.M. 2009. *An Excel® Workbook for identifying redox processes in ground water*. USGS Open-File Report 2009–1004. Reston, Virginia: USGS. 8 p. http://pubs.usgs.gov/of/2009/1004/ (last accessed July 6, 2014).

LARROQUE, F. & FRANCESCHI, M. 2011. Impact of chemical clogging on de-watering well productivity: numerical assessment, *Environmental Earth Sciences*, 64 (1): 119–131.

LOVLEY, DR. 2000. Fe(III) and Mn(IV) reduction. *In*: LOVLEY D.R. (ed.), *Environmental Metal-Microbe Interactions*, 3–30. Washington DC, ASM Press.

MADIGAN M., MARTINKO J., DUNLAP J.P. & CLARK, D. 2009: *Brock: Biology of Microorganisms*. 12th edition, 1161 pp. Pearson Benjamin Cummings, San Francisco.

MAJKIĆ-DURSUN, B., POPOVIĆ, Lj., MIOLSKI, D. & ANĐELKOVIĆ, O. 2012. Effect of declining groundwater levels on well ageing processes: case study of the water supply source of Trnovče, *Vodoprivreda,* 258-260, v. 44 (4–6): 181–187 (in Serbian).

MAJKIĆ, B. 2013. *Water well ageing in alluvial sediments of different oxic conditions*, unpublished, PhD Thesis, 301 pp. Faculty of Mining and Geology, University of Belgrade, Belgrade (in Serbian, English summary)

Martin, S. 2005. Precipitation and dissolution of iron and manganese oxides, Chapter 4: *In*: Grassian V.H. (ed.), *Environmental Catalysis*, 44 pp. CRC Publishing, Boca Raton, FL, USA.

Mann, S., Sparks, N.H.C., Frankel, R.B., Bazylinski, D.A. & Jannasch, H.W. 1990. Biomineralization of ferromagnetic greigite (Fe_3S_4) and iron pyrite (FeS_2) in a magnetotactic bacterium. *Nature,* 343: 258–261.

Martinez, C.E. & McBride, M.B. 1998. Coprecipitation of Cd, Cu, Pb and Zn in iron oxides: solid phase transformations and metal solubility after ageing and thermal treatment. *Clays and Clay Minerals*, 46: 537–545.

McMahon, P.B. & Chapelle, F.H. 2008. Redox processes and the water quality of selected principal aquifer systems of the United States. *Ground Water,* 44 (2): 259–271.

Mortimer, R.J.G., Coleman, M.L. & Rae, J.E. 1997. Effect of bacteria on the elemental composition of early diagenetic siderite: implications for palaeoenvironmental interpretations. *Sedimentology,* 44: 759–765.

Postfai, M. Buseck, P.R., Bazylinski, D.A. & Frankel, R.B. 1998. Reaction sequence of iron sulfide minerals in bacteria and their use as biomarkers. *Science,* 280: 880–883.

Poulton, S.W., Krom, M.D. & Raiswell R. 2004. A revised scheme for the reactivity of iron (oxyhydro)oxide minerals towards dissolved sulfides. *Geochimica et Cosmochimica Acta,* 68: 3703–3715.

Rickard, D. & Luther III, G.W. 2007. Chemistry of iron sulfides, *Chemical Review,* 107: 514–562.

Roden, E.E., Sobolev, D., Glazer, B. & Luther III, G.W. 2004. Potential for microscale bacterial Fe redox cycling at the aerobic-anaerobic interface. *Geomicrobiological Journal,* 21: 379–391.

Schwertmann, U. & Murad, E. 1983. Effects of pH on the formation of goethite and hematite from ferrihydrite. *Clay and Clay Minerals,* 31: 277–284.

Smith, S.A. & Tuovinen, O.H. 1985. Environmental analysis of iron-precipitating bacteria in ground water and wells. *Groundwater Monitoring Review,* 5 (4): 45–52.

Straub, K.L., Benz, M. & Schink, B. 2001. Iron metabolism in anoxic environments at near neutral pH. FEMS *Microbial. Ecology,* 34: 181–186.

Stumm W & Morgan J.J. 1996. *Aquatic Chemistry*. 1022 pp. John Wiley & Sons, New York.

Tadesse, B. 1997. *Iron and Manganese oxides in the soil-water environments*, PhD thesis, Department of Chemistry, Brunel University, London

Walter, D.A. 1997. The effects and occurrence of iron-related well screen incrustation, Suffolk County, N.Y. U.S. Geological Survey Water-Resources Investigations Report 96–4217, 29 p.

Wang, X., Liu, F., Tan ,W., Li, W., Feng, X. & Sparks, D., 2013. Characteristic of Phosphate adsorption – desorption onto ferrihydrite: comparison with well-crystalline Fe (Hydr)oxides, *Soil Science,* 178 (1): 1–11.

Резиме

Колмирање бунара за јавно водоснабдевање у алувијалним аквиферима централне Србије минералним инкрустацијама

Опадање капацитета бунара у времену настаје као последица процеса корозије и колмирања. Процесе корозије могуће је спречити уградњом одговарајућих филтерских конструкција отпорних на корозију, док процеси колмирања могу настати без обзира на врсту уграђеног материјала. Колмирање бунара доводи до опадања капацитета бунара, повећања паразитских губитака, пораста економских средства неопходних за трошкове одржавања и на крају напуштања водозахвата. Формирање талога може бити механичко, хемијско и биохемијско. У циљу сагледавања врста талога формираних у бунарима за јавно водоснабдевање који каптирају алувијалне издани, одабрано је 15 узорака за детаљне анализе. Одабир узорака вршен је тако да се задовоље критеријуми различитих оксидо-редукционих средина (мешано оксично-аноксична средина – извориште Трновче, 6 узорака), аноксична средина у којој преовлађује процес редукције Fe(III) (Београдско извориште подземних вода – 6 узорака) и мешана аноксична средина са преовлађујућим процесом паралелне редукције Fe(III)-SO_4 у подземној води (Београдско извориште подземних вода – 3 узорка). Хемијске и микробиолошке анализе подземних вода извршене су у лабораторији Института „Јарослав Черни“, док су семи-квантитативне анализе хемијског састава талога и ренгенска дифракција извршене на Рударско-геолошком факултету.

Као доминантне наслаге у бунарима, који каптирају алувијалне издани Велике Мораве и Саве, јављају се (окси)хидроксиди гвожђа. Просечан удео ових талога креће се од 18.1 до 79.3 тежинских процента, са средњом вредношћу од 63.7 теж. процената. Узорци са изворишта Трновче показују да се услед мешања кисеоника са подземним водама богатим двовалентним гвожђем брзо формирају наслаге ферихидрита (625.9 до 762.2 g/kg). У мањем уделу у талозима се јавља манган-хидроксид ниског степена кристалинитета (2.67 g/kg до 212.8 g/kg). Обзиром да је за формирање талога мангана неопходан већи редокс потенцијал манганове инкрустације нису детектоване у аноксичним срединама. Само у једном узорку (Bn-8a) било је довољно времена између две регенерације бунара за формирање гетита (α-FeOOH). Гвожђе-оксидишуће бактерије у условима брзе хемијске оксидације гвожђа таложе око себе слој ферихидрита чиме се прилагођавају условима мешовите оксично-аноксичне средине. *Gallionella ferruginea* и *Leptothrix* sp. катализују процесе оксидо-редукције гвожђа и

учествују у формирању талога. За разлику од бунара на Трновчу, београдски бунари са хоризонталним дреновима показују да је махом дошло до рекристализације ферихидрита до гетита (α-FeOOH) који формира наслаге на дреновима. Дужи периоди између регенерација бунара омогућују „очвршћавање" наслага а самим тим и отежавају физичкохемијске регенерације. Осим гетита, сва три узорка талога из дренова бунара који каптирају мешану аноксичну средину (тип преовлађујућег процеса дефинисан као паралелна редукција Fe(III)-SO_4) карактерише присуство грејгита (Fe_3S_4), док је у једном узорку одређено присуство берналита $Fe(OH)_3$ и моноклиничног сумпора S_8. У њиховом формирању улогу имају сулфато-редукујуће бактерије. У бунарима захваћеним парелелно процесима колмирања и корозије (RB-3, RB-42 и RB-46) значајније је учешће кварца и глиновитих минерала који су пасивно инкорпорирани у талоге. Учешће кварца у овим узорцима износи до 54.8 тежинских процената и указује на пескарење бунара.

Одређивање минерала који чине бунарски талог пре опредељења за одређени тип физичко-хемијске регенерације, повећава ефикасност примењених поступака, смањује трошкове одржавања изворишта и продужава век трајања водозахватних објеката.

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Impact of river bank filtration on alluvial groundwater quality: a case study of the Velika Morava River in central Serbia

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Abstract. Alluvial aquifers are preferred sites for drinking water production. Riverbed sediments and saturated alluvial sediments have great potential for groundwater purification which is essential for preserving the stability of the groundwater quality. Conducted research in the area of groundwater source Brzan in central Serbia showed that intergranular aquifer has potential not only to purify polluted surface water but also to enrich water quality. Main aquifer recharge is infiltration of surface water from the Velika Morava River. The quality of surface water is very variable, especially for some components such as turbidity, conductivity, $KMnO_4$ consumption, and iron, chloride and nitrates content. On the other hand, the quality of groundwater is characterised with minimal oscillation particularly regarding mentioned components. Based on numerous results on surface and groundwater quality we can conclude that water from the groundwater source Brzan is with good quality and can be used for drinking consumption with minimal treatment despite the fact that aquifer is in strong hydraulic connection with the Velika Morava River. Improvement of water quality is result manly of water filtration through river bad sediments and aquifer body.

Key words: River bank filtration, Alluvium, Groundwater recharge, Groundwater quality, the Velika Morava River.

Апстракт. Алувијалне издани се у свету најчешће користе за водоснабдевање становништва. Самопречишћавање подземних вода у алувијалним седиментима речног корита и обале има велики значај у очувању стабилности квалитета подземних вода које се добијају из ових средина. Спроведена хидрогеолошка истраживања на изворишту Брзан у централној Србији су показала способност интергрануларне издани да речну воду не само пречисти него јој и побољша квалитет. Прихрањивање овог изворишта се врши на рачун инфилтрације речне воде из Велике Мораве. Док су површинске воде променљивог квалитета, посебно у погледу мутноће, проводљивости, утрошка $KMnO_4$, садржаја јона гвожђа, хлорида и нитрата, квалитет подземних вода акумулираних у интергрануларној издани је са минималним осцилацијама поготово у садржају поменутих компоненти. Извориште Брзан се одликује подземним водама доброг квалитета које се уз минималан третман дистрибуирају крајњим потрошачима, упркос томе што се налази под јаким хидрауличким утицајем Велике Мораве захваљујући изузетној способности издани да побољша квалитет подземне воде.

Кључне речи: филтрација кроз обалске и седименте речног корита, алувијални седименти, прихрањивање подземних вода, квалитет подземних вода, Велика Морава.

Introduction

In many countries worldwide, alluvial aquifers which are hydraulically connected to watercourses are preferred sites for drinking water production. These aquifers are relatively easy to exploit, generally highly productive and located close to the consumers. However, because of their location, their shallowness and their close relationship with the water course, these aquifers are particularly sensitive to pollutants (Doussan *et al*. 1997).

River bank filtration (RBF) is a simple technology for surface water treatment which has been widely applied along major rivers throughout Europe for

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many decades. For example, 30–60 % of the population in Germany, Hungary and Serbia consume drinking water which originates from RBF (STAUDER *et al*. 2012). One example is the city of Berlin (Germany) where the public water supply strongly depends on bank filtration and groundwater precipitation recharge. Nearly 70% of the 220 million m^3/year of exploited water rely on the recharge processes (56% from bank filtration and 14% from precipitation recharge). Surface water is not directly tapped for water supply of city of Berlin, even though there are several proximate rivers and lakes (GRÜNHEID *et al*. 2005). This approach has been increasingly being applied in USA and Asia recently (RAY *et al*. 2002; JHA *et al.* 2009; CHANG *et al*. 2011).

period of deterioration of the river water quality will not harm the quality of alluvial aquifer (SONTHEIMER 1991; MÄLZER *et al*. 2002; RAY 2004).

Effects of the RBF are well explained on the example of groundwater recharge of Velika Morava alluvial aquifer. The groundwater source "Morava-Brzan" is located on the left bank of the broad alluvial plain of the Velika Morava River (Fig. 1), upstream of the confluence with the Lepenica River at one of the meanders that the Velika Morava River creates right after leaving the Bagrdan gorge. The water supply system is based on tapping groundwater from the alluvial deposits of the Velika Morava River. It was built in 1970's and immediately incorporated in Kragujevac city water supply system (PETROVIĆ & ŽIVANOVIĆ 2014). A total

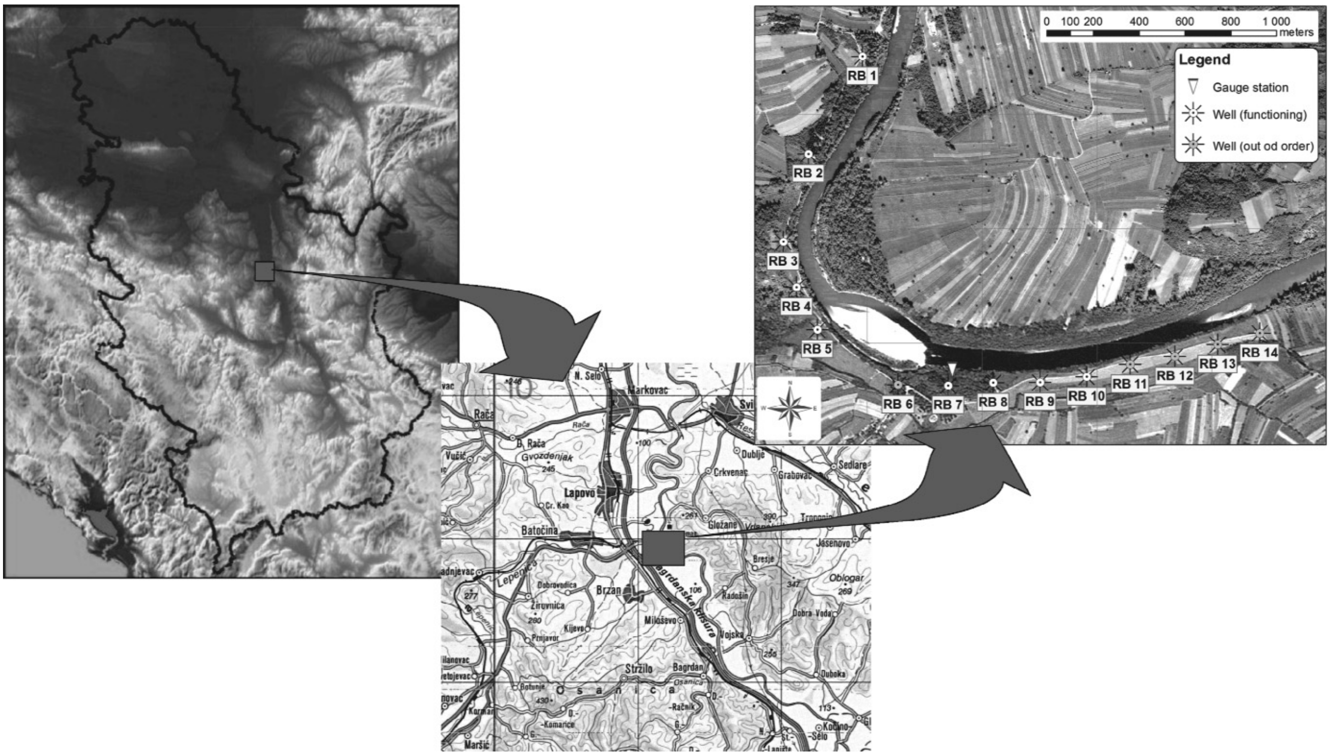

Fig. 1. Geographical location of the groundwater source "Morava-Brzan" and positions of the wells within.

River bank filtration is based on the natural biological and sorptive cleaning powers of the sediment and on the high efficiency in removing diffuse pollutants (e.g. organics and pathogenic microorganism) from waste water discharge (HISCOCK & GRISCHEK 2002; GRÜNHEID *et al*. 2005; DIMKIC *et al*. 2007). Moreover, RBF serves as an efficient barrier against many substances which can be accidentally discharged into a river for a short period ("shock load"). Other important issue is that water tapped from an RBF-well is a mixture of drained river water and present groundwater which flows much longer (weeks, months, years). A shock load usually lasts for 1–3 days and can result in shutting down the river water treatment plant until the pollution passes. On the other hand, such brief

number of 14 radial wells (RB-1 up to RB-14) were built on the concave bank of the river in the period from 1970 to 1976 (STOJADINOVIĆ 1997). Although wells were designed and built with the intent to deliver more than 400 l/s in total, during the period of investigation and in the earlier period of the system operating they rarely reached a total capacity greater than 150 l/s (PETROVIĆ & ŽIVANOVIĆ 2014). One of the reasons for such low level of exploitability of the water supply system is that 5 wells are idle for more than 15 years.

The Velika Morava Valley is open to the north and is under influence of the continental climate. Summers are hot and dry, winters are cold with precipitation in the form of snow and rarely rain. The hilly and mountainous terrains of the catchment area of the Velika Morava River made of low permeable rocks with small retardation capacity causing significant river flow variations in correlation to the amount of rain.

The composition of the plain, from hydrogeological point of view, can be divided into 3 major layers (Fig. 2): a. clayey overlaying sediments with thickness of 4–6 m (alluvial deposits); b. aquifer layer with thickness of 5–10 m (mean 6 m), mainly composed of gravel and sand (alluvial deposits); and c. bottom low permeable layer (aquitard) at a depth of 13–16 m below ground surface. The low permeable layer consists of Neogene clay sediments in the middle area of the groundwater source, and of Palaeozoic schists in the upstream and downstream part of the groundwater source (Fig. 3).

in this period. River levels were measured at staff gauge located in the area of the groundwater source. The measurements were conducted on daily bases. Groundwater level at all wells and piezometers (34 measuring points) were manually measured on a weekly basis. One well (RB-9) and one piezometer (P-11N) were selected for installing data loggers (Schlumberger Mini-Diver) for continuous water level measurements.

Influence of climate parameters was analysed using climate data from nearby state meteorological station Bagrdan-Vojska. Rainfall and temperature data were obtained for each day during the research period.

Water quality of the Velika Morava River and groundwater from the alluvial aquifer was monitored by conducting series of chemical analyses that included following parameters: water temperature, turbidity,

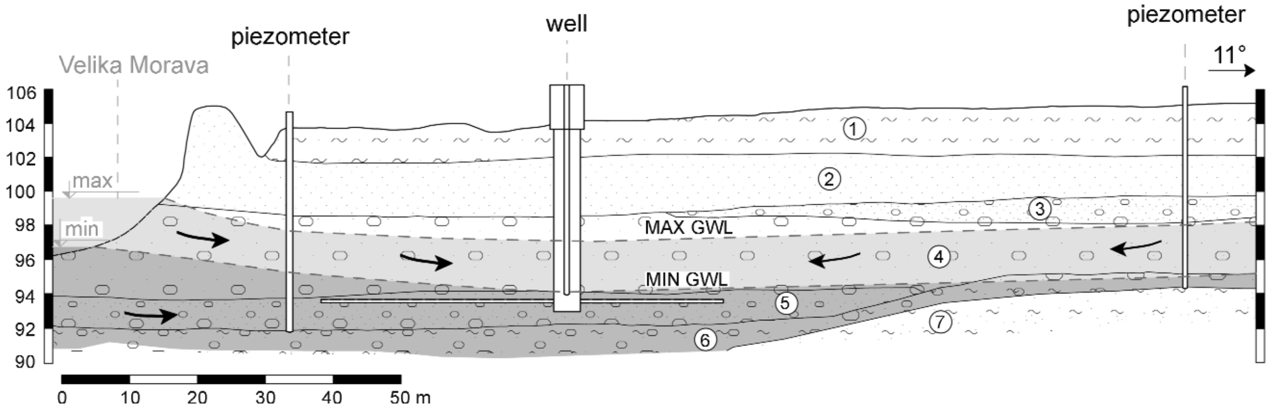

Fig. 2. Hydrogeological profile across the "Morava-Brzan" groundwater source. Legend: **1,** clay – overlaying alluvial sediments; **2,** sand – alluvial sediments; **3,** sandy gravel – alluvial flood facies; **4,** gravel – alluvial facies of river bed; **5,** sandy gravel – alluvial lower facies of river bed; **6,** gravel and sand with clay – alluvial facies of river bed; **7,** silty-sandy clay – Neogene sediments.

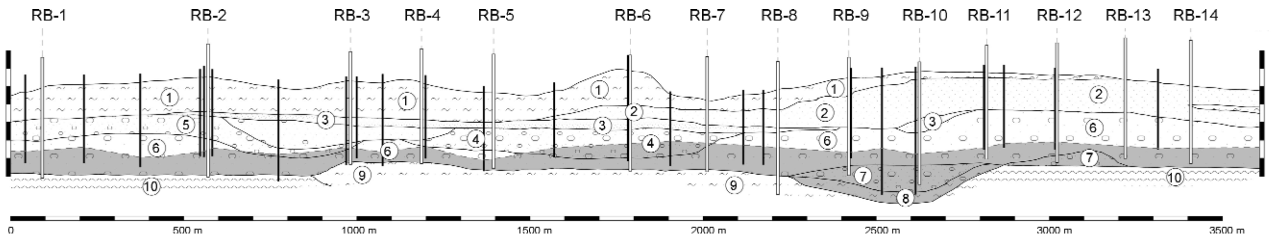

Fig. 3. Hydrogeological profile along the "Morava-Brzan" groundwater source. Legend: **1,** clay – overlaying alluvial sediments; **2,** sand – alluvial sediments; **3,** sandy gravel – alluvial flood facies; **4,** gravel – alluvial facies of river bed; **5,** sandy gravel – alluvial flood facies; **6,** gravel – alluvial facies of river bed; **7,** sandy gravel – alluvial lower facies of river bed; **8,** gravel and sand with clay – alluvial facies of river bed; **9,** silty-sandy clay – Neogene sediments; **10,** Palaeozoic shale.

Methods

Groundwater regime of alluvial aquifer and surface water regime of the Velika Morava River were monitored in the period Nov. 2011 – Jan. 2013. Changes of groundwater and surface water levels were observed

colour, pH, specific conductivity, hardness, dissolved cations (Na^+ , K^+ , Mg^{2+} , Ca^{2+}, Fe^{2+}or Fe^{3+}, Mn^{2+}, Al^{3+}, etc.) and anions (Cl^-, F^-, I^-, Br^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, NO_3^-, NO_2^-), metals that act like cations mostly (Cu, Zn, Pb, Co, Ni, Cr, As, Se, Mo, etc.), nonmetals (HS^-, F^-, B, P, silica as SiO_2 etc.), consumption of $KMnO_4$, dissolved gases (oxygen, carbon-dioxide, hydrogen sulphide, ammonia), phenolic compounds, anionic detergents, residual chlorine, mineral oil, polycyclic aromatic hydrocarbons, cyanide, etc. Water samples were also microbiologically analysed to detect and count aromatic hydrocarbons the total coliform and E. coli as well as faecal streptococci, aerobic mesophilic bacteria, Proteus spec., etc.

Groundwater and Velika Morava River water samples were analysed periodically, once per month by representatives of Water Supply System of Kragujevac city. Water sampling and analyses were also conducted by representatives of Institute of Public Health in Kragujevac city periodically, once in two months during the research period. Parameter list for these analyses was reduced and only main parameters of water quality and health indicators were monitored. Institute of Chemistry, Technology and Metallurgy of the University of Belgrade conducted analysis of water samples from "Morava-Brzan" groundwater source, for each season (spring, summer, autumn, winter), in order to get a full picture of groundwater quality during seasonal changes. Obtained results were used to analyse quantitative and qualitative regime of alluvial aquifer as well as the Velika Morava River.

Results and conclusions

Hydraulic connection of alluvial aquifer and the Velika Morava River has been proven by observation of water stage of the river and groundwater level during the period of research (Fig. 4). The regime of quantity of groundwater showed large fluctuations and it is especially influenced by seasonal changes as well as periodical storm rain events. The synthesis of the collected data from the water supply system: the capacity of wells, groundwater levels (GWL), correlations of GWL and the precipitation and the impact of the Velika Morava River on the GWL helps us to conclude that quantity of water in aquifer the most depends of water stage of the river. However, we cannot exclude influence of precipitation during low water stage (especially storm events) and influence of quantity of groundwater that infiltrates from surrounding aquifers.

A comparative analysis of total monthly precipitation and fluctuations of groundwater levels in wells at the "Morava-Brzan" could not find any direct functional dependency between rainfall and groundwater levels. The amount and timing of rainfall have no direct effect on the capacity of the water supply system. As a result, the amount of tapped water is about 100 l/s even during the summer and autumn months, when smallest amounts of precipitation occur. On the other hand, diagram at figure 5 shows strong correlation between the river stage and observed groundwater level. Therefore we can conclude that the groundwater level depends, on three factors: the pumping capacity of the source and the flow of the Velika Morava River and to some point on amount of rainfall (PETROVIĆ & ŽIVANOVIĆ 2014).

In accordance with the foregoing, it can be noticed that the regime of groundwater depend on direct contact with the Velika Morava River all the time, and coming under greater influence of rainfall in part of the periods when the river does not have enough water to recharge aquifer. Then the GWL increases only in short intervals, after storm rainfall events (daily rainfall of 20 mm or more). Capacity of wells, and thus the whole water supply system, directly and significantly affects the condition of GWL only in the period when the water level in the Velika Morava River stagnates and precipitation is decreased or absent, as in the case of the end of July 2012 to mid-October 2012 (Fig. 4).

Based on data obtained from the water quality analysis, we can conclude that the groundwater in the alluvium of the Velika Morava River tapped by the water supply system "Morava-Brzan" has a good and constant quality. Unlike groundwater quality, quality of water in the Velika Morava River varies greatly during the year (PETROVIĆ & ŽIVANOVIĆ 2014). The water in the Velika Morava River is characterized by fluctuations in the physical and chemical composition, under the influence of the condition of river and rainfall. Noticeable changes beside the obvious parameters (turbidity and water temperature) suffered electrical conductivity, consumption of $KMnO_4$, total iron concentration, concentration of chloride and nitrate ions.

Values of electrical conductivity of groundwater are inversely dependent of the flow of the Velika Morava River and amount of precipitation. Values of electrical conductivity of river water are two times lower than those recorded in the groundwater (Fig. 5). Based on the changes of this parameter, with a certain probability, we can conclude that the water exchange is quick and happens in few days or weeks, depending on the season. During the periods of intense infiltration the conductivity decreases which is especially noticeable in late spring, when a wave of high water level of the river passes due to melting of snow and heavy spring rains in the upper reaches and tributaries component of the Velika Morava River. Values of electrical conductivity of the groundwater at that time decrease more than 200 μS/cm in comparison to the "low water" periods when we can see a twofold increase in the quantity of dissolved substances in groundwater, due to its long stay in contact with the particles of aquifer.

Consumption of $KMnO_4$ can only be considered as a conditional criterion of amount of organic matter in the water. The content of organic matter in the groundwater reached equilibrium and there is no significant impact of the external factors. On the other side same parameter in the river water varies depending on the flow with lowest values during the winter

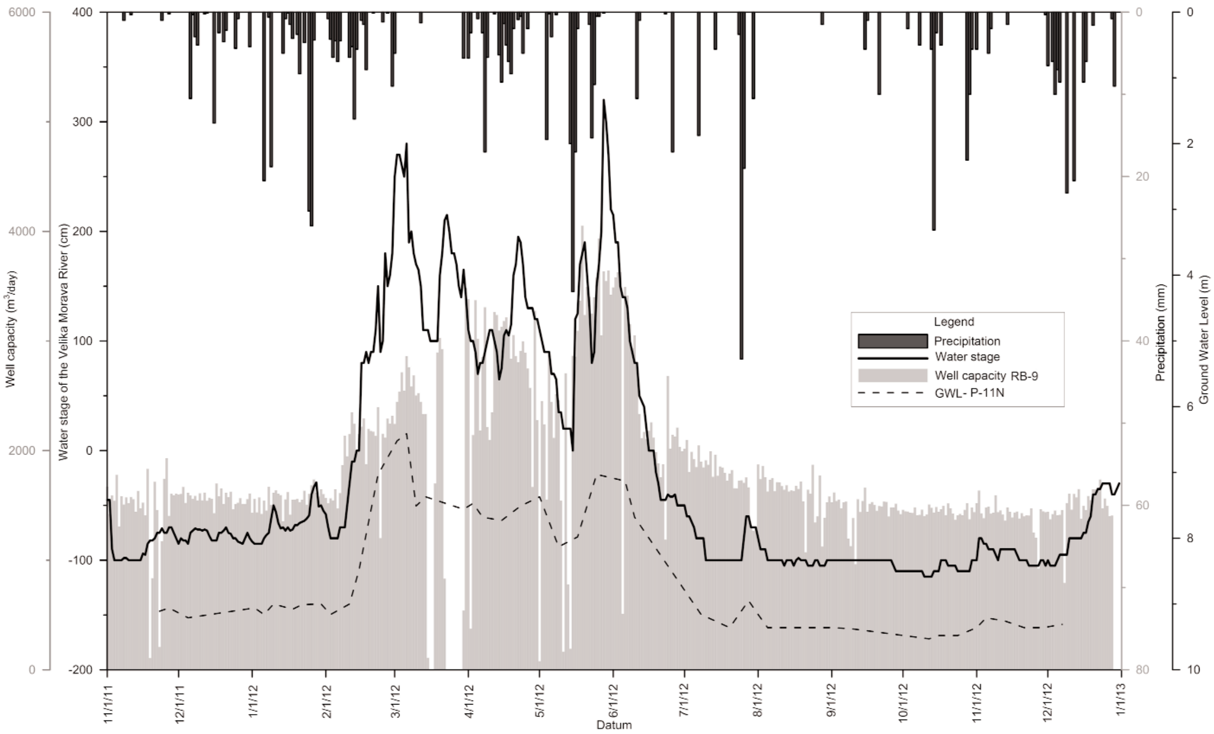

Fig. 4. Diagram of precipitation, water stage of the river, capacity of RB-9 well and GWL in piezometer P-11N.

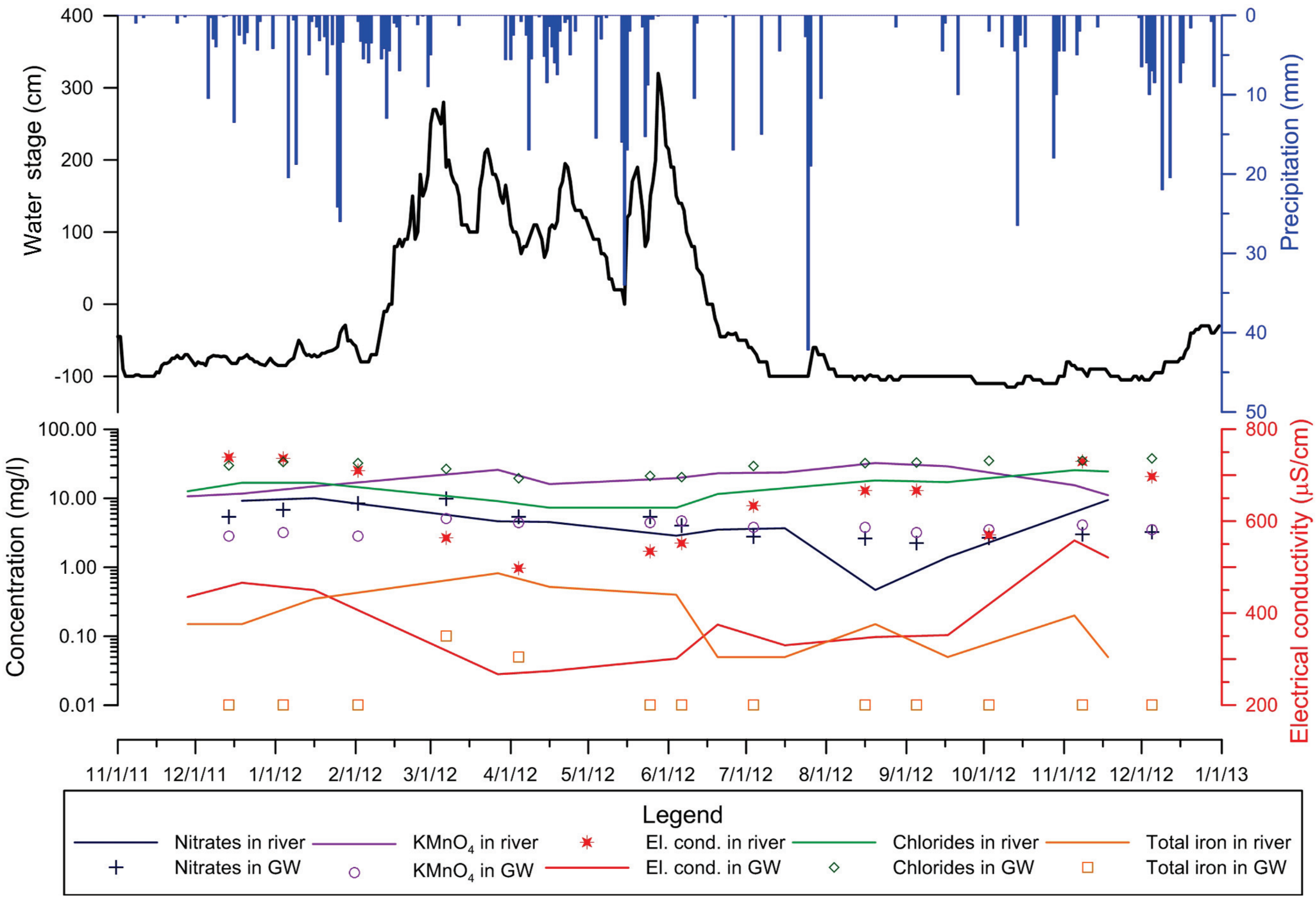

Fig. 5. Diagram of chemical parameters of groundwater and water from the Velika Morava River, compared to precipitation and water stage.

when river water level reaches the minimum value (Fig. 5).

One can notice two "peaks" of recorded concentrations of total iron, the first at a time of high water and the second at time of low water levels of the Velika Morava River (Fig. 5). However, none of them exceeding the maximum permissible concentration for groundwater (GAZETTE SRY 1998). Here we point out the existence of a great "mechanism of purification" of water that was formed within the aquifer (STAUDER *et al.* 2012). The increase in the concentration of iron in groundwater during high water is due to increased infiltration of river water into the aquifer, which in this period contains higher concentrations of ferrous ions from the upper reaches of the constituents. On the other hand, the concentration of Fe^{2+} ions in a period of low water has increased due to the general decrease in the amount of water in the aquifer and the river, and slower movement through the intergranular aquifer and longer time of contact with the particles containing ferrous ions.

The concentration of chloride ions in the analysed samples of groundwater is inversely proportional to the water level and the amount of precipitation, and in surface water it is half the concentration of ions in groundwater, observed during the same period (Fig. 5). This difference is due to the dissolution of mineral matter from the environment (sandy-gravel sediments, with a significant presence of dust and clay fractions), in which groundwater reside.

Concentration of nitrate ions in groundwater shows a certain dependence on the amount of infiltrated water (Fig. 5). There is certain causality, but also the period of delay in response to increase of the amount of rainfall and water levels in the river, in the period February–March, when the concentration of NO_3^- ions decreases due to the increase in the amount of infiltrating water. However, when it comes to the stabilization of flow of the Velika Morava River and the amount of rainfall, decreasing trend of nitrate concentration is maintained until September, when again there is an increase in the concentration of nitrate. The nitrate concentration in groundwater and surface water, which are analysed, do not exceed permissible levels. This data also imply the existence of good protection of overlaying layer of aquifer and excellent autopurification mechanisms of river, because despite the expressed agricultural activities in the Velika Morava River area and in the upstream areas of the catchment of the river and its tributaries, there is no significant burden of water by nitrates.

Stability of regime of groundwater quality in the observed aquifer formed in the alluvium of the Velika Morava River indicates excellent rejuvenating properties of the environment and it is of great importance for use of this resource for municipal water supply. We must emphasize the fact that despite the huge hydraulic impact that river has, the environment was able to create specific conditions for the creation and maintaining of a groundwater quality, which remains beyond the reach of lower-quality of surface water.

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References

CHANG, L.C., HO, C.C., YEH, M.S. & YANG, C.C. 2011. An integrating approach for conjunctive-use planning of surface and subsurface water system. *Water Resources Management*, 25 (1): 59–78. DOI: 10.1007/s11269-010-9687-8

DIMKIC, M., STEVANOVIC, Z. & DJURIC, D. 2007. Utilization, protection and status of groundwater in Serbia, Keynote lect. Proceedings of Regional IWA Conference on "Groundwater Management in the Danube River Basin and Other Large River Basins", Belgrade. 83–102

DOUSSAN, C., POITEVIN, G., LEDOUX, E. & DETAY, M. 1997. River bank filtration: modelling of the changes in water chemistry with emphasis on nitrogen species. *Journal of Contaminant Hydrology*, 25: 129–156. DOI: 10.1016/S0169-7722(96)00024-1

GRÜNHEID, S., AMY, G. & JEKEL, M. 2005. Removal of bulk dissolved organic carbon (DOC) and trace organic compounds by bank filtration and artificial recharge. *Water Research*, 39: 3219–3228. DOI: 10.1016/j.watres.2005.05.030

OFFICIAL GAZZET OF THE SRJ 1998. The rule book on hygienic correctness of the water for drinking purposes. 42/98 and 44/99 (In Serbian).

HISCOCK, K.M. & GRISCHEK, T. 2002. Attenuation of groundwater pollution by bank filtration. *Journal of Hydrology*, 266: 139–144. DOI: 10.1016/S0022-1694(02)00158-0

JHA, K.M., KAMII, Y. & CHIKAMORI, K. 2009. Cost-effective approaches for sustainable groundwater management in alluvial aquifer systems. *Water Resources Management*, 23 (2): 219–233. DOI: 10.1007/s11269-008-9272-6

Petrović, B. & Živanović, V. 2014. Analysis of changes of quality of groundwater during recharge process of alluvial source "Morava-Brzan". *Proceedings of the XVI Serbian Geological Congress*: 400–406. Serbian Geological Society, Donji Milanovac (In Serbian and English)

RAY, C., MELIN, G. & LINSKY, R.B. (eds) 2002. Riverbank filtration: improving source water quality. Kluwer Academic Publishers, 394 pp., Dordrecht.

Stauder, S., Stevanovic, Z., Richter, C., Milanovic, S., Tucovic, A. & Petrovic, B. 2012. Evaluating Bank Filtration as an Alternative to the Current Water Supply from Deeper Aquifer: A Case Study from the Pannonian Basin, Serbia. *Water Resources Management*, 26 (2): 581–594. DOI: 10.1007/s11269-011-9932-9

Stojadinović, D. 1997. *Hydrogeological characteristics of the Velika Morava Basin,* Zadužbina Andrejević, Belgrade, p. 91, (In Serbian, English summary)

Vodoinženjering. 1995. Technical solution of water supply system „Brzan" for Kragujevac city, 120 p. Belgrade (In Serbian)

Резиме

Утицај филтрације кроз седименте речне обале и корита на квалитет алувијалних подземних вода: пример реке Велике Мораве у централној Србији

Алувијалне издани се у свету најчешће користе за водоснабдевање становништва, али су истовремено и јако изложене потенцијалном загађењу. Самопречишћавање подземних вода у изданској зони има велики значај у очувању стабилности квалитета подземних вода које се добијају из збијене издани формиране у алувијалним седиментима. Спроведена хидрогеолошка истраживања на изворишту „Морава-Брзан" у централној Србији (сл. 1) су показала способност интергрануларне издани да речну воду не само пречисти него јој и побољша квалитет. Извориште је лоцирано на левој обали реке Велике Мораве, неколико километара узводно од уливања реке Лепенице. Настало је 70-тих година XX века, када је израђено 14 бунара са хоризонталним дреновима. Континентална клима подручја заједно са геолошким условима унутар слива Велике Мораве изазива велике промене водостаја током године. Са хидрогеолошког аспекта, речну долину у области истраживања можемо поделити у 3 велика слоја (сл. 2 и 3): 1. глиновити седименти „кровине" дебљине 4–6 метара; 2. шљунковити и песковити седименти збијене издани дебљине 5–10 метара; и 3. „подина" издани, на дубини 13–16 метара, састављена од слабо пропусних и непропусних неогених седимената у средишњем делу изворишта и непропусних палеозојских шкриљаца у узводном и низводном делу изворишта. Истраживања на подручју изворишта спроведена су од новембра 2011. године до јануара 2013. године. Извршена су осматрања нивоа подземних вода (НПВ), водостаја реке и количина падавина. Прихрањивање овог изворишта се врши на рачун инфилтрације речне воде из Велике Мораве, делимично из суседних издани и инфилтрацијом падавина (пре свега током лета, када је водостај реке низак) (сл. 4). Можемо да закључимо да је НПВ збијене издани формиране у алувијалним седиментима Велике Мораве под значајним утицајем водостаја реке, али да у периодима ниског водостаја долази под утицај инфилтрираних падавина и утицај НПВ суседних издани. У наведеном периоду вршен је мониторинг квалитета изданских вода и речне воде, лабораторије ЈКП „Водовод и канализација" и Института за јавног здравља, оба из Крагујевца, су пратили параметре санитарне исправности на месечном тј. двомесечном нивоу, док су стручњаци Института за хемију, технологију и металургију (ИХТМ) израдили комплетне анализе у оквиру сваког годишњег доба. Површинске воде су изузетно промењивог квалитета (Сл. 5), посебно у погледу мутноће и електричне проводљивости, али и утрошка $KMnO_4$, садржаја јона гвожђа (Fe^{2+}), хлорида (Cl^-) и нитрата (NO_3^-), а квалитет подземних вода акумулираних у интергрануларној издани је са минималним осцилацијама концентрација поменутих компоненти. Уколико посматрамо вредности електричне проводљивости у реци и у издани можемо закључити да је водозамена брза и одиграва се у оквиру неколико дана (евентуално недеља), и зависи само од годишњег доба. Што се тиче промена осталих наведених параметара морамо нагласити да су варијације током посматраног периода у речној води лако уочљиве. Промене концентрација издвојених параметара у подземној води постоје али су под контролом средине у којој је издан формирана, стога су варијације мале, и никада не прелазе максимално дозвољене концентрације прописане правилником. Стабилност режима квалитета подземних вода изворишта „Морава-Брзан", упркос томе што се извориште налази под јаким хидрауличким утицајем Велике Мораве одржава се захваљујући изузетној способности издани да „пречисти и побољша" квалитет инфилтриране воде. Самопречишћавајућа својства издани омогућавају да се подземна вода само уз минималан третман (филтрирање и хлорисање) дистрибуира крајњим потрошачима.

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Geoheritage sites with palaeogeographical value: some geotourism perspectives with examples from Mountainous Adygeja (Russia)

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Abstract. Geoheritage sites with palaeogeographical value are excellent venues for geotourism. These sites preserve information about ancient environments, ecosystems, and their dynamics that may be of interest to professionals, students, amateur scientists, and the general public. Palaeogeographical geoheritage sites (geosites) can be used to successfully increase public awareness of past and future climate changes. However, because palaeogeographical information is typically complex and not directly visible, professional interpretation is necessary. Successful interpretive tools include posted signs and education activities that engage visitors in scientific research. Using modern analogues to help visitors visualize past environments and ecosystems may be particularly effective. Professional interpretation helps foster visitor awareness of a geosite's value. We suggest that some geosites can be visited sequentially on a guided excursion and propose a route for observing five geosites that exemplify the geodiversity of Mountainous Adygeja (Western Caucasus, southwestern Russia). Guided geosite excursions would introduce visitors to a broad diversity of palaeoenvironments and deepen their understanding of palaeogeographical phenomena. However, carrying capacity should be evaluated seriously for any geosites that are incorporated into palaeogeographical tourist excursions.

Key words: palaeogeography, geoheritage, geosite, geotourism, Mountainous Adygeja.

Апстракт: Објекти геонаслеђа са палеогеографским вредностима представљају изузетне локалитете за геотуризам. Ови објекти садрже информације о некадашњим срединама, екосистемима као и о њиховој динамици и могу бити веома занимљиви професионалцима, студентима, аматерским истраживачима као и широј јавности. Палеогеографски објекти геонаслеђа могу бити веома корисни приликом подизања свести шире јавности о климатским променама које су се дешавале у прошлости а такође и о онима које ће се дешавати у будућности. Међутим, с обзиром да су информације које се тичу палеогеографије углавном веома сложене и нису лако схватљиве неопходна је њихова стручна интерпретација. Успешна интерпретација подразумева постављање обавештења као и едукативне активности које би посетиоце укључиле у научно истраживање. Од нарочитог је значаја употреба одговарајућих примера из савременог доба како би се посетиоцима помогло да створе што бољу слику

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о некадашњим срединама и екосистемима. Стручно тумачење помаже посетиоцима да што боље разумеју значај геолошких објеката. Предлажемо да поједини геообјекти постепено буду уврштивани у стручне екскурзије и препоручујемо одређене руте за обилазак пет геообјеката који на добар начин илуструју геодиверзитет Адигеја планина (Западни Кавказ, југозападна Русија). Стручне екскурзије би упознале посетиоце са великом разноврсношћу палеосредина и прошириле би њихово разумевање палеогеографских феномена. Међутим, за сваки геообјекат који је уврштен у палеогеографску туристичку екскурзију број посетиоца би требало веома прецизно одредити.

Кључне речи: палеогеографија, геонаслеђе, објекти геонаслеђа, геотуризам, Адигеја планине.

Introduction

Owing to the activity of individual researchers, research institutions, and international organizations such as the European Association for the Conservation of the Geological Heritage (ProGEO), studies of geological heritage (geoheritage) have become an important direction of Earth Science over the past two decades (e.g., WIMBLEDON & SMITH-MEYER 2012; PROSSER 2013). Yet despite numerous achievements and certain standardization of the relevant term definitions, concepts, and methods at both international and national levels (WIMBLEDON & SMITH-MEYER 2012), further progress is necessary. Inconsistencies in classifications and approaches remain (e.g., BRADBURY 2014; GARCIA-ORTIZ *et al*. 2014), and the perspectives of geoheritage for academic and public policies still need discussion.

Palaeogeographical information is preserved in many geological heritage sites (geosites). Palaeogeographical geosites are different from the other types of geosites because of the presence of valuable information about palaeoenvironments, palaeoecosystems, etc. (BRUNO *et al*. 2014; see also below). These sites are also valuable from the point of view of geotourism (DOWLING & NEWSOME 2010; NEWSOME & DOWLING 2010; DOWLING 2011; GRAY 2013; HENRIET *et al*. 2014; BRUNO *et al*. 2014; RUBAN 2015). Geotourists, who may include nature enthusiasts, students, amateur scientists, or professionals on vacation or participating in conference excursions (see also HOSE 1996, 2000; HOSE & WICKENS 2004; DOWLING & NEWSOME 2010), are excited by the possibility of seeing features that reflect the history of the Earth, its ancient life, and past environments. The modern increase in geotourism activities on the international scale (DOWLING & NEWSOME 2010; NEWSOME & DOWLING 2010; DOWLING 2011; HOSE & VASILJEVIĆ 2012; RUBAN 2015) contributes to the importance of palaeogeographical geosites as tourist attractions. Deeper interest in the Earth's dynamics stimulates curiosity in phenomena more complex than solely collecting minerals and fossils.

This paper continues a discussion started in previous papers by BRUNO *et al*. (2014) and HENRIET *et al*. (2014). In this brief review, we address three topics related to palaeogeographical geosites and geotourism:

1) the importance of palaeogeographical geosites for increasing climate change awareness;
2) the challenges of facilitating and managing geotourism;
3) the opportunity of including multiple palaeogeographical geosites in guided excursions.

Our goal is to alert specialists in geology as well as geoconservation to the immense potential of palaeogeographical geosites for geotourism development. However, we do not intend to propose something new to tourism. In contrast, we consider that brochures, guided excursions, and other "standard" attributes of tourism activity can be employed successfully for the purposes of palaeogeography-based geotourism, which itself is a kind of novelty.

Terminology

The terms "geoheritage" and "geosites" were defined by ProGEO. Geoheritage "encompasses the special places and objects that have a key role in our understanding of the history of the Earth - its rocks, minerals and fossils, and landscapes" (WIMBLEDON & SMITH-MEYER 2012, p. 18). A geosite is "a key locality ... or area showing geological features of intrinsic scientific interest, features that allow us to understand the key stages in the evolution of the Earth" (WIMBLEDON & SMITH-MEYER 2012, p. 19). Our definition of geotourism follows HOSE (2000), DOWNLING & NEWSOME (2010), and HOSE & VASILJEVIĆ (2012). Generally, geotourism refers to any kind of tourism activity related to geoheritage.

The value of palaeogeographical features and even the palaeogeographical type of geoheritage are widely recognized (WIMBLEDON *et al*. 2008; REYNARD *et al*. 2007; BRUSCHI & CENDRERO 2009; RUBAN 2010; BRUNO *et al*. 2014). We follow the relevant definitions proposed by BRUNO *et al*. (2014). Particularly, palaeogeographical geosites are understood as "geological heritage sites that represent paleoenvironments in general or highlight particular paleoenvironmental features, which are of special interest for science, education, or tourism/recreation" (BRUNO *et al*. 2014, p. 301). The use of these geosites for the purposes of geotourism is defined provisionally as palaeogeography-related geotourism. Palaeogeographical geosites are diverse, and several subtypes can be distinguished (BRUNO *et al*. 2014).

Palaeogeographical geoheritage and climate change awareness

Palaeogeographical geosites serve several tourism purposes (Fig. 1). Among these purposes, increasing public awareness of climate change is of crucial importance. Anthropogenically-induced global climate change (labelled commonly as "global warming") will be a serious and growing challenge for our species (HOUGHTON, 2009; see also general discussions in DIMENTO & DOUGHMAN 2007; PROTHERO 2011; ZALASIEWICZ & WILLIAMS 2012). Therefore, increasing the awareness of policy-makers and the general public about this challenge is an urgent task (e.g., SHEPPARD 2005; DIMENTO & DOUGHMAN 2007; HOUGHTON 2009; WHITMARSH *et al.* 2011; BICHARD & KAZMIERCZAK 2012; LIBARKIN *et al.* 2012; PIDGEON 2012; RATTER *et al.* 2012; TILLER & SCHOTT 2013; LIESKE *et al.* 2014).

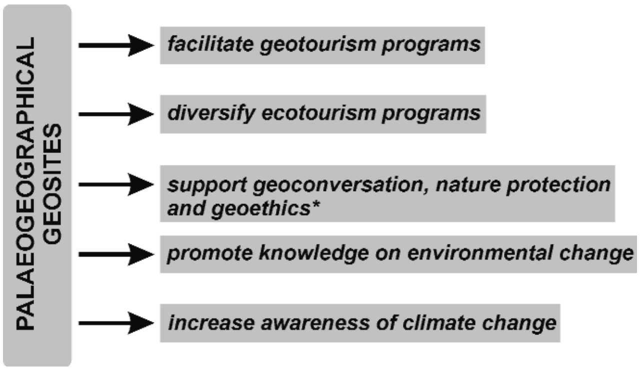

Fig. 1. Tourism utility of palaeogeographical geosites. Perspectives of such geosites go far beyond communication of 'purely' palaeogeographical information. * See PEPPOLONI & DI CAPUA (2012) for discussion of geoethics.

Palaeogeographical geosites can preserve information about ancient climates (BRUNO *et al.* 2014). Some geosites exhibit features that reflect climate extremes reached in the past, providing clues for understanding the factors that trigger unusual climatic regimes, and demonstrating the consequences of icehouse and greenhouse conditions. As shown by ARCHER (2008), HAY (2011), and BOTTJER (2012), extreme climate shifts that are comparable to current climate change and its consequences can be found in the geological history of our planet. Palaeogeographical geosites could, therefore, serve as educational tools, facilitating public awareness and comprehension of past and current climate change, and stimulating mitigation and adaptation efforts. For instance, fluvial deposits, palaeosols, and fossils preserved at the Agate Fossil Beds National Monument (Nebraska, USA) document significant climatic fluctuations and their ecological ramifications from the Oligocene into the Holocene (JOHNSGARD *et al.* 2007).

Similarly, marine terraces that border many Italian coasts were formed by frequent marine transgressions and regressions during Pleistocene glacial and interglacial phases. These terraces (e.g., BIANCA *et al.* 2011), which are currently exposed high above sea level, contain an abundance of molluscs and corals, providing evidence for how climatically induced sea-level changes (balanced with local tectonics) can affect nearshore ecosystems (CAROBENE & DAI PRA 1990). The corestones, or boulders, of the Sila Massif (Calabria, Italy) provide another example of fluctuating climate in the past. These boulders are embedded in roughly 100 m of saprolite and regolith of granitoid and low-grade metamorphic rocks, representing ancient tropical weathering on a massive scale (GUZZETTA 1974; see LE PERA & SORRISO-VALVO 2000 and SCARCIGLIA *et al.* 2005 for the other explanations). In Puglia (Italy), the most part of the coast is characterized by numerous caves result of interaction between the karstic phenomena and sea level fluctuations during glacial and interglacial episodes of Quaternary (CANORA *et al.* 2012). In the same region, red bauxite deposits fill old palaeokarst basins developed in the Bari Limestone (mid-Cenomanian) during the continental meso-Cretacic phase. These deposits represent residual rocks that occur on carbonate rocks formed in tropical to sub tropical climates (BARDOSSY 1982). The bauxites mark local or regional unconformities associated with subaerially exposed carbonates. These deposits are important for provenance studies (BONI *et al.* 2012) and palaeogeographic reconstructions (MONGELLI *et al.* 2014). A similar example can be found at the famous Giant's Causeway World Heritage Site, Ireland. Here, a thick palaeosol between Paleogene basalt lava flows provides evidence for a tropical palaeoclimate in a place that currently experiences temperate conditions (LYLE 1996; SMITH 2005). Such sites can facilitate public understanding of the magnitude of regional changes in climate as well as climate extremes.

Challenges of palaeogeography-related geotourism activities

The necessity of professional interpretation for geoheritage is a serious challenge for geotourism because many visitors of geosites and geoparks are occasional tourists with no background in the Earth Sciences (HOSE 1996, 2000; HOSE & WICKENS 2004). This is particularly true for palaeogeographical geosites, which are inherently complex. "Palaeogeography" could potentially become a key word attracting tourists, but these tourists will need to know what this word means. Understanding the preserved feature may be beyond the abilities of most people without proper guidance. Geoscientists offer interpretation of features that are not easily visualized by ordinary visitors.

In addition, these sites may appear unspectacular, and therefore would be unlikely to generate excitement, with some exceptions. Providing an explanation for the connections between observed rocks and fossils with environments and ecosystems of the past and present to such geotourists is crucial. The above-mentioned Agate Fossil Beds National Monument offers an excellent example of proper tourist guidance. Park visitors are presented with abundant information about the geologic history of the site, the palaeoclimatic and paleoenvironmental information it preserves, and the ecology of its fossil mammals (http://www.nps.gov/agfo/naturescience/). Conversely, a well-established tourist trail offering a 360° panoramic view of the Oshten Mountain, which is an impressive Late Jurassic reef in Mountainous Adygeja (Western Caucasus Russia) with outstanding heritage value (BRUNO *et al*. 2014), lacks any accompanying interpretative information. This trail is used daily by dozens of tourists travelling individually or in groups, generally for holiday outdoor recreation, but also for adventure tourism and ecotourism. However, without a guide or any interpretative signs, few visitors will recognize that the exposed carbonate rocks and their fossil content preserve an ancient coral reef.

There are many interpretative approaches that could be used in geotourism to help the public appreciate palaeogeographical geosites. These include distribution of posters and brochures (these have been used successfully in many countries for decades - e.g., PURI & VERNON (1959); for the general importance of brochures in tourism see MOLINA & ESTEBAN (2006) and QUELHAS BRITO & PRATAS (2015)), installation of interpretative signs, and interpretation by professional excursion guides (see HOSE (2000), HUGHES & BALLANTYNE (2010), CARDOZO MOREIRA (2012), and GORDON (2012) for an evaluation of the efficacy of these approaches). An example of a well-designed and useful brochure is the field guidebook to the “Jurassic Coast”, which is a famous World Heritage Site in southern England. This brochure provides informative explanations of geological features exposed at the site, for instance Triassic cross-bedding and Jurassic tree stumps that were preserved due to algal growth on ancient trees (WESTWOOD 2011; BRUNSDEN 2013). On-line tools may also work well for the purposes of palaeogeographical interpretations* .

In our opinion, interpretative approaches to palaeogeographical geosites are most useful if they provide visitors with modern examples to visualize palaeoenvironments and palaeoecosystems. This requires some simplifications and imagination, but finding approximate analogues is possible, even for ancient environments and ecosystems (e.g., RUSSELL 2009). On rare occasions, such analogues might exist near the interpreted geosites, which is an outstanding opportunity for geotourism. An example is the Merzhanovo section (northern Azov Sea, southwestern Russia), where upper Miocene deposits representing a cliffed coast facies are exposed in a modern steep slope situated on a very similar seashore (RUBAN 2011). Such coincidence of palaeogeographical phenomena with their modern analogue(s) greatly facilitates visitor comprehension. Additionally, souvenir vendors, local restaurants, etc. may offer products explaining the essence of palaeogeographical geosites and promoting deeper knowledge (cf. the idea of “geoproducts” presented by RODRIGUEZ & NETO DE CARVALHO (2009)). For instance, the traditional food of the Adygejans is sold at the tourism destination “Rufabgo” in the Western Caucasus (Russia), which is known for its splendid waterfalls as well as outstanding geology (see below). Boxes with this food accompanied by an explanation could potentially be used to promote the picturesque geological features of the canyon, including those linked to palaeogeography.

Geosites where a person or family can actively view or take part in scientific research can also greatly enhance public appreciation and awareness of these valuable natural historic resources. With increased public interest follows the increased likelihood of preservation of important geosites (although without proper conservation measures, there is also the increased potential for geosite destruction). An excellent example of a geosite where visitors can view scientific research is the Dinosaur National Monument (Colorado and Utah, USA) (www.nps.gov/dino/parkmgmt/statistics.htm). This actively excavated palaeontological site works like a museum in the field. The site contains an enclosure of a large quarry of fossils comprised of hundreds of bones from 10 different species of dinosaurs and has an open viewing area for visitors to see how an active, scientific dig site works. Archaeological materials such as petroglyphs and pictographs from local Native Americans are also available for viewing.

At some geosites, visitors are given the opportunity to receive rudimentary training in fieldwork methods and then participate in the scientific process. For example, the Two Medicine Dinosaur Center (Montana, USA) is dedicated to hands-on education of the public through experience in active scientific research (www.timescale.org/about.html). Visitors are trained in some of the basics of geological and local history as well as palaeontological field prospecting, and then participate in documenting, uncovering and relocating dinosaur bones to the museum. All fossils and documentation are retained by the museum for scientific study

* http://travel.nationalgeographic.com/travel/sustainable/about_geotourism html,
http://thecentralcascades.com/explore/?map,
http://www.naturbornholm.dk/top/forside.aspx)

and perhaps later museum display. At places like this, visitors gain a clearer understanding of various aspects of the procedures used to properly find and excavate fossils as well as how excavated material can be utilized to enhance scientific knowledge. They also gain an appreciation for the importance of this type of work, including the value of documentation and site preservation.

Similar to other geosites (GRAY 2013), palaeogeographical geosites are prone to anthropogenic influences. An increase in their exploitation for geotourism purposes can have negative consequences, including irreparable damage. This concern can be clearly seen in Iceland, where geotourism is greatly on the rise in response to the decline of traditional economies, such as fishing, and the country's 2008 banking crisis (BRAUN 1999; JÓHANNESSON & HUIJBENS 2010). Iceland's sits directly on the Mid-Atlantic rift and resides on two tectonic plates and a hot spot. This unique geographic setting offers numerous nationwide opportunities to see active volcanoes, geothermal phenomena (i.e. geysers and "mudpots"), and glaciers (DÓRASÆÞÓSDÓTTIR 2010). These geological phenomena make Iceland an important geotourism destination (it should be noted that large quantities of visitors to a few popular attractions can endanger the natural environment and ecosystems surrounding sites there (JÓHANNESSON & HUIJBENS 2010)).

Attempts to minimize anthropogenic influences may be challenging. The community of the largest Westman Island, Vestmannaeyjar, is currently constructing a state-sanctioned museum at the remains of several partially-excavated homes that were buried during the last large volcanic eruption in 1973. This is a useful and informative way to observe how the environment is perturbed by a natural hazard as well as exploit a devastating natural phenomenon.

Despite the above-mentioned problems, it should be noted that promoting awareness of palaeogeographical heritage in schools and other educational centres can increase the awareness of regional residents and visitors to the heritage value of these sites and the necessity of their protection, including safety and conservation concerns (e.g., PROSSER *et al*. 2006). Among other benefits, this increased awareness may help reduce the need for excessive signage or protective barriers.

Consideration of the consequences of geotourism activities is very important at any geosite; proper policy and careful management are always required. Such concerns, however, are typical for all kinds of nature-based tourism (e.g., KRÜGER 2005; STOLTON *et al*. 2010). Unfortunately, the legal basis for adequate management and conservation of palaeogeographical geosites is ambiguous. As shown by some examples (e.g., CAIRNCROSS 2011; TIESS & RUBAN 2013), even those policies that recognize geoheritage as a special legal category, frequently use very general terms, or restrict the heritage to include only minerals and fossils. Proper conservation of palaeogeographical heritage will require a more comprehensive approach, and, at the very least, recognition of the fact that geological phenomena exposed today represent important, irreplaceable fragments of past environments. Rapidly evolving geoconservation legislation in European countries (WIMBLEDON & SMITH-MEYER 2012) leaves a hope that the problem will be resolved successfully. Additionally, development of an on-line dictionary and thesaurus for proper and broadly-accepted definitions of all terminology related to palaeogeography, geoconservation, and geotourism will help improve existing policies. This would be a single website maintained by an international organization that would be accessible to both researchers and the public from around the world (see example in RAPISARDI *et al*. 2013). It should be noted that not only specialists in geoconservation and geotourism should be involved, but also stratigraphers and palaeontologists. We envision that this on-line resource would serve as a "participatory open space" that is constantly updated following the growing requests for revised terminology in this topic, combined with linked data. Of course, edits to this resource would require some moderation (e.g., to prevent the development of superficial or incorrect definitions). This is an effort that will probably require collaboration between multiple research institutions, but would likely have a large payoff. ProGEO has made a lot of relevant developments (e.g., WIMBLEDON & SMITH-MEYER 2012). Organizations like this may help to establish research networks and resolve international debates about terminology.

Potential for guided palaeogeographical excursions

Because palaeogeographical geosites reflect various palaeoenvironments and palaeoecosystems (BRUNO *et al*. 2014), a series of different geosites located within the same territory could be combined to illustrate a more complete geological history or diversity of ancient environments. For example, in the same general area, there may be one outcrop that exhibits Paleocene continental rocks and fossils, a second that shows Eocene shallow-marine rocks and fossils, and a third that exposes Oligocene deep-marine rocks and fossils. If these outcrops are located close to one another, they could be used to demonstrate the spectrum of regional palaeoenvironments associated with bathymetrical changes through the Paleogene. In other words, we propose that local or even regional palaeogeographical geosites can be linked to form geotourism excursion routes. Due to the common necessity of professional geosite interpretation, such excursions would be most valuable if guided.

We use the excellent example of Mountainous Adygeja (Western Caucasus, Russia) to consider the opportunities and challenges of organizing such excursions. This geodiversity hotspot, recognized by RUBAN (2010), would be ideal for palaeogeography-related guided excursions. The study area includes several important geoheritage sites with palaeogeographical value, and it is a nationally important destination for nature-based tourism and recreation.

We have selected five geosites for a proposed palaeogeographical excursion route (Fig. 2). Specific information about these sites has been previously published (RUBAN 2010; PLYUSNINA *et al*. 2015) and is not repeated here. The main selection criterion is their significant and complementary palaeogeographical value. Following this route, a geotourist would be exposed to a large spectrum of palaeoenvironments and their fossil assemblages preserved in sedimentary rocks (Table 1). The one-day excursion would start at the Khamyshki Section representing continental strata (geosite 1), then lead to the Little Khadzhokh Valley with lagoonal sandstones and clays (geosite 2). The excursion would next stop at two geosites representing shelf deposits (the Lago-Naki Highlands and the Rufabgo Canyon; geosites 3 and 4, respectively) and finish at the Partisan Glade Section, where deep-marine organic-rich shales outcrop (geosite 5). Because of the loop-like configuration of its route (Fig. 2), this excursion could be split into two parts (Part 1: geosites 1 and 2; Part 2: geosites 3, 4, and 5) or shortened (i.e., starting with geosite 2, where some evidence of a continental palaeoenvironment can be demonstrated). This excursion would contribute significantly to the local development of geotourism because it provides an exceptional opportunity to present information about the diversity of palaeoenvironments that existed in Mountainous Adygeja. Mountainous Adygeja is a significant Russian tourist destination that is visited by numerous "occasional" geotourists. Moreover, several large universities use this territory for field educational programs in geology, geography, and tourism. Thus, one should expect a large number of visitors to potentially be interested in learning about its geological past.

Undoubtedly, the possible palaeogeographical excursion mentioned above should be guided.

Table 1. Geosites to be included into the possible guided palaeogeographical excursion in Mountainous Adygeja (Western Caucasus).

Geosite ID (see Fig. 2 for location)	Geosite affinity* and type	Geological formations	Age	Interpreted palaeoenvironment	Carrying capacity**	Safety and accessibility issues***
1	Khamyshki Section (~5 km-long series of lengthy outcrops along the road)	red-coloured silicilastic Molasse	Early?–Middle Permian	mountainous land	7–10	hectic traffic on road, unstable slope
2	Little Khadzhokh Valley (a few smal outcrops in the steep slope of the river valley)	sandstones and clays of variegated colour	Late Jurassic	desiccated lagoon	5–7	wet and slippery soil, possible stream flooding, limited space for visitors, ongoing construction
3	Lago-Naki Highlands (~5-km series of small outcrops in the roadcut)	carbonates	Late Jurassic	carbonate shelf	7–10	hectic traffic on road, unstable slope
4	Rufabgo Canyon (~1.5 km-long series of small and middle-sized outcrops in the slopes of the canyon)	folded carbonates with siliciclastic interbeds (quasi-flysch)	?Early–Middle Triassic	outer carbonate shelf to upper part of continental slope	7–10	insufficient space for visitors, crowds of tourists visiting the Rufabgo Waterfalls
5	Partisan Glade Section (~10 km-long series of lengthy outcrops in the roadcut)	Dark-coloured shales with siderite concretions intercalated with medium-sized siliciclastics	Early–Middle Jurassic	deep-marine oxygen-depleted setting of ontinental slope	10–15	unstable slope, poor quality of some parts of the road

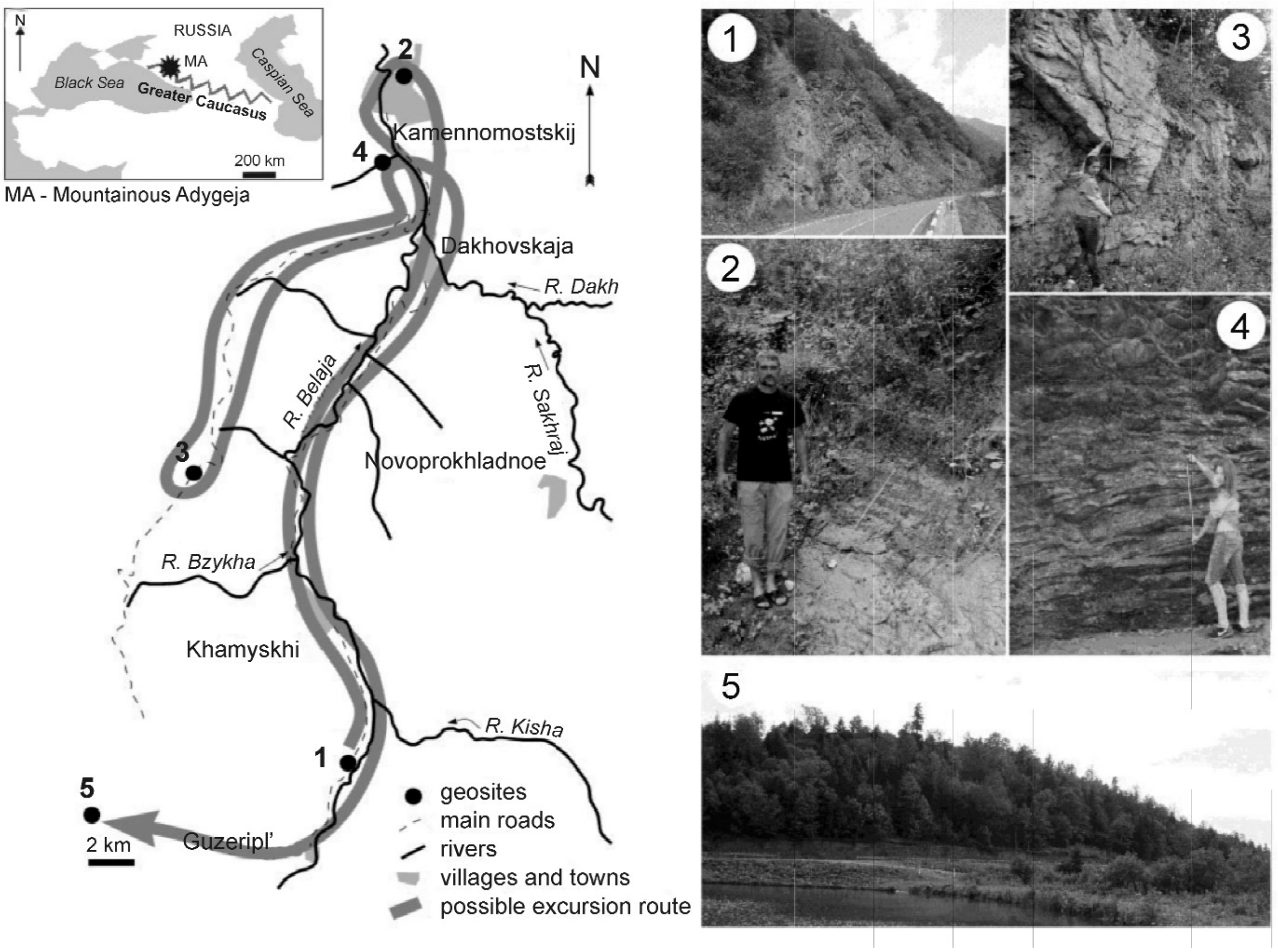

Fig. 2. Outline of a possible palaeogeographical excursion in the Mountainous Adygeja (Western Caucasus). Numbers for photos correspond to geosite numbers on the map. See Table 1 for geosite names and more details.

Professional geologists may understand the geological setting without guides. However, students and various non-professional visitors would need some explanation of what the observed deposits and fossils mean. For instance, understanding the nature of Triassic quasi-flysch strata (e.g., GAETANI *et al.* 2005) or Jurassic lagoonal and carbonate platform deposits (e.g., RUBAN 2006) might be difficult even for geologists. This proposed excursion might be especially suitable for a conference field experience or a student field trip. Professional guidance could be provided by the staff of a university camp (specially created for student field practice), which is located in the midst of the considered territory, or by the staff of the Caucasus State Natural Biosphere Reserve that is situated in southern Mountainous Adygeja. Interpretative signs installed near the geosites may also help, although their efficacy would be limited.

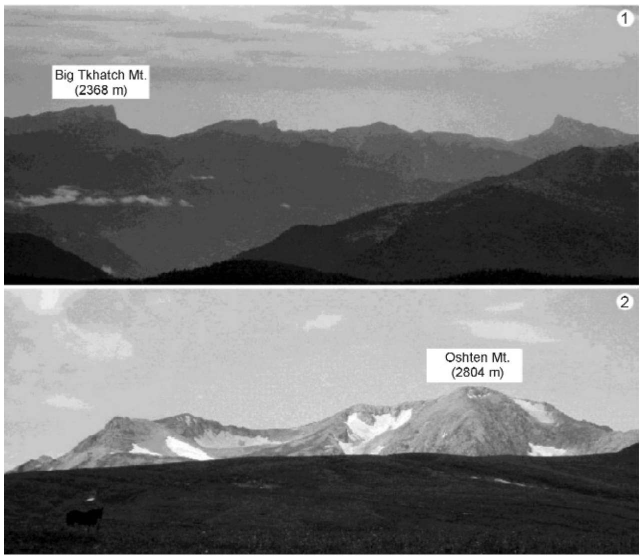

Fig. 3. Big Tkhatch Mountain (1) and Oshten Mountain (2), which are Late Triassic and Late Jurassic reefs, respectively, are visible from the same place on the top of the Stonesea Range of the Lago-Naki Highlands.

The other possibility for palaeogeography-related geotourism in Mountainous Adygeja exists in the Lago-Naki Highlands. There, on the top of the Stonesea Range, one can observe a 360°-panoramic view of the mountains of the Western Caucasus. Two tall mountains are visible: the Big Tkhatch Mountain and the Oshten Mountain (Fig. 3). Both are ancient reefs of Late Triassic and Late Jurassic age, respectively. Thus, a geotourist can view the carbonate build-ups of different palaeoseas in one place by just turning the head. This site has great potential as a geotourism locality. However, the importance of this panoramic view for understanding the latter cannot be understood without professional guidance.

Organization of guided palaeogeographical excursions faces an additional challenge, which is not limited to Mountainous Adygeja. The carrying capacity of geosites, which is used for the purposes of crowd management and stipulates the maximum number of visitors that can visit a site at once (JIN & RUBAN 2011), is very limited. Efficient communication of palaeogeographical information requires small, compact groups of tourists. The carrying capacity for groups at selected geosites should always be carefully considered when planning palaeogeography-related geotourism excursions (Fig. 4). The geometry of the geosites, as well as safety and accessibility issues may leave only a few places for groups to gather. In the case of Mountainous Adygeja, the maximum size of a group at any given locality should not exceed 10 persons in most cases (Table 1), even if some of the geosites (e.g., the Khamyshki Section) are very large and can host dozens if not hundreds of individual visitors. Of course, the accessibility and tourist perception of the above-mentioned (and all other) palaeogeographical geosites can be improved with "standard" geoconservation procedures like vegetation removal (full or partial), renewal of road sections, etc. (see PROSSER *et al*. 2006). Various factors that affect the "natural beauty" of these sites should be also taken into consideration (KIRILLOVA *et al*. 2014).

Fig. 4. Differences in carrying capacity of the Little Khadzhokh Valley and the Rufabgo Canyon (see Fig. 2 and Table 1 for location and general characteristics of these geosites): 1 (Little Khadzhokh Valley) – a student (first author) at the toe of the slope and near the stream to indicate discontinuity in the Upper Jurassic siliciclastics that probably mark the palaeorelief surface (note that the space is very limited); 2 (Rufabgo Canyon) – a geologist (second author) that has enough space to comfortably examine folds in the Triassic carbonates.

Conclusions

Palaeogeographical geoheritage sites can facilitate understanding of the Earth's ancient environments and ecosystems, and they can also enhance awareness of past and future climate change. However, effective communication of palaeogeographical information to tourists requires professional explanation and use of interpretative tools. Palaeogeographical geosites can be visited sequentially on guided excursions that enable deeper appreciation of the geological past. An important topic for further research is discussion of the tourism potential of palaeogeographical geosites based on quantitative assessment of tourist preferences.

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References

ARCHER, D. 2008. *The Long Thaw: How Humans are Changing the Next 100,000 years of Earth's Climate*. Princeton University Press, Princeton, 180 pp.

BARDOSSY, G. 1982. *Karst bauxites, bauxite deposits on carbonate rocks*. Elsevier, Amsterdam, 441 pp.

BIANCA, M., CATALANO, S., DE GUIDI, G., GUELI, A.M., RISTUCCIA, G.M., STELLA, G., TORTORICI, G., TORTORICI, L. & TROJA, S.O. 2011. Luminescence chronology of Pleistocene marine terraces of Capo Vaticano peninsula (Calabria, Southern Italy). *Quaternary International*, 232: 114–121.

BICHARD, E. & KAZMIERCZAK, A. 2012. Are homeowners willing to adapt to and to mitigate the effects of climate change? *Climate Change*, 112: 633–654.

BONI, M., REDDY, S.M., MONDILLO, N., BALASSONE, G. & TAYLOR, R. 2012. A distant magmatic source for Cretaceous karst bauxites of southern Apennines (Italy) revealed through SHRIMP zircon age dating. *Terra Nova*, 24: 326–332.

BOTTJER, D.J. 2012. A climate carol: ancient greenhouse mass extinctions and implications for a future greenhouse world. *Geological Society of America Abstracts with Programs*, 44: 165.

BRADBURY, J. 2014. A keyed classification of natural geodiversity for land management and nature conservation purposes. *Proceedings of the Geologists Association*, 125: 329–349.

BRAUN, T. 1999. North Atlantic fisheries and tourism's response: the cases of Iceland and Newfoundland. *Current Issues of Tourism*, 2: 47–67.

BRUNO, D.E., CROWLEY, B.E., GUTAK, JA.M., MORONI, A., NAZARENKO, O.V., OHEIM, K.B., RUBAN, D.A., TIESS, G. & ZORINA, S.O. 2014. Paleogeography as geological heritage: Developing geosite classification. *Earth-Science Reviews*, 138: 300–312.

BRUSCHI, V.M. & CENDRERO, A. 2009. Direct and parametric methods for the assessment of geosites and geomorphosites. *In*: REYNARD, E., CORATZA, P. & REGOLINI-BISSIG, G. (Eds). *Geomorphosites*, 73–88. F. Pfeil, München.

BRUNSDEN, D. (Ed), 2013. *The Official Guide to the Jurassic Coast. Dorset and East Devon's World Heritage Coast. A Walk Through Time*. Coastal Publishing, Wareham, 64 pp.

CAIRNCROSS, B. 2011. The National Heritage Resource Act (1999): Can legislation protect South Africa's rare geoheritage resources? *Resources Policy*, 36: 204–213.

CANORA, F., FIDELIBUS, D. & SPILOTRO G. 2012. Coastal and inland karst morphologies driven by sea level stands: a GIS based method for their evaluation. *Earth Surface Processes and Landforms*, 37: 1376–1386.

CARDOZO MOREIRA, J. 2012. Interpretative Panels About the Geological Heritage-A Case Study at the Iguassu Falls National Park (Brazil). *Geoheritage*, 4: 127–137.

CAROBENE L. & DAI PRA G. 1990. Genesis, chronology and tectonics of the quaternary marine terraces of the Tyrrhenian coast of northern Calabria (Italy). *Il Quaternario*, 3: 75–94.

DIMENTO, J.F.C. & DOUGHMAN, P. (Eds) 2007. *Climate Change. What It Means for Us, Our Children, and Our Grandchildren*. Massachusetts Institute of Technology Press, Cambridge, 217 pp.

DÓRASÆÞÓSDÓTTIR, A. 2010. Planning nature tourism in Iceland based on tourist attitudes. *Tourism Geographies*, 12: 25–52.

DOWLING, R. 2011. Geotourism's Global Growth. *Geoheritage*, 3: 1–13.

DOWLING, R. & NEWSOME, D. 2010. Geoutourism: a Global Activity. *In*: DOWLING, R. & NEWSOME, D. (Eds). *Global geotourism perspectives*, 1–17. Goodfellow Publishers, Woodeaton.

GAETANI, M., GARZANTI, E., POLINE, R., KIRICKO, YU., KORSAKHOV, S., CIRILLI, S., NICORA, A., RETTORI, R., LARGHI, C. & BUCEFALO PALLIANI, R. 2005. Stratigraphic evidence for Cimmerian events in NW Caucasus (Russia). *Bulletin de la Société géologique de France*, 176: 283–299.

GARCIA-ORTIZ, E., FUERTES-GUTIERREZ, I. & FERNANDEZ-MARTINEZ, E. 2014. Concepts and terminology for the risk of degradation of geological heritage sites: fragility and natural vulnerability, a case study. *Proceedings of the Geologists' Association*, 125: 463–479.

GORDON, J.E. 2012. Rediscovering a Sense of Wonder: Geoheritage, Geotourism and Cultural Landscape Experiences. *Geoheritage*, 4: 65–77.

GRAY, M. 2013. *Geodiversity: Valuing and conserving abiotic nature*. Wiley-Blackwell, Chichester, 495 pp.

GUZZETTA, G. 1974. Ancient tropical weathering in Calabria. *Nature*, 251: 302–303.

HAY, W.W. 2011. Can humans force a return to a 'Cretaceous' climate? *Sedimentary Geology*, 235: 5–26.

HENRIET, J.P., HAMOUMI, N., DA SILVA, A.C., FOUBERT, A., LAURIDSEN, B.W., RUGGEBERG, A. & VAN ROOIJ, D. 2014. Carbonate mounds: From paradox to World Heritage. *Marine Geology*, 352: 89–110.

HOSE, T.A. 1996. Geotourism, or can tourists become casual rock hounds? *In*: BENNETT, M.R., DOYLE, P., LARWOOD, J. & PROSSER, C.P. (Eds). *Geology on your doorstep: the role of urban geology in earth heritage conservation*, 207–228. Geological Society, London.

HOSE, T.A. 2000. European 'geotourism' - geological interpretation and conservation promotion for tourists. *In*: BARETTINO, D., WIMBLEDON, W.A.P. & GALLEGO, E. (Eds). *Geological heritage: its conservation and management*, 127–146. ITGE, Madrid.

HOSE, T.A. & WICKENS, E. 2004. Typologies, tourism locations and images: meeting the real needs of real tourists. *In*: WEBER, S. & TOMLJENOVIĆ, R. (Eds). *Reinventing a tourism destination: facing the challenge*, 103–114. Institute for Tourism, Zagreb.

HOSE, T.A. & VASILJEVIĆ, D.A. 2012. Definig the nature and purpose of modern geotourism with particular reference to the United Kingdom and south-east Europe. *Geoheritage*, 4: 25–43.

HOUGHTON, J. 2009. *Global Warming. The Complete Briefing*. Cambridge University Press, Cambridge, 438 pp.

HUGHES, K. & BALLANTYNE, R. 2010. Interpretation rocks! Designing signs for geotourism sites. *In*: NEWSOME, D. & DOWLING, R.K. (Eds). *Geotourism: The Tourism of Geology and Landscape*, 184–199. Goodfellow Publishers, Oxford.

JIN, Q. & RUBAN, D.A. 2011. A conceptual framework of tourism crowding management at geological heritage sites. *Natura Nascosta,* 43: 1–17.

JÓHANNESSON, G. & HUIJBENS, E. 2010. Tourism in times of crisis: exploring the discourse of tourism development in Iceland. *Current Issues in Tourism*, 13: 419–434.

JOHNSGARD, P.A., FARRER, J. & GUDGEL, D. 2007. *The Niobrara: A River Running Through Time*. University of Nebraska Press, Lincoln, 375 pp.

KIRILLOVA, K., FU, X., LEHTO, X. & CAI, L. 2014. What makes a destination beautiful? Dimensions of tourist aesthetic judgment. *Tourism Management*, 42: 282–293.

KRÜGER, O. 2005. The role of ecotourism in conservation: panacea or Pandora's box? *Biodiversity and Conservation*, 14: 579–600.

LE PERA, E. & SORRISO-VALVO, M. 2000. Weathering and morphogenesis in a mediterranean climate, Calabria, Italy. *Geomorphology*, 34: 251–270.

LIBARKIN, J., MCNEAL, K. & TEMPLETON, C. 2012. Climate change communication: barriers and knowing what people know. *Geological Society of America Abstracts with Programs*, 44: 468.

LIESKE, D.J., WADE, T. & RONESS, L.A. 2014. Climate change awareness and strategies for communicating the risk of coastal flooding: A Canadian Maritime case example. *Estuarine, Coastal and Shelf Science*, 140: 83–94.

LYLE, P. 1996. *A Geological Excursion Guide to the Causeway Coast*. HMSO, Belfast, 90 pp.

MOLINA, A. & ESTEBAN, Á. 2006. Tourism Brochures: Usefulness and Image. *Annals of Tourism Research*, 33: 1036–1056.

MONGELLI, G., BONI, M., BUCCIONE, R. & SINISI, R. 2014. Geochemistry of the Apulian karst bauxites (southern Italy): Chemical fractionation and parental affinities. *Ore Geology Reviews*, 63: 9–21.

NEWSOME, D. & DOWLING, R. 2010. Geoutourism: Opportunity and Tourism Significance. *In*: DOWLING, R. & NEWSOME, D. (Eds). *Global geotourism perspectives*, 230–247. Goodfellow Publishers, Woodeaton.

PEPPOLONI, S. & DI CAPUA, G. 2012. Geoethics and geological culture: Awareness, responsibility and challenges. *Annals of Geophysics*, 55: 335–341.

PIDGEON, N. 2012. Public understanding of, and attitudes to, climate change: UK and international perspectives and policy. *Climate Policy*, 12 (suppl. 1): 85–106.

PLYUSNINA, E.E., RUBAN, D.A. & ZAYATS, P.P. 2015. Thematic dimension of geological heritage: an evidence from the Western Caucasus. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, 65: 59–76.

PROSSER, C.D. 2013. Our rich and varied geoconservation portfolio: the foundation for the future. *Proceedings of the Geologists' Association*, 124: 568–580.

PROSSER, C., MURPHY, M. & LARWOOD, J. 2006. *Geological conservation: a guide to good practice*. English Nature, Peterborough, 145 pp.

PROTHERO, D.L. 2009. *Greenhouse Of The Dinosaurs: Evolution, Extinction, And The Future Of Our Planet*. Columbia University Press, New York, 274 pp.

PURI, H.S. & VERNON, R.O. 1959. *Summary of the Geology of Florida and a Guidebook to the Classic Exposures*. Florida Geological Survey, Special Publication, 255 pp.

QUELHAS BRITO, P. & PRATAS, J. 2015. Tourism brochures: Linking message strategies, tactics and brand destination attributes. *Tourism Management*, 48: 123–138.

RAPISARDI, E., DI FRANCO, S. & GIARDINO, M. 2013. The «Natural Hazard WIKISAURUS» Explanation and Understanding of Natural Hazards to Build Disaster Resilience. *European Geosciences Union, General Assembly, Wien, 07 – 12 April 2013*.

RATTER, B.M.W., PHILIPP, K.H.I. & VON STORCH, H. 2012. Between hype and decline: recent trends in public perception of climate change. *Environmental Science and Policy*, 18: 3–8.

REYNARD, E., FONTANA, G., KOZLIK, L. & SCAPOZZA, C. 2007. A method for assessing "scientific" and "additional values" of geomorphosites. *Geographica Helvetica*, 62: 148–158.

RODRIGUEZ, J. & NETO DE CAVALHO, C. 2009. Geoproducts in geopark naturtejo. *In*: Neto de Carvalho, C. & Rodrigues, J. (Eds). *New Challenges with geotourism*. Proceedings of the VIII European Geoparks Conference. Idanha-a-Nova, 4-6 September 2009, Portugal, pp. 82–86.

RUBAN, D.A. 2006. Taxonomic diversity dynamics of the Jurassic bivalves in the Caucasus: regional trends and recognition of global patterns. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 239: 63–74.

RUBAN, D.A. 2010. Quantification of geodiversity and its loss. *Proceedings of the Geologists' Association*, 121: 326–333.

RUBAN, D.A. 2011. New data on deposits of Maeotian cliffed coast of the Tanais Palaeobay of the Eastern Paratethys. *In*: LISITSYN, A.P. (Ed.), *Materialy XIX Mezhdunarodnoj nautchnoj konferentsii (Shkoly) po morskoj geologii*. Vol. 1, 237–241. GEOS, Moskva. (in Russian)

RUBAN, D.A. 2015. Geotourism - A geographical review of the literature. *Tourism Management Perspectives*, 15: 1–15.

RUSSELL, D.A. 2009. *Islands in the Cosmos. The Evolution of Life on Land*. Indiana University Press, Bloomington, Indianapolis, 456 pp.

SCARCIGLIA, F., LE PERA, E. & CRITELLI, S. 2005. Weathering and pedogenesis in the Sila Grande Massif (Calabria, South Italy): From field scale to micromorphology. CATENA, 61: 1–29.

SHEPPARD, S.R.J. 2005. Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science and Policy*, 8: 637–654.

SMITH, B.J. 2005. The World Heritage Value of Basalt Geosites: The Experience the Giant's Causeway World Heritage Site. *In*: Lin, J.-C. (Ed). *The Penghu Vision*, 240–258. Penghu County Government, Magong City.

STOLTON, S., DUDLEY, N. & KUN, Z. 2010. Diverting Places: Linking Travel, Pleasure and Protection. *In*: STOLTON, S.

& Dudley, N. (Eds). *Arguments for Protected Areas: Multiple Benefits for Conservation and Use*, 189–204. Earthscan, Abingdon.

Tiess, G. & Ruban, D.A. 2013. Geological heritage and mining legislation: a brief conceptual assessment of the principal legal acts of selected EU countries. *Proceedings of the Geologists' Association*, 124: 411–416.

Tiller, T.R. & Schott, C. 2013. The Critical Relationship between Climate Change Awareness and Action: an Origin-Based Perspective. *Asia Pacific Journal of Tourism Research*, 18: 21–34.

Westwood, R. 2011. *Fossils, Rocks of the Jurassic Coast*. Inspiring Places Publishing, Fordingbridge, 40 pp.

Whitmarsh, L., Seyfang, G. & O'Neill, S. 2011. Public engagement with carbon and climate change: To what extent is the public 'carbon capable'? *Global Environmental Change*, 21: 56–65.

Wimbledon, W.A.P. & Smith-Meyer, S. (Eds) 2012. *Geoheritage in Europe and its conservation*. ProGEO, Oslo, 405 pp.

Wimbledon, W., Ishchenko, A., Gerasimenko, N., Alexandrowicz, Z., Vinokurov, V., Liscak, P., Vozar, J., Bezak, V., Kohut, M., Polak, M., Mello, J., Potfaj, M., Gross, P., Elecko, M., Nagy, A., Barath, I., Lapo, A., Vdovets, M., Klincharov, S., Marjanac, L., Mijovic, D., Dimitrijevic, M., Gavrolovic, D., Theodossiou-Drandaki, I., Serjani, A., Todorov, T., Nakov, R., Zagorchev, I., Perez-Gonzalez, A., Benvenuti, M., Boni, M., Bracucci, G., Bortolani, G., Burlando, M., Costantini, E., D'Andrea, M., Gisotti, G., Guado, G., Marchetti, M., Massolli-Novelli, R., Panizza, M., Pavia, G., Poli, G., Zarlenga, F., Satkunas, J., Mikulenas, V., Suominen, V., Kananajo, T., Lehtinen, M., Gonggrijp, G., Look, E., Grube, A., Johansson, C., Karis, L., Parkes, M., Paudsep, R., Andersen, S., Cleal, C. & Bevins, R. 1998. A first attempt at a GEOSITES framework for Europe - an IUGS initiative to support recogniztion of world heritage and European geodiversity. *Geologica Balcanica*, 28: 5–32.

Zalasiewicz, J. & Williams, M. 2012. *The Goldilocks planet. The four billion year story of Earth's climate*. Oxford University Press, Oxford, 303 pp.

Резиме

Обејекти геонаслеђа са палеогеографским значајем: перспектива геотуризма на примерима Адигеја планина (Русија)

Палеогеографске информације су сачуване у многим објектима геонаслеђа (геообјекти). Палеогеографски објекти геонаслеђа се разликују од других типова геонаслеђа по томе јер садрже корисне податке о палеосрединама, палеоекосистемима и др. Ови објекти су такође корисни са становишта геотуризма. Палеогеографски објекти геонаслеђа имају вишеструки значај за туризам. Посебну пажњу јавности заузимају климатске промене које су од изузетног значаја.

Глобалне климатске промене проузроковане антропогеним факторм (познате као "глобално отопљавање") биће озбиљан и све већи проблем за савременог човека. Неки објекти геонаслеђа одсликавају климатске екстреме из прошлости и омогућавају боље разумевање фактора који су проузроковали необичне климатске услове, а такође указују и на последице које настају услед ефеката ледених и стаклених башта. Стога, палеогеографски објекти би могли да послуже као едукативно средство, повећавајући свест јавности о актуелним климатским променама као и онима које су се дешавале у прошлости, подстичући при томе иницијативу за смањење глобалних климатских промена. Неопходна је стручна интерпретација геонаслеђа и она представља прави изазов за геотуризам с бзиром да су многи посетиоци геообјеката и геопаркова туристи који не поседују довољно знања о наукама о Земљи. Ово се нарочито односи на палеогеографске објекте геонаслеђа који су по својој природи веома комплексни. "Палеогеографија" може потенцијално постати кључна реч за привлачење туриста али будући туристи би требало да буду упознати са значењем те речи. Разумевање карактеристика које поседују објекти геонаслеђа за већину људи је тешко разумљиво без стручног објашњења.

Геолози могу да понуде објашњења оних карактеристика геообјеката које обичан посетилац не може лако да уочи. Постоје многи различити приступи за објашњавање палеогеографских геообјеката. Најкориснији приступи којима се објашњавају палеогеографски геообјекти су они који омогућују посетиоцу да кроз савремене примере стекне бољу слику о палеосрединама и палеоекосистемима. Овакав приступ захтева одређено упрошћавање и употребу маште, али свакако да је могуће наћи одговарајуће примере за некадашње средине и екосистеме. С обзиром да палеогеографски објекти одражавају слику различитих палеосредина и палеоекосистема, неколико различитих геообјеката који се налазе на истој области могу да се комбинују како би се стекла што потпунија слика геолошке историје или разноврсности некадашњих средина. Одличан пример за ово су Адигеја планине (Западни Кавказ, Русија) које дозвољавају да разматрамо могућност и изазов за организовање такве екскурзије. За предложену палеогеографску екскурзију изабрано је пет геообјеката. Током ове екскурзије геотуристима би био показан велики број палеосредина заједно са њховим фосилним заједницама које су сачуване у седиментним стенама. Једнодневна екскурзија би започела са Камишким профилом који је представљен континенталним слојевима, а затим би се

обишла долина Мала Кадзхок са лагунским седиментима и глинама. Ескурзија би се затим зауставила на два геообјекта представљеним шелфним седиментима (узвишење Лаго-Наки и кањон Руфабго) и завршила код профила Партизанског пропланка, где су откривени дубокоморски алевролити богати органском материјом. Због руте која је кривудава екскурзија може бити подељена у два дела или скраћена. Екскурзија би значајно допринела локалном развоју геотуризма јер пружа изузетну могучност за представљање информација о разноликости палеосредина које постоје на Адигеја планинама. Несумљиво да предложену горе поменуту палеогеографску екскурзију треба реализовати. Професионални геолози могу да разумеју геолошку грађу и без водића. Међутим, студентима и не професионалним посетиоцима било би потребно објаснити значење посматраних седимената и фосила. Друга могућност палеогеографског геотуризма у Адигеја планинама је узвишење Лаго-Наки. На врху планинског венца Стонесеа пружа се могућност панорамског погледа од 360° на планине Западног Кавказа. Могу се посматрати два висока узвишење: Велика Ткач планина и Осхтен планина. Оба представљају старе спрудове горњег тријаса и горње јуре. Тако, геотуристи могу видети карбонатне творевине различитих палеомора на једном месту.

Приликом планирања палеогеографских геотуристичких екскурзија требало би пажљиво испланирати број посетилаца у групама за одређене геообјекте. Облик геообјекта као и његова безбедност и приступачност оставља на располагању свега неколико локалитета на којима се могу окупити групе.

Б. Р.

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Methodological guidelines for geoheritage site assessment: a proposal for Serbia

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Abstract: Various minerals, rocks, soil types, ore and fossiliferous deposits, structural and tectonic elements, surface and subterranean landforms, all those natural phenomena representing geodiversity in a small scale contribute to our understanding the significant events and episodes of the geological history of the Earth. Intended methodology for qualitative and quantitative assessment is presented, including valuing criteria and their numerical indicators, which serve as analytical instruments to identify and select potential geoheritage objects in Serbia. Objective assessing and categorizing the geoheritage objects are the starting points for their rational utilization, adequate conservation, proper interpretation and promotion.

Key words: geodiversity, geoheritage, geoparks, methodological guidelines, assessment, Serbia.

Апстракт: Разноврсни минерали, стене, типови земљишта, рудна и фосилоносна налазишта, структурни и тектонски елементи, површински и подземни облици рељефа, сви ови природни феномени представљајући геодиверзитет „у малом“, доприносе нашем разумевању значајних догађаја и епизода из геолошке историје Земље. Осмишљена је и у раду приказана методологија за квантитативну и квалитативну процену, укључујући вредноносне критеријуме и одговарајуће нумеричке параметре који, као аналитичка средства, служе да се идентификују и издвоје потенцијални објекти геонаслеђа у Србији. Објективна процена и категоризација објеката геонаслеђа полазне су основе за њихово рационално коришћење, примену адекватних мера заштите, одговарајућу интерпретацију и промоцију.

Кључне речи: геодиверзитет, геонаслеђе, геопаркови, методолошке смернице, процена, Србија.

Introduction

The term geodiversity first appeared in a Tasmanian Forest Commission document, intending to describe the diversity of Earth's features and systems (Sharples 1993). Geodiversity is defined as the variety within the entire abiotic world that encompasses the natural range of geological, geomorphological and soil features, assemblages, systems and processes (Australian Natural Heritage Charter 2002). It also includes evidence of the history of the Earth (evidence of ancient life, paleoecosystems, and paleoenvironments) and a range of relict and active biological, hydrological and atmospheric processes.

There is no doubt that many geodiversity phenomena are mainly endangered by humans neglect, mismanagement, overexploitation and unplanned construction. Geodiversity is so diverse that is difficult to decide which phenomena should be protected and preserved. Regarding the fact that is overall geodiversity is impossible to conserve, it is necessary to recognize those phenomena that are scientifically, educationally, culturally and economically explored and valuable. Geoheritage is the representative part of geodiversity that may be specifically identified as having conservation significance.

The geodiversity and geoheritage phenomena are finite and the principles of sustainable development advise wise use of these resources for the sake of future generations who might also want to use them (Maran 2008). Geoconservation involves a set of actions focus on protecting, conserving, presenting and promoting the geodiversity and geoheritage for their intrinsic, ecological and heritage values. Beside

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the preventive protection, geoconservation also includes development and improvement in the field of scientific and professional research, legislation, education, spatial and urban planning and tourism (MARAN STEVANOVIĆ 2014).

Geoeducation plays an important role in promoting geoheritage values, in order to gain support for the implementation of geoconservation objectives and to ensure effective practical management of geoheritage (MARAN 2012, unpublished doctoral thesis). Geotourism is recognized as new form of tourism, which original reason for developing is to promote an understanding of earth sciences, tourism to geosites and the conservation of geodiversity through appreciation and learning (HOSE 2000, NEWSOME & DOWLING 2010, FARSANI *et al.* 2011). All these aspects are incorporated within the Geopark concept (ZOUROS & MARTINI 2003, EDER 2004, MC KEEVER & ZOUROS 2005) (Fig. 1). Establishment of geoparks, the European Geoparks Network (EGN) and the Global Network of National Geological Parks (GGN) was one of the most important international initiatives in the field of geoconservation. Synergy of geodiversity, biodiversity and cultural heritage is the basis for the functioning of each geopark; educational activities are primarily oriented towards exploring the integrity of natural and cultural heritage through development of geotourism in order to provide a wide range of employment opportunities to the local population and to stimulate economic development of the region (MARAN STEVANOVIĆ 2014a).

Fig. 1. Spectacular dolomites of the Brenta Group, Geopark Adamello Brenta, an open geological laboratory for appreciation and learning (photo: A. Maran Stevanović).

Importance of geodiversity and geoheritage

Study of geodiversity and geoheritage develops different scientific methods and procedures to identify features, processes, sites and specimens that have nature conservation values (MARAN 2012a). Identification, registration and evaluation of geodiversity and then selection and conservation of valuable geoheritage sites and objects are complex tasks which require good background knowledge in the field of geosciences, multidisciplinary approach, scientific analysis and application of various methodologies and principles.

The definition of guidelines to manage geodiversity assessments and register geoheritage sites and objects were among the main geoconservation aims in different countries (MARAN 2010 and references herein). However, diverse national geoheritage contexts and objectives have not allowed the development of universal guidelines (PEREIRA & PEREIRA 2010). Consequently, many experts and researchers have proposed various methodological procedures based on different characteristics of geoheritage objects (JOYCE 1994, WILSON 1994, WIMBLEDON *et al.* 1995, WIMBLEDON 1998, DOYLE & BENNET 1998, ALCALA 1999, PEMBERTON 2001, SHARPLES 2002, GREY 2004, BRUSCHI & CENDRERO 2005, WHITE & MITCHELL 2006, PEREIRA *et al.* 2007, ZOUROS 2007, REYNARD *et al.* 2007, REYNARD 2008, BROCX 2008, CARCAVILLA *et al.* 2009, PENA DOS REIS & HENRIQUES 2009, PEREIRA & PEREIRA 2010, FASSOULAS *et al.* 2012). In general, the combined values that arise from geodiversity can be classified into five main categories (MARAN 2012):

1. Intrinsic
2. Ecological
3. Economic
4. Cultural
5. Research and educational.

1. The concept of **intrinsic value** means that Earth possesses and phenomena may have value beyond the social, economic or cultural values held by humans (SHARPLES 2002). In nature conservation, this concept is widely accepted but it is very difficult to justify since it involves ethical and philosophical dimensions of the relationships between humans and nature (GRAY 2004).

2. Ecosystems depend entirely on their non-living parts such as bedrock, landforms and soils that are habitats of animals and plants. In this sense, the **ecological value** of geodiversity refers to its importance in sustaining geological, geomorphologic and soil processes as well as biological processes, which depend upon those systems.

3. Rocks, minerals and fossils, all have **economic value**. Varied rocks and minerals are essential as they supply humans with mineral fuels (e.g. petroleum and coal), industrial metallic and precious minerals (ores and gemstones) and construction materials (aggregates and building stone) (GREY 2004). Fossils also have significant commercial value, particularly if they are well preserved and well known (e.g. dinosaur' fos-

sils, ammonite, trilobite or rudist "jewelry", fossiliferous ornamental stones, etc.).

4. The **cultural value** of geodiversity implies the significance placed by global society on some aspect of physical environment, such as mythology, archeological-historical, spiritual and aesthetic value (e.g. Lepenski Vir archeological site, NP Djerdap, eastern Serbia, Fig. 2).

Fig. 2. Lepenski Vir archeological site and museum, included in the UNESCO World Heritage List (photo: A. Maran Stevanović).

5. Georesources have important **research and educational values**. Geological features illustrate the huge periods of time they took to form the natural resources on which today's society depends. They are rich in evidence of changing climates, shifting boundaries between continents and oceans and extinction events. Rock exposures, landforms and soils, all they can provide *in situ* polygons for training of the new generation of geologists, geomorphologists, pedologists, amateurs and children.

The assessment of geoheritage sites in Serbia

The Serbian LAW ON CULTURAL PROPERTIES (71/1994) recognizes the two large categories of the national cultural and natural legacy: the non-moveable (*in situ*) and the moveable (*ex situ*). Following that general classification, the non-moveable heritage may correspond to the geosites with clearly pronounced geological, geomorphologic or pedological features whereas particular rock, ore and mineral samples as well as fossil specimens represent moveable geoheritage objects (MARAN 2005). In detail, the components that should be recognized as geoheritage include (MARAN 2012):

- Igneous, metamorphic and sedimentary rocks and their processes of formation;
- Mineral resources (minerals and mineralization), mines and quarries;
- Structural and tectonic features on different scales;
- Fossils and fossiliferous sites;
- Stratigraphical contacts;
- Relict and active landforms and their forming processes;
- Relict and active hydrogeological features;
- Relict and active soils and soil forming processes;
- Building stones and related products.

In Serbia, prior to 1995, 75 geoheritage objects were protected based on sporadically given individual proposals, including 73 geosites and 2 moveable geological objects (source: INSTITUTE FOR NATURE CONSERVATION OF SERBIA, personal communication 2014). Except geomorphological, hydrogeological and rare fossiliferous localities, other sites have only named "officially protected", without adequate geoconservation measures and actions. The project "Inventory of the geoheritage sites of Serbia", initiated by the Serbian National Council for Geoheritage Conservation in 1996, was aimed to collect proposals for geosites that mark important events in the geological history of Serbian territory. The work on the inventory was undertaken between 1996 and 2003 and in 2004 preliminary list has been created. It includes 552 geosites proposed for conservation; they are classified into eleven categories according to recommendations of the European Association for the Conservation of the Geological Heritage (ProGEO). In Serbia, the establishment of comprehensive National geoconservation strategy is still missing despite many warnings from specialists. Prior to define the strategy, however, many researches should take place, including preliminary selection of important geodiversity sites, valuing geodiversity, assessing potential threats, and identifying general actions to prevent or enhance significant geoheritage features (MARAN 2012a).

The choice of criteria for judging the value and significance of geodiversity for geoconservation is considered the first stage in any assessment. During the last two decades, several attempts have been done to develop appropriate criteria for identification and selection of potential geoheritage objects in Serbia. Prior to 2000, most researchers have proposed different geosites for inventory based mainly on their subjective observations and field experiences or simply applying the ProGEO recommendations (MIJOVIĆ & MILJANOVIĆ 1999), which intended to serve only as guidelines not as clearly defined principles. In recent years, some authors offer improved approach to assessment of geoheritage objects aimed at scientific, educational and tourist valorization and promotion, including qualitative and quantitative evaluation (STANKOVIĆ 2004, MARAN 2010, TOMIĆ 2011, MARAN STEVANOVIĆ 2014, VIŠNJIĆ & BEGAN 2015).

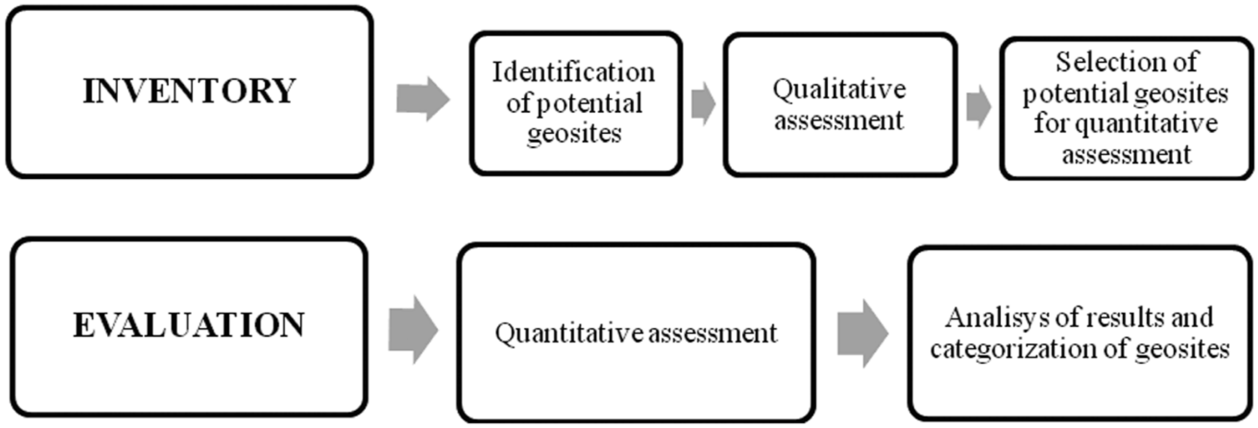

Fig. 3. Stages in geosite assessment.

As a member of the Working group for the establishment of potential Djerdap geopark in eastern Serbia, appointed by the Serbian Ministry of Natural Resources, Mining and Spatial Planning, the author of this paper was asked to prepare a set of qualitative and quantitative parameters in order to estimate the geodiversity potential within the area of National Park Djerdap and its vicinity (MARAN STEVANOVIĆ 2013, unpublished report). These starting indicators are used to develop methodology for the quantitative and qualitative assessments of geosites that should support geoconservation and management of geoheritage sites within potential geopark area. Adapting the methodologies and procedures suggested by REYNARD *et al.* (2007), REYNARD (2008) and PEREIRA & PEREIRA (2010) to our circumstances and objectives, the two main stages are taken into consideration, the inventory and evaluation with corresponding substages (Fig. 3). The inventory includes: 1) identification of potential geosites, 2) qualitative assessment of potential geosites and 3) selection of geosites for quantitative assessment. The evaluation phase involves two substages: 1) quantitative assessment of selected geosites, and 2) analysis of results and categorization (ranking) of geosites.

Operating criteria used to evaluate and quantify geodiversity values as well as to choose potential geoheritage sites are presented. Some basic criteria have been explained previously (MARAN 2005, 2008, 2010) whereas "new" ones are designed for particular case. They are divided into four groups, including scientific value (**SV**), other (additional) values (**OV**), functional values (**FV**) and vulnerability of sites (**VU**) (Table 1). Each category has its final score and the total value (**TV**) will be reached by algorithm (MARAN STEVANOVIĆ 2014b):

Total value
(TV) = (3×SV) + (2×OV) + (2×FV) + (2×VU) / 2,5
maximum number of points = 100

The criterion scientific value (**SV**) of geoheritage is the most important and includes several parameters for its designation such as uniqueness, representativeness, complexity, educative value and level of exploration (research).

Uniqueness (**U**) means that a phenomenon (mineralogical, petrological, paleontological, hydrogeological, geomorphological, pedological etc.) is the only one of that type within a spatial unit (continent, state) and represents the etalon for estimating values of all other phenomena (e.g. stratotype). Value and importance of such a phenomenon is universal. Representativeness (**R**) refers to the most complete representation of characteristics of a certain phenomenon. Out of various objects (mineralogical, petrologic, paleontological, hydrogeological, geomorphologic etc.) one is chosen if it illustrates nature and origin of a certain

Table 1. Criteria for evaluation of geoheritage sites (MARAN STEVANOVIĆ 2014b).

Scientific value (SV)	Other values (OV)	Functional values (FV)	Vulnerability (VU)
Uniqueness Representativeness Complexity Educative value Level of exploration	Ecological Cultural Aesthetic	Accessibility Visibility Connection with other natural and cultural objects Infrastructure facilities Economic potential	Level of threat Level of preservation

phenomenon, form or process in the best (most complete) way. The complexity (**C**) of certain phenomenon means that its features have multipurpose character (e.g. a cave with specific cave ornaments, fossilized remains and prehistoric artifacts is, at the same time, the speleological, paleontological and archeological site). Educational value (**EV**) relates to the possibility of particular phenomenon to be used in affirmation, popularization and presentation of geology and geosciences, geodiversity and geoheritage. Level of exploration (**LE**) means amount of collected information about certain phenomenon obtained through literature, field data, personal experiences or oral communications. Each mentioned parameter has its numerical indicator (Table 2) and the final value is presented by the algorithm:

SV = (4×U) + (2×R) + C + (2×EV) + LE
(maximum number of points = 50)

Table 2. Parameters and their numerical indices used to estimate the scientific value of each geoheritage site.

Scientific value (SV)	Score
Uniqueness (U) Representativeness (R) Complexity (C) Educative value (EV) Level of exploration (LE)	0 – absent 1 – insufficient 2 – low 3 – medium 4 – high 5 – very high

The second criterion implies **other values** (**OV**) of geoheritage viewed from ecological (**E**), cultural (**CU**) and aesthetic aspects (**A**) (Table 3). Ecological value of geosite represents its contribution to the interaction between biodiversity and geodiversity in the area (e.g. development of particular ecotype, existence of endemic plant or animal species). Geosite can contribute to the cultural identity of an area in different ways, including its historic perspective (connection of certain site with historic events and people), local religion, tradition and art. Aesthetic value refers to the site visual appearance and its possibility to attract observer attention. The algorithm shows the final value of certain parameters:

OV = E + CU + (2 × A)
(maximum number of points = 20)

As geoheritage sites are most commonly promoted for tourism purposes, their **functional values** (**FV**) are also significant and comprise the following indicators (Table 4): a) accessibility (**AC**) (topography, distance from the main traffic roads, access to the object, presence of asphalt roads or pathways in the area); b) visibility (**V**); c) spatial connection (**SC**) with other important natural and cultural sites; d) infrastructure facilities (**IF**) (presence of infrastructure objects, services and products intended for visitors, e. g. accommodation, restaurants, shops, information centers, museums, walking tours, informative panels, maps, souvenirs) and e) economic potential (**EP**) (possibility of using sites for commercial purposes to gain profit). The final value is determined through the following algorithm:

Table 3. Parameters and numerical indices of parameters used to estimate other values of each geoheritage site.

Other values (OV)	Score
Ecological (E) Cultural (CU) Aesthetic (A)	0 – absent 1 – insufficient 2 – low 3 – medium 4 – high 5 – very high

FV = AC + V + SC + IF + (2 × EP)
(maximum number of points = 20)

Table 4. Parameters and their numerical indices used to estimate the functional value of each geoheritage site.

Functional value (FV)	Score
Accessibility (AC)	1 – inaccessible 2 – medium 3 – good
Visibility (V)	1 – difficult to notice 2 – medium 3 – good
Spatial connection with other natural and cultural sites (SC)	1 – absent or weak 2 – medium 3 – good
Infrastructure facilities (IF)	1 – absent or minimal 2 – medium 3 – good
Economic potential (EP)	1 – absent or low 2 – medium 3 – high 4 – very high

In order to choose appropriate conservation methods, it is necessary to assess the site **vulnerability** (**VU**), which includes two indicators, the current level of threat (**LT**) and current level of preservation (**LP**) (Table 5). Threats to the integrity of geoheritage sites are numerous and can be grouped as natural or anthropogenic. The first category mainly relates to natural degradation caused by erosion and weathering processes, landslides or vegetation growth. The second group of threats, although almost unintended, resulted from human activities including the expansion of urban areas, commercial quarrying, improper waste storage, inappropriate collecting and excessive tourist pressure (MARAN STEVANOVIĆ 2014). The final value will be reached through the following algorithm:

$$VU = LT + LP$$
(maximum number of points = 10)

Table 5. Parameters and numerical values of parameters used to estimate the level of threat and level of preservation for each geoheritage site.

Vulnerability (VU)	Score
Level of threat (LT)	0 – not threatened 1 – potentially threatened 2 – partially threatened 3 – threatened 4 – partially damaged 5 – highly damaged
Level of preservation (LP)	0 – very high 1 – high 2 – medium 3 – low 4 – very low 5 – not preserved

These qualitative and quantitative parameters have been used to test the categories of geoheritage sites, previously proposed and discussed (MARAN 2010, 2012, 2012a). Accordingly, proposed numerical value for each category is:

- The category Internationally Important Geosites (IIG) includes sites with the total score that must be greater than 85 points. They have to satisfy the combination of three groups of classification criteria, including scientific, additional and functional values. In accordance to the current level of threat and current level of preservation, sites must be well preserved and not threatened (or potentially threatened only).
- The category Nationally Important Geosites (NIG) refers to sites with the total score between 75 and 85 points.
- The category Regionally Important Geosites (RIG) incorporates sites with the total score between 60 and 75 points.
- The category Locally Important Geosites (LIG) may include sites with total score between 40 and 60 points, but exclusively, the score of scientific value (SV) must be above 25 (SV > 25).

Qualitative and quantitative assessments are also tested in process of selection of potential geoheritage sites in studied areas in eastern and western Serbia (Boljevac and Mokra Gora) (MARAN 2012). In addition to the verification of site rank, the evaluation of site value and significance helps to determine relevant measures for geoconservation, including physical protection, site monitoring and site preparation for visitors as well as different scientific, educational and cultural activities (e.g. establishment of georoutes). The application of quantitative (numerical) evaluation is important because it can minimize the assessor subjectivity. It is expected that proposed methodology for qualitative and quantitative assessments could be accepted by relevant authorities and put into practice.

Final remarks and recommendations

Based on our previous experience, it can be concluded that the researcher subjectivity dominated largely in the process of site selection and suggestion for conservation. Even today, most researchers obviously prefer their fields of expertise to considering objective and realistic proposals. These circumstances can be explained by the ignorance of basic standards and a limited access to existing literature and practice. This is the reason why more objective and quantitative analysis should be carried out.

Proposed methodology includes qualitative and quantitative assessments, which can serve as useful instrument to meet the needs for appropriate management and conservation of valuable geoheritage sites in certain territory. It can reveal priorities for geosite conservation, development of geotourism and educational activities.

It is generally accepted that the selected geosites must be of top quality, complex in information, well-preserved, and the most representative in their group of phenomena. Consideration of the geoheritage sites should be done through documentation, assessment and comparison, at international, national, regional and local levels. Site information must be reviewed on the basis of personal experience, fieldwork, literature and consultation with other geologists and geoscientists with specific knowledge and expertise. The significance rating assigned to the site must be periodically reassessed in light of new information and site condition. Precise, objective and detailed explanation should clearly indicate the site important characteristics and its possible functions.

The qualitative and quantitative assessment should become an integral part of the methodology of scientific and professional researches that implies: a) study on geodiversity of an area, b) qualitative evaluation and selection of potential geoheritage sites, c) quantitative evaluation, d) assessment of the site condition and its vulnerability (level of threat and level of preservation), and e) proposals for adequate conservation measures and activities aimed at popularizing, presentation and promotion of geosites.

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References

ALCALA, L. 1999. Spanish steps towards geoconservation. *Earth heritage*, 11: 14–15.

AUSTRALIAN HERITAGE COMMISSION 2002. Australian Natural Heritage Charter for the conservation of places of natural heritage significance. Australian Heritage Commission & Australian Committee for the International Union for the Conservation of Nature (ACIUCN), 2nd edition, 25 pp.

BROCX, M. 2008. *Geoharitage – from global perspective to local principles for conservation and planning.* Western Australian Museum, Perth, 175 pp.

BRUSCHI, V. & CENDRERO A. 2005. Geosite evaluation: can we measure intangible values? *Italian Journal of Quaternary Sciences*, 18 (1): 293–306.

CARCAVILLA, L., JOSE DURAN, J., GARCIA-CORTES, A. & LOPEZ-MARTINEZ, J. 2009. Geological Heritage and Geoconservation in Spain: Past, Present, and Future. *Geoheritage*, 1: 75–91.

DOYLE, P. & BENNETT, M. R. 1998. Earth heritage conservation: past, present and future agendas. *In*: BENNETT, M. R. & DOYLE, P. (Eds.) *Issues in Environmental Geology: A British Perspective*, 41–67. Geological Society of London, London.

EDER, F.W. 2004. The Global UNESCO Network of Geoparks. *In*: ZHAO, X., JIANG, J.J., DONG, S.W., LI. M.L. & ZHAO, T. (Eds.) Proceedings of the First International Conference on Geoparks, Beijing June 27-29, Geological Publishing House, Beijing, 1–3.

FARSANI, T.N., COELHO, C. & COSTA C. 2011. Geotourism and geoparks as novel strategies for socio-economic development in rural areas, *International Journal of Tourism Research*, 13 (1): 68–81.

FASSOULAS, C., MOURIKI, D., DIMITRIOU-NIKOLAKIS, P. & ILIOPOULOS, G. 2012. Quantitative Assessment of Geotopes as an Effective Tool for Geoheritage Management. *Geoheritage*, 4: 177–193.

GRAY, M. 2004. *Geodiversity: Valuing and Conserving Abiotic Nature*. 434 pp. John Wiley & Sons Ltd, Chichester.

HOSE, T.A. 2000. European 'Geotourism' - geological interpretation and geoconservation promotion for tourists. *In*: BARETTINO, D., WIMBLEDON, W.A.P. & GALLEGO, E. (Eds.), *Geological Heritage: its conservation and management*, 127–146. Madrid, Spain.

JOYCE, E.B. 1994. Assessing the significance of geological heritage sites: from the local level to world heritage. First international symposium on the conservation of our geological heritage, Proceedings, *Memoire de la Societe Geologique de France*, Nouvelle Series, 165: 37–43.

MARAN, A. 2005. The criteria for categorization and evaluation of the geoheritage objects in Serbia - paleontological collections and sites. Archive of the NHM in Belgrade, 15 pp. (in Serbian).

MARAN, A. 2008. Geoconservation in the Balkan region - Practices and legal instruments. *Bulletin of the Natural History Museum in Belgrade*, 1: 41–63.

MARAN, A. 2010. Valuing the geological heritage of Serbia. *Bulletin of the Natural History Museum in Belgrade*, 3: 47–66.

MARAN, A. 2012: Geoconservation of the Cretaceous marine geosites from Serbia: Boljevac and Mokra Gora. Archive of the Bucharest University, 210 pp. + 4 annexes (unpublished doctoral thesis).

MARAN, A. 2012a. Geoconservation in Serbia - State of play and perspectives. *Journal of the European Federation of Geologists*, Geoheritage, 34: 29–35.

MARAN STEVANOVIĆ, A. 2013. The methodological base for evaluating the significance and value of geoheritage objects. [The basis for the strategy of establishing the geopark Djerdap, unpublished report], Ministry of Natural Resources, Mining and Spatial Planning of Serbia, Belgrade, 10 pp. (in Serbian).

MARAN STEVANOVIĆ, A., 2014. Conservation of paleontological heritage in Serbia: from philosophy to practice. *Bulletin of the Natural History Museum in Belgrade*, 7: 7–28.

MARAN STEVANOVIĆ, A. 2014a. Geoparks, an example of good practice in geodiversity conservation: Geopark Haute-Provence, France. *Reports of the Serbian Geological Society for the year 2013*, 121–134, Belgrade.

MARAN STEVANOVIĆ, A. 2014b. Methodological guidelines for assessment of geoheritage sites. Proceedings of the XVI Serbian Geological Congress, Donji Milanovac 22–25. 05.2014, 842–845 (in Serbian and English).

MC KEEVER, P. & ZOUROS, N. 2005. Geoparks: Celebrating Earth heritage, sustaining local communities. *Episodes*, 28 (4): 274–278.

MIJOVIĆ, D. & MILJANOVIĆ D. 1999. Scientific and educative criteria of evaluation of geo-heritage in the planning of landscape. *Protection of nature*, 51 (2): 133–139 (in Serbian with English summary).

NEWSOME, D. & DOWLING, R. K. 2010. Setting an Agenda for Geotourism. *In*: NEWSOME, D. & DOWLING, R. (Eds.) *Geotourism: The Tourism of Geology and Landscape*, Goodfellow Publishers Limited, 1: 5–11.

PEMBERTON, M. 2001. Conserving geodiversity, the importance of valuing our geological heritage. (Paper presented at the Geological Society of Australia National Conference, 7 pp.) http://dpipwe.tas.gov.au/Documents/geocon_abstract.pdf [Date of access: 26 Sep. 2009]

PENA DOS REIS, R. & HENRIQUES, H. M. 2009. Approaching an Integrated Qualification and Evaluation System for Geological Heritage, *Geoheritage*, 1: 1–10.

PEREIRA, P., PEREIRA, D. & ALVES, M.I. 2007. Geomorphosite assessment in Montesinho Natural Park, Portugal. *Geographica Helvetica*, 62 (3): 159–168.

PEREIRA, P. & PEREIRA, D. 2010. Methodological guidelines for geomorphosite assessment. *Geomorphologie, Relief, Processus, Environnement*, 2: 215–222.

REYNARD, E. 2008. Scientific research and tourist promotion of geomorphological heritage. *Geografia Fisica e Dinammica Quaternaria*, 31: 225–230.

REYNARD, E., FONTANA, G., KOZLIK, L. & SCAPOZZA C. 2007. A method for assessing "scientific" and "additional values" of geomorphosites. *Geographica Helvetica*, 62: 148–158.

SHARPLES, C. 1993. A Methodology for the Identification of Significant Landforms and Geological Sites for Geoconservation Purposes. Report to Forestry Commission, Tasmania, 31 pp.

SHARPLES, C. 1995. Geoconservation in forest management - principles and procedures. *Tasforests*, 7: 37–50, Forestry Tasmania, Hobart.

SHARPLES, C. 2002. Concepts and principles of geoconservation. 79 pp. [Published electronically on the Tasmanian Parks & Wildlife Service website, September, 2002, Version 3] - www.dpiwe.tas.gov.au

STANKOVIĆ, S. 2004. Touristic valorization of geomorphological objects of geo-heritage in Serbia. *Bulletin of the Serbian Geographic Society*, 84 (1): 78–88 (in Serbian with English summary).

TOMIĆ, N. 2011. The Potential of Lazar Canyon (Serbia) as a geotourism destination: inventory and evaluation. *Geographica Pannonica*, 15 (3): 103–112.

VIŠNJIĆ, T. & BEGAN, M. 2015. Geoheritage sites in the function of geotourism development in the Republic of Serbia. Book of proceedings, Synthesis, International scientific conference of IT and Business Related Research, Belgrade, 16–17 April 2015, 552–557.

WHITE, S. & MITCHELL, M. 2006. Geological heritage sites: a procedure and protocol for documentation and assessment. Geological Society of Australia, Special Publication, 26: 1–2.

WILSON, C. 1994. *Earth Heritage Conservation*. 272 pp. Geological Society of London & Open University, London.

WIMBLEDON, W. A. 1998. A European geosite inventory: GEOSITE - an International Union of Geological Sciences initiative to conserve our geological heritage. *In*: DURAN, J.J. & VALLEJO, M. (Eds.) *Comunicaciones de la IV Reunion Nacional del Patrimonio Geologico, Miraflores de la Sierra (Madrid)*, 15–18. Sociedad Geologica de Espania, Madrid.

WIMBLEDON, W.A., BENTON, M.J., BEVINS, R.E., BLACK, G.P., BRIDGLAND, D.R., CLEAL, C.J., COOPER, R.G. & MAY, V.J. 1995. The development of a methodology for the selection of British sites for conservation. *Modern Geology*, 20 (1): 159–202.

ZOUROS, N. 2007. Geomorphosite assessment and management in protected areas of Greece. Case study of the Lesvos Island-coastal geomorphosites. *Geographica Helvetica*, 62 (3): 69–180.

ZOUROS, N. & MARTINI, G. 2003: Introduction to the European Geoparks Network. *In*: ZOUROS, N., MARTINI, G. & FREY, M. L. (Eds.) *Proceedings of the International Symposium on Geological Heritage Protection and Local Development,* 17–21. 2nd European Geoparks Network Meeting, Lesvos Island.

Legal documents

LAW ON CULTURAL PROPERTIES, Official Gazette of the Republic of Serbia, 71/1994.

Резиме

Методолошке смернице за процену објеката геонаслеђа: пример из Србије

Појам геодиверзитет уведен је у научну и стручну литературу да би се описала разноврсност облика, појава и процеса у оквиру неживе природе и истакао њихов значај за настанак и развој живота на Земљи. Геонаслеђе чине репрезентативни феномени геодиверзитета, издвојени као посебне природне вредности од значаја за науку, образовање, културу или економију. Следећи смернице ЗАКОНА О КУЛТУРНИМ ДОБРИМА (71/1994) којим је регулисана заштита националне културне и природне баштине, објекти геонаслеђа груписани су у две основне категорије:

- Непокретни објекти геонаслеђа или геонаслеђе *in situ* су геолошки локалитети и профили, површински и подземни облици рељефа, различити типови земљишта.
- Геонаслеђе *ex situ* или покретни објекти геонаслеђа обухватају примерке стена, минерала, руда и фосила, који се након идентификације могу однети са локалитета или налазишта где су откривени ради научних и стручних истраживања.

На основу нашег досадашњег искуства може се закључити да у процесу селекције и предлагања објеката геонаслеђа који треба да се заштите у великој мери доминира субјективност предлагача. Очигледно је да чак и данас већина истраживача фаворизује оно чиме се бави, а не објективне и реалне предлоге. Овакво чињенично стање може се објаснити непознавањем основних принципа геозаштите и ограниченим увидом у постојећу литературу и праксу.

Значај и вредност објеката геонаслеђа утврђује се на основу свих прикупљених релевантних информација (преглед литературе и документације, теренски рад, консултације са стручњацима различитих специјалности, лично искуство) као и поређењем са сродним објектима на међународном, националном, регионалном и локалном нивоу. У својству члана Радне групе за оснивање потенцијалног геопарка Ђердап, источна Србија, од

аутора овог рада тражено је да предложи метод за процену значаја и вредности непокретних објеката геонаслеђа (геолошки локалитети и профили, површински и подземни облици рељефа, различити типови земљишта) на подручју постојећег Националног парка Ђердап и његове околине. Прилагођавајући методологије и процедуре које су дефинисали REYNARD *et al*. (2007), REYNARD (2008) и PEREIRA & PEREIRA (2010) нашим условима и потребама, издвојене су две основне методолошке фазе или етапе: инвентаризација и евалуација. Фаза инвентаризације састоји се од три подфазе: 1) идентификација потенцијалних непокретних објеката геонаслеђа, 2) квалитативна процена непокретних објеката геонаслеђа и 3) избор објеката за квантитативну анализу. Фаза евалуације обухвата две подфазе: 1) квантитативна процена објеката геонаслеђа и 2) анализа резултата и категоризација (рангирање) објеката.

Предуслов а уједно и полазна основа за евалуацију објеката је правилан избор критеријума, који служе као аналитичка средства да се из групе истоветних или сродних одабере објекат који најкомплетније илуструје одређени феномен. Издвојени су критеријуми за евалуацију, подељени у четири групе: научни значај (**НЗ**), друге вредности (**ДВ**), употребна вредност (**УВ**) и рањивост (**Р**) објеката. Сваки од критеријума има своје подкритеријуме или параметре као и одговарајуће нумеричке ознаке. Укупна вредност одређеног објекта (**УВО**) одређује се алгоритмом:

УКУПНА ВРЕДНОСТ
(УВО) = (3×НЗ) + (2×ДВ) + (2×УВ) + (2×Р) / 2,5
махимални број поена = 100

У функцији оперативних инструмената, наведени критеријуми предложени су као основ за идентификацију, евалуацију, селекцију и категоризацију потенцијалних објекати геонаслеђа не само на територији НП Ђердап већ и на било ком другом подручју у Србији. Препорука аутора је да квалитативна и квантитативна процена објеката геонаслеђа треба да буде саставни део методологије научног и стручног истраживања у оквиру геозаштите, која обухвата: истраживање и проучавање геодиверзита одређеног подручја, квалитативну евалуацију и издвајање потенцијалних објеката геонаслеђа, квантитативну процену објеката, процену постојећег стања и степена угрожености објеката, и предлоге одговарајућих заштитних мера као и активности усмерених на популаризацију, презентацију и промоцију објеката геонаслеђа. Примена квантитативне (нумеричка) процене објеката један је од начина да се субјективност процењивача сведе на најмању могућу меру.

Review

Geologists of Russian origin in the USA

Platon Tchoumatchenco[1] & Michel Wiazemsky[2]

Abstract. Many ethnic Russian geologists lived and worked in the Unites States of America. We describe in this paper the life and career of geologists, (ie all Earth scientists – geologists, mineralogists, tectonicians, geophysicists, geochemists, paleontologists, mining and drilling engineers, hydrogeologists, cosmos- geologists, etc.), regardless of their original nationality (Russians, Ukrainians, Tatars, Germans, etc.) who were born in the Russian Empire, the Soviet Union or the Russian Federation, as well as descendants of Russian émigrés who had the call of geology and worked in this part of the world, without necessarily settling there.

We subdivide the history of the Russian emigration into three periods: a) first generation emigrants, before the October 1917 Revolution, or their descendants (6 persons); b) second wave of emigration after the Revolution (white emigration) and their descendants (47 persons); c) a third wave, during and after WWII (1941–2013) (27 persons), totalling 80 Russian geologists in the United States of America.

Introduction

Russian emigrant geologists in the United States of America arrived at different times and for different reasons. The first period of immigration took place at the end of the 19th and beggining of the 20th centuries (6 persons). The big wave came after the October Revolution and the Civil War, before WW II (the white emigration totaling 47 persons including their descendants). It was followed by a last wave after WW II (27 geologists).

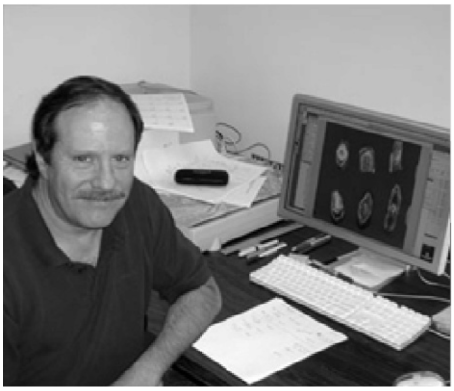
Included under the term "geologists" are all earth sciences specialists – geologists, mineralogists, tectonicians, geophysicists, geochemists, paleontologists, mine or drilling engineers, hydrogeologists, cosmos-geologists, etc. Under the nomination "Russian origin" we include people from various nationalities, who live or lived on the territory of the Russian Empire, the USSR or the Russian Federation.

We are not formal authors (in the strict meaning of the word), but compilers of biographic data we could find through collegues, the literature or the Internet and that are listed below as a biographical contribution to the field of the History of Geology.

List of the geologists of Russian origin who worked or are presently working in the United States of America.

1. John N. Aleinikoff (*1950, Denver, USA), geochronology and isotope analysis specialist (second generation white emigrant).

John N. Aleinikoff was born in Colorado (United States). We ignore the arrival date of his ancestors in America. John N. Aleinikov is a field geologist, specialized in the isotopic age measure-



J. Aleinikoff. (Internet:esp.cr.usgs.gov)

ments of igneous rocks, based on an integrated analysis which allows his team to determine the geological age of both sedimentary and igneous rocks. He works at the US Geological Survey in Denver (Colo), Federal Center, Rocky Mountain District. He collaborates with University of Virginia geologists, including Prof. Robert P. Wintsch. In 1978, he was a member of a geological expedition in Guatemala comprising a large group of geologists. He co-authored many papers on the geochronology of Precambrian and Paleozoic metamorphic and igneous rocks in various regions of the U.S., including Alaska.

2. Alexander Andronikov (*1957, Leningrad, Russia), geologist, volcanologist, geochemist, petrologist, Ph.D. Emigrated after the WWII. Arizona

Alexander was born in a family of biologists, Dr.Vladimir Borisovich Andronikov and Inna Nikolaevna Andronikova (née

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A. Andronikov (Personal archives)

Baranova). In 1980 Alexander graduated from the Leningrad University Faculty of Geology of as a "research geologist" specializing in historical geology. 10 years later he presented his thesis on "The Mesozoic alkaline-ultrabasic magmatic rocks of the Jetty Oasis, Prince Charles Mountains, East Antarctica". In the Institute of Oceanographic geology Alexander undertook research on the geology and volcanology of East Antarctica in the course of three Antarctic expeditions. In 1993 he was invited on temporary duty as a researcher at the Department of Geology, University of Tasmania, and from 1995 to 1997 was a Fellow of Alexander von Humboldt in the Mineralogical and Petrological Institute of the University of Gottingen in Germany (Mineralogisches-Petrologisches Institut, Universität Göttingen), where he studied the geochemistry of the peridotitic xenoliths of the Mesozoic alkaline - ultrabasic rocks of Antarctica. Alexander Andronikov was invited in the Department of Geological Sciences, University of Michigan in 1997, later being joined by his wife Irina, a geochemist and mineralogist (1999). His research focused on the Cenozoic basalts of western and central Alaska and the Cretaceous basalts of the central Arctic Ocean. Since 2010, Alexander is a researcher in the Lunar and Planetary Laboratory, University of Arizona, Tucson. He is currently involved in the study of chondritic meteorites and a member of the NASA OSIRIS-REx program, planned for 2016 and designed to study the so-called Yarkovsky effect on the asteroid (101955) Bennu (formerly named 1999 RQ36 before May 1st, 2013), an Apollo-class (Earth-crossing) asteroid. The Yarkovsky effect is supposed to deflect the trajectory of Earth-threatening asteroids. The mission is also designed to bring back a sample from the surface of the asteroid for petrographic studies. Together with his wife, he also leads a world-wide survey of a large meteorite shower impact event that supposedly struk Earth around 13,000 years ago. He also participated in two Arctic expeditions (2008, 2009) and in 2011 was engaged in field work in Belgium, Holland and Russia in the course of the meteoric impact survey, also maintaining active contacts with Quaternary geologists of the St. Petersburg Pedagogical University. As an author and co-author A. Andronikov published about 50 articles in various magazines (Lithos, Chemical Geology, Contributions to Mineralogy and Petrology, etc.).

3. Irina Andronikova (née Egorova) (*1958, Leningrad, Russia), geologist, geochemist, mineralogist, Alexander Andronikov's wife. Emigrated after the WWII; Arizona.

In 1980, Irina graduated from the Leningrad University Faculty of Geology and Mineralogy. She undertook a petrographic study of Western and Eastern Antarctica rocks at the Institute of Oceanographic geology. In 1984 she worked in the St Petersburg-based "Sevzapgeologiya" Company, studying the potentially diamondiferous rocks of Karelia and the Kola Peninsula. In 1989 she moved to the organization "Rudgeofizics" where she aggregated data on mineral deposits in Russia in order to make recommendations on the application of geophysical methods of research. After a short stay with her husband in Australia, she returned to the Geology Department at the Saint Petersburg University Mineralogical and Geolgical Museum. In 1999 she moved to the United States in order to work with her husband.

Irina Andronikova (Personal archives)

4. Alex Mark Alexander (*1898? Russian Empire – †1934, USA), petroleum engineer, geophysicist. Emigrated after the October Revolution and the Civil War – first generation. Oklahoma.

Alexei's original name was probably americanized after resettlement in the United States. Alex Alexander's studies were supported by the Russian Student Foundation. He graduated in 1925 from Pittsburgh University as a petroleum engineer. He was engaged for seven years in the Empire Oil and Gas Company in Bartlesville (Oklahoma) being involved in the development and calibration of magnetometers used for the measurement of magnetic fields. Alex Alexander died young at only 36.

5. Irina Artemief (*1961, Moscow, Russia), geophysicist, geochemist, PhD., Associate professor.

Irina Artemieva (Tchoumatchenco P. *et al*. 2014) graduated from the Moscow Faculty of Physics in 1984. Two years later, she presented her thesis at the Russian Academy of Sciences' Institute of Physics of the Earth in Moscow, where she was employed until 1999, studying the structure and evolution of the continental lithosphere, based on the integration of geophysical data. From 1999 to 2001 Irina Artemieva was at the University of Uppsala in Sweden, then for one year a research associate at the University of Strasbourg (France), then for two years a senior fellow at the Geological Commission of California (USA). Since 2005 she is a professor at the University of Copenhagen's Geological Institute (Denmark). I. Artemieva studied the thermodynamics of the continental mantle and lithosphere, from the comparative study of petrological data, lithospheric structures and seismic models in Europe. She published a number of articles, including the monograph "The Lithosphere. An Interdisciplinary Approach." She is the editor of the newspaper "Geodynamics", member of the Geophysical Society of America and the Astronomical Society of London.

6. Boris Avdeev (*1980, Leningrad, Russia – †2012, Dallas, USA), geologist, tectonician, Ph.D. Emigrated after WW II. Michigan.

B. Avdeev (Internet: borisavdeev.ru)

Boris Avdeev received BS and MS degrees in geology at the St. Petersburg State University. He moved to the United States in 2003, quickly learned English and received his second master's degree (geostatistics) at the University of Texas Arlington. In 2006 he was joined the University of Michigan at the Faculty of Earth and Environmental Sciences until his tragic death in 2012. In 2011 he presented his Ph.D. thesis on "The evolution of tectonic movements of the Greater Caucasus ridge running along the borders of Russia, Georgia and Azerbaijan, and forming the northern tectonic element of the Arabian- Eurasian contact zone" at the University of Michigan under the direction of prof. Nathan Niemi.

Boris Avdeev engaged in the development of new numerical methods for data processing and interpretation, and low-temperature thermochronology. In 2012 he received a post- doctoral fellowship at UC Berkeley, but did not join. He managed to publish at least 8 scientific papers on tectonics and geodynamics, erosion and climate models, and statistical treatment of the Greater Caucasus and the Eurasian - Arabian Orogen. In 2010, together with the Austrian climber Peter Schoen he climbed and measured the height of the tallest mountain of Georgia, the Shkhara (5,193 m). Boris was an experienced skier, but tragically died April 19, 2012 at the age of 31 in the mountains of the High Sierra during an ascent he performed alone. Boris Avdeev was a cheerful, tireless, highly intelligent and creative thinking person. He walked through life with energy and enthusiasm, never stopping halfway. In memory of Boris Avdeev, a fund was established at the Faculty of Earth and Environmental Sciences to support young graduate students and researchers.

7. Alexander Belousov (*1962 Village Olhovka, Volgograd region, Russia), geologist, volcanologist, PhD.

A. Belousov (Personal Archives)

Alexander Belousov was born in a geologists family. His grandfather Boris Ivanovich Piip, a volcanologist and corresponding member of the USSR Academy of Sciences, founded the Kamchatka Institute of Volcanology, so influencing his grandson's choices. Alexander's parents are Valentina Piip, professor of geophysics at the Moscow State University and Boris Belousov, Director at Gazprom. Alexander loves photography, scuba diving and science. In 1984 he graduated from Moscow State University's Faculty of Geology, specializing in "geological studies, mineral prospecting and exploration". Ten years later he presented a thesis on "The catastrophic eruptions pyroclastic deposits of the Bezimenny, Chivelouch and St. Helens Volcanoes" under the direction of Professor VT Frolov. Alexander was a researcher at the Kamchatka Institute of Volcanology in the decade 1984–2004 and again from 2012 to present. In 2004–2007 he was a research fellow at the Sakhalin Institute of Geology and Marine Geophysics. Belousov is engaged in the domains of physical volcanology, pyroclastic stratigraphy of volcanic edifices and the monitoring of volcanic activity in Kamchatka, Sakhalin Island and the Kuril Islands. He made 30 field seasons on active and dormant volcanoes.

Alexander Belousov (Tchoumatchenco P. *et al*. 2014) also traveled as a visiting foreign researcher. He completed stays of 3 to 6 months in the Universities of Arizona and Pennsylvania (USA), in the Laboratory of volcanology at the University Blaise Pascal (France), the Academia Sinica of Taiwan (2008–2009) and the Observatory of Earth Sciences in Singapore (2009–2012). In the years 2000–2004 he was a fellow of the Humboldt Foundation at the Leibniz-Institut für Meereswissenschaften of Kiel University, IFM-GEOMAR. Also specializing in the reconstitution of volcanic eruptions, Alexander Belousov published over 80 scientific books as author or co-author, including about 25 overseas publications in English and Spanish, on the observations of geysers, the characterization of volcanic eruptions processes, the reconstitution of past eruptions and pyroclastic deposits. He is a member of the International Association of Volcanology and Chemistry of the Earth's interior (IAVCEI) and the American Geophysical Union (AGU).

8. Boris Brajnikoff / Борис Владимирович Бражников (*1904, Far East, Russian Empire – †1988, USA), geologist, hydrogeologist, petrographer, Dr.

Data collected on B. Brajnikoff from various sources are not always reliable. The first mention of the family goes back to Basil the Hawk, a magistrate sent by King Ivan in 1496 on the grounds of Ugra at the head of an army.

Boris's father, Vladimir K. Brajnikoff (*1870 – †1921), was a famous ichthyologist involved in fisheries. After graduating from Moscow University, he was responsible for fisheries in the Far East, then head of the Russian fisheries since 1912, responsible for scientific research and commercial production. For professional reasons, the Brajnikoff family moved to Japan. It is there that they learned about the 1917 revolution. The Japanese, aware of Vladimir's scientific capacities, offered him a professorship at Tokyo University. He spent there the last years of his life, lecturing at the Fish Institute. Vladimir's wife, Ella Eduardovna (*? – †1969) moved to France after her husband's death and then to the United States, where she died.

For 30 years Boris Brajnikoff (Tchoumatchenco P. *et al.* 2014) was a geologist at the Ministry of Mineral Resources and professor at Paris University. He participated in the geological mapping of Brazil and equatorial Africa. From 1931 on, he taught geology at the Instituto de Tecnologia Industrial de Minas Gerais in Brazil. In 1939, he married Eugenia Karlovna Miller (*1907 – †1980), who was the daughter of the History professor Karl Karlovich Miller and the niece of the Lieutenant General of the Northern Russian White Army E.K. Miller. Eugenia Karlovna had lived in Japan and studied art in Italy, where his father was a representative of the Ministry of Trade and Industry in the Russian embassy. She then moved to France where she took to painting and lithography. In 1960, the couple settled permanently in Berkeley (California, USA), where Brajnikoff once worked. We have indications that he was in the United States in 1982, and taught at the Theological Academy. B.V. Brajnikoff published many articles on the topics of geology, petrology and hydrogeology, in Paris, the United States and particularly in Brazil. He also translated the Russian geological literature in English. He and his wife are buried in the cemetery of the Orthodox Monastery of the Holy Trinity in Jordanville, New York (USA).

9. George V. Chilingar (Chilingarian) (*1929, Tbilisi, Georgia, USSR), engineering petroleum geologist, Ph. D., professor (professor emeritus). Emigrated after the October Revolution and the Civil War – first generation. California.

Prof. G. Chilingar, Moscow, 2008

Prof. G. Chilingar, 2011 (Personal Archives)

A native of Georgia, George Chilingar is familiar with, and is honored by presidents and kings. His long and bright life-story is worthy of a science fiction novel. He is one of the best-known petroleum geologists in the world and the founder of several prestigious journals in the oil and gas industry. He is fluent in nine languages, and Russian is his maternal language at the time when he was Gevorg Varosovich Chilingarian –which is the full name of the scientist. Settling in the U.S. he slightly shortened his name while serving in the Air Force, so that his chiefs had no difficulty in pronouncing his name, when he was commanded to jump from an airplane. He said "I always jump first, I really wanted to fly," (Manucharova N. 2008).

George comes from an Armenian-Russian family established in Georgia. His father was a Persian subject who, after graduating in Georgia, returned to Iran to become the Shah's personnal physician. His Russian wife and son were rescued by the Shah, in an exchange for two Soviet spies caught in Iran. George received his primary education in Tehran and in 1940 his family immigrated to the United States, where George graduated in 1950 from the South California University as an oilfield specialist. Four years later he presented his Ph.D. thesis in Geology and Petroleum Engineering. During voluntary military service at Wright-Patterson Air Force in Dayton (Ohio), he headed the petrochemical laboratory. He then returned to the University of Southern California as an assistant, quickly becoming a professor at the Faculty of Petroleum Geology SCU, then head of the oil department (1965).

G. Chilingar made significant contribution to the geology of oil and gas, with emphasis on petroleum reservoirs, petrophysics and sedimentology of oil-gas rocks. His major achievement was the development of a methodology for assessing the rich oil deposits: "The analysis of the Ca/Mg ratio in core samples." This method enabled to discover one of the richest Iranian oil fields, named "Chilingar" after his name. His publications on the geology of the Gulf (Iran, Saudi Arabia), South America, Thailand and Vietnam are well known to geologists around the world. He published 72 books and over 500 articles on geology, petroleum engineering and environmental engineering, which have been translated in many languages, including Russian and Chinese.

At the turn of the 20th century, G. Chilingar collaborated with the Russian petroleum specialist N.A. Eremenko for producing in Russian a global review of the 20th century petroleum geology achievements with recommandations and predictions for its development in the next century. He also worked with petroleum geologist Leonid Alexeyevich Buryakovsky from the Baku Research Institute of the Azerbainjan SSR., before moving to Houston. With L. Khilyuk he published the paper "On global forces of nature driving the Earth's climate" (KHILYUK L. & CHILINGAR G.F. 2006) in which they defended the idea of global cooling instead of warming. His recent research work concentrated on environmental aspects of oil and gas production, petrophysical properties of rocks and drilling fluids, surface and subsurface operations in petroleum production and subsidence due to the fluid withdrawal, testing and storage of petroleum products.

Prof. Chilingar founded two scientific journals: "Energy Sources" and "Journal of Petroleum Science and Engineering", also is a member of the editorial board of the "Russian geology and geophysics" journal. He is the first American petroleum specialist who also is a member of the Russian Academy of Sciences, an honorary professor at the "Gubkin"State University of Oil and Gas. During his visits to Russia, he stressed that "the friendship between Russia and the U.S. is the only way to rescue the two great nations in today's challenging situation."

In his live, Prof. Chilingarian received more than 100 awards and medals, including the award of the Saudi Arabian King for his outstanding contribution to the success of the Saudi Aramco Company. He served as senior petroleum engineering adviser to the United Nations from 1967 to 1969, and then again from 1978 to 1987. He was also an energy policy adviser to California Governor Ronald Reagan in 1973, was an Honorary Consul of the Republic of Honduras in the United States. In memory of his military service, the "Chilingar Medal" was created for cadets and instructors of the U.S. Air Force.

10. MICHAEL CHURKIN JR. (*1932, San Francisco, USA – †? 2009, USA) , geologist , stratigrapher , paleontologist, plate tectonician, Ph.D. Emigrated after the October Revolution and the Civil War –Second generation white emigrant., Alaska, California, Nevada.

Michael's father, Michael F. Churkin (*1901, Russian Empire), his mother Eugenia Churkin (*1903, Russian Empire) and grandmother Fedosya Churkina (*1875, Russian Empire – †1989, USA), emigrated from Russia and settled in the United States, San Francisco , where they took American citizenship (1929). Their son Michael was born in America and received a Ph.D. degree (1961).

M. Churkin Jr. entered the US Geological Survey at Menlo Park, California, beginning with the study of Silurian and Ordovician graptolites from Nevada and Alaska (CARTER C., CHURKIN M. JR. *et al.* 1973), Paleozoic corals of Alaska, then studying the structural development of Alaska in the Precambrian and Paleozoic. He was engaged in the correlation of different facies of Paleozoic tectonic plates along the western boundary of the North American continental plate (CHURKIN M.Jr. 1971), which he traced back to the territory of Siberia, Alaska, with stratigraphic correlations with Eastern Russia. He published more than 20 papers on the above mentioned topics.

11. VLADIMIR DAVYDOV (*1951, Dushanbe, Tajikistan, paleontologist, biostratigrapher, PhD, research professor. Emigrated after WW II. Idaho.

V. Davydov (Personal Archives)

In his last school-year, Vladimir Davydov went on a geological expedition that determined his future career. In 1973 he graduated from the Tajik State University as a geologist. Nine years later, he presented his PhD thesis. He then was engaged in geological survey at the Tajik Geological Department and subsequently as a paleontologist at the VSEGEI Institute in Leningrad. During this period, he participated in geological tours to Austria , Spain, Canada, USA and Norway. In 1995, he was invited at the Department of Geosciences, Boise State University, Idaho, USA, hired as a professor and researcher, teaching paleontology and biostratigraphy. Specialist of Paleozoic foraminifera, Davydov also deals with computer methods of biostratigraphic correlation, chronostratigraphy and radiometric dating of the world's Devonian, Carboniferous and Permian strata. He cooperates with colleagues from the Ural Institute of Geology and Geochemistry in Yekaterinburg , the Institute of Geology in Ufa, the Bashkir Branch of the Russian Academy of Sciences , the Institute of Geology in Dushanbe and Magadan . He is the author or co-author of numerous articles on the Paleozoic stratigraphy, paleontology and tectonics in foreign scientific journals. Vladimir is member of the subcommittee of the International Stratigraphic Commission, member of the Geological and Paleontological Society of America and the American Geophysical Union.

12. JACOB L. DELEVSKY (*1868 Pruzany, Grodno province, Russian Empire – †1957, New York York, USA), petroleum geologist and publicist. Emigrated before the October Revolution. New York.

Jacob Delevsky was a brilliant and highly educated man. In Russia he received distinction diploma in Law and Mathematics-Physics at the St. Petersburg University. Being engaged in activities considered subversive by the regime (he was the publisher of "The will of the people", and reader at the Russian Popular University), he was arrested in 1890 and sent to prison, then in exile in Yakutia and in the city of Grodno.

After his release in 1900, Jacob Delevsky immigrated to France where, following a degree in Mathematics at the Sorbonne, he graduated from the Ecole des Mines de Paris (1904); he engaged in oil exploration in Europe, Africa and Argentina, becoming an expert in the geological study and development of oil fields, publishing in scientific journals. In the years 1924–1935 he was a consultant for oil exploration campaigns in France, Tunisia, Algeria, Spain and other countries. J. Delevsky also was interested in various topics, such as natural philosophy, sociology, Spanish grammar, subjects on which he wrote books. He was an honorary member of the French Astronomical Society, where he gave public lectures.

J.L. Delevsky was also an active and committed journalist, publishing with V.K. Agafonoff, in the years 1908-1909, the newspaper "Revolutionary Ideas" in London and Paris. He also was in charge of the scientific section of the Paris newspaper "Latest News" and a member of a Masonic Lodge. In the years 1927–1937 he was a Board member of the Turgenev Library, and one of the founders of the Russian Scientific and Philosophical Society, writing in literary magazines under the pseudonym Yuri Delevsky. J. Delevsky was married to the revolutionary Marie Semenovna Schaeffer. In 1941, he moved to the United States where he joined the literary society in New York.

13. Paul S. Dvorkovich / Rubin – Pinkhus Zelmanovich (Solomonovich) Dvorkovich (*1858, Lithuania, Russian Empire – †1929, Paris, France , is buried in London); petro chemist, petroleum specialist. Emigrated before the October Revolution, returned to Russia and after then emigarated again – after the October Revolution – first generation. USA (Texas?).

Pavel S. Dvorkovich graduated from the Medical Academy and the University of Moscow. His eventful career includes experiments in biology, officer in the military department , master of pharmacy, contacts with the revolutionaries wanted by the Department of the tsarist police to arrest. In 1887, he lived in Moscow with the noblewoman Nadezhda (? Mihajlovna) Protopopova. In 1890, in association with the merchant Julius Miller, he owned the "Establishments for the Manufacture of Manganese and Salts" close to the Simonov monastery near Moscow.

In 1889 he travelled abroad, living in London in March 1890, devoting his activities to the oil industry. He then travelled to the U.S, Mexico, Romania and Asian countries. P.S. Dvorkovich was a consultant for the Shell Company, founded the Petroleum Institute in England, edited and published the magazine "Petroleum Times". In 1900 he organized in Paris the first International Petroleum Congress, which was attended by eminent experts and industrial businesmen all over the world. He was instrumental in introducing as Honorary President of the Congress the corresponding member of the St. Petersburg Imperial Academy of Sciences, Dmitry Ivanovich Mendeleev, the discoverer of the periodic law of the chemical elements. The Congress awarded P.S. Dvorkovich a gold medal for his contribution to the development of oil exploration.

During the First World War he saved English families from occupied territory, organized the Day of the Anglo-Russian flag and collected 500,000 pounds for the Russian Red Cross society. After the revolution Paul Dvorkovich was appointed chairman of the Chemistry Department of one of the ministries in the government of Soviet Russia. In 1921 P. Dvorkovich emigrated and lived mainly in London. He visited in Paris many times, participated in the organization of oil companies and the creation of laboratories and factories.

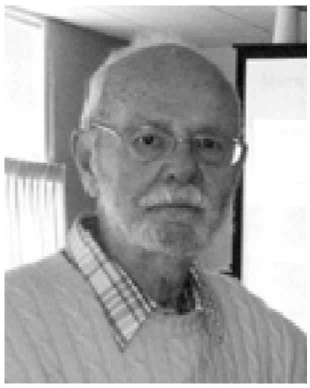
14. Stephen I. Dworkin / Steve Dworkin (* 1959, USA), geochemis , hydrogeologist, petrologist, PhD., Professor. Emigrated after the October Revolution and the Civil War –second generation. Texas.

S. Dworkin (Baylor University: baylor.edu

Steve Dworkin's grand-father emigrated from Minsk, in about 1912. Steve received a geological education from the University of Michigan (1983) and a PhD. from the University of Texas, Austin (1991). He is a professor at the Department of Geology, Baylor University, Texas, engaged in low-temperature and water isotope geochemistry, sedimentary petrology and hydrogeology. His research interests focus on paleoclimatic reconstructions of continental basins on the basis the chemistry of calcite and organic Triassic paleosols preserved in the petrified Chinle Formation in the Arizona National Park, as well as western Texas soils of the Jurassic–Cretaceous boundary.

In his teachings, Professor Steve Dworkin is orginal and very inventive. His students comment on how communicatively enthusiast he is at teaching geology, a charming professor who captures even those who hitherto were not very interested in the subject. Teaching geochemistry in practice is an art which he perfectly masters.

15. Stephen Eugene Dwornik (*1926, Buffalo, United States – †2012, Washington, USA), a soil scientist, geologist, planetary geologist , Ph.D. Emigrated after the October Revolution and the Civil War – second generation. Virginia.



S. Dwornik (Internet: rock.geosociety.org

Stephen E. Dwornik, the son of Polish and Ukrainian immigrants during WWII, served in the U.S. Army. In the 60s he studied changes in soils and vegetation following underground nuclear explosions tests. From 1968 to 1976 he was head of the department of global programs of the Office of Space Science and Technology, and then for 3 years NASA chief planetary geologist, receiveing a NASA award in 1974. After retiring from NASA, he worked at Ball Aerospace, then on the organization of space research at the William and Mary College.

In the 1970s, Stephen Dwornik became concerned that very few American students engaged into planetary science. In 1991, he made donations to the Geological Society of America in support of American students. An award was created for students of American citizenship, the "Stephen E. Dwornik Planetary Geoscience Award Fund", aimed at acquainting students to the problems of NASA and planetary research, addressing the fundamental problems of planetary geology in the broadest sense, including geochemistry, mineralogy, petrology, geophysics, geological mapping and remote sensing, under the supervisions of the Geological Society of America, Planetary Geology Division. The award consists of a medal and a monetary prize, awarded to the best student presentation at the Annual Scientific Research Conference on the Moon and other planets.

16. Edward John Dwornik (*1920? – †2004, Lewes, Delaware, USA), kosmogeolog, mineralogist. Emigrated after the October Revolution and the Civil War – first generation. Arkansas.

Edward J. Dwornik was a descendant of Polish-Ukrainian immigrants. He worked at the U.S. Geological Survey in Washington, concentrating on vanadium deposits. He studied minerals (aragonite, kolbekite, sterrenite) and rocks (mainly primary dolomite) with the electron microscope and X-ray analysis difractometer, participating in the discovery of new minerals (the mackelveyite, etc.). The mineral dwornikite (or millerite, an hydrated nickel sulfate), discovered in 1982, was called after his name:

"We named the mineral in honor of Edward J. Dwornik, mineralogist at the U.S. Geological Survey, who spent extensive studies of vanadium minerals from Arkansas and Peru. The name was adopted by the Commission on New Minerals and Mineral Names at the International Mineralogical Association" (Milton C. *et al.* 1982; Dunn P.J. 1983).

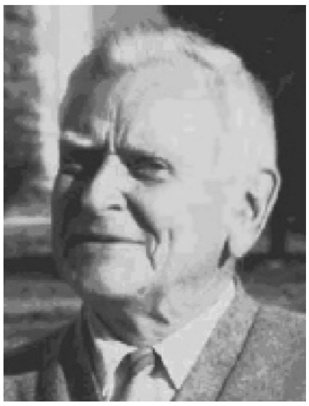
Edward J. Dwornik is also known for his research on the geology of the Moon.

17. Nicholas Antonovich Efremov / pseudonym N. Nizhalsky (*1904 st. Migulinskaya Taganrog district, Russian Empire – †1962, New York, USA), geologist, geochemist, journalist, Dr. Emigrated after WW II. New York.

Nicholas Efremov, the son of a miller, grew up in a wealthy family of the Don Cossacks. He received higher education at the Polytechnic Institute in Novocherkassk. After completion of his studies, N.E. Efremov was hired in Novocherkassk at the Geological Institute of the Academy of Sciences and the Geological Survey of Moscow, participating in surveys in Siberia and the Kazakhstan, the Caucasus and the Urals.

On January 5, 1931, during a wave of persecution of intellectuals, he was arrested for "the cause of the Industrial Party " with a group of professors, many of whom were geologists, including the geologist Peter N. Chirvinsky (*1880 – †1955), the mineralogist and graduated from Novocherkassk Pyotr Petrovich Sushchinskii (*1895 – †1937), the custodian of the Imperial Mineralogical cabinet of St. Petersburg University, and others, on charges of sabotage (concealment of mineral reserves). Efremov was sentenced to five years of imprisonement, the period being reduced to one year. He was sent along with Prof. P. Sushchinskii through Moscow to a camp on the isle of Vaygach at the exploration and mining expedition of the OGPU, at Anderma on the coast of the Kara Sea. In 1930, a camp had been established on the isle of Vaygach, known as the "Vaygach expedition" and later as the "Anderma camp", which was inhabited by 30 geologists. Under the leadership of P.A. Shrubko the Amderma fluorite deposit was discovered, at the time the largest in the USSR. Upon his return from exile he was appointed to the University of Rostov at the Geology Department of Professor V.V. Bogachyov. During WWII, when the Germans occupied Rostov-on-Don, N.E. Efremov was deported to Europe, the end of the war finding him in Germany. After the war he remained as a university professor for "displaced persons" at the UNRRA in Munich, lecturing in Regensburg and Munich at the Ukrainian institutes, moving to the United States in 1950. In America, he lived in New York, engaged in geochemistry and mineralogy (Gul R., 1962), publishing on his material from Russia. He became a member of the American Geological Society, the American Geophysical Union, the American Mineralogical Society and the American Geographical Society, where he made search reports. He also was a member of the Ukrainian Academy of Sciences in New York, lecturing to a public of Russian culture. N.E. Efremov published many scientific and popular articles and essays, authoring about 80 publications on geology, mineralogy and geochemistry in Russia, Germany and the US. In exile, he was known under the pseudonym N. Nizhalsky, speaking as a scientific commentator on radio "Freedom" aimed at the USSR. In 1989, N.E. Efremov was posthumously rehabilitated in Russia.

18. Max Eliash (Eliashevich) (*1889, Minsk, Russian Empire – †1982 Elyans, USA) palaeobotanist, paleoecologist, biostratigrapher, Ph.D. (first generation emigrant).



M. Eliash (Lesnikovska A., 1995)

Max Eliash studied at the Imperial School of Mines in St. Petersburg, where in 1917 he received his degree in mining engineering. He began working as a geologist in the coal mines of the Urals Mining Enterprise, and later wrote several papers on the coal deposits of the Ussuri region. During the Civil War he was evacuated to Vladivostok, fleeing the Red Army on the cargo trains. Here he taught for some time at the Polytechnic Institute, became a member of the Russian Geographical Society, and later moved to Japan, where he stayed but for a short while.

In 1922 he moved to the U.S. and until 1937 worked as a geologist at the Kansas State Geological Survey, taking American citizenship in 1930. In 1938 Max Eliash led a geological expedition in Colombia (South America). A year later, he presented his Ph.D. thesis at Yale University and immediately thereafter began to work in the Conservation and Survey Division of the University of Nebraska, where he worked for 20 years - until retirement. While retired, Max Elias taught at The Research Institute, University of Oklahoma.

19. WACLAW STANISLAVOVICH FEDUKOWICZ (*1897, Wilenskaya gubernya, Russian Empire – †1979, Florida, USA), geophysicist, Ph.D., Professor. Emigrated during the WWII. New York.

W. Fedukowicz (Alexandrov E., 1980)

Waclaw Fedukowicz was born in eastern Poland, later included in the Russian Empire (ALEXANDROV E.A. 1980; FEDUKOWICZ W. 1975). During the WWI, the family Fedukovicz moved to Russia. Waclaw attended lectures at the St. Petersburg Mining Institute, which were interrupted by the revolution and Civil War. In 1924 he graduated from Ekaterynoslav (later Dnepropetrovsk) Mining Institute, working at the same time as laboratory assistant in the Department of Geophysics where he began teaching geophysics after graduation.

In 1930 at the Kiev Mining Institute, he was involved in teaching and research activities, being associate dean of the Faculty of Geology, and editing the Department's publications. In 1935 W. Fedukowicz received a PhD in Physics and Mathematics and the title of professor, then moving to the Dnepropetrovsk Mining Institute. His students subsequently occupied leading positions in geophysics as scientists, researchers and teachers. During the 1930s wave of persecution, his two brothers were arrested on false charges and died in Stalin's camps. Waclaw escaped together with his wife Elena Terentievna Fedukowicz (née Biantovskaja, *1900 – †1998), a prominent ophthalmologist, daughter of an Orthodox priest. In 1938 they could return to Kiev, where Waclaw headed the Geophysical Department of the Geological Institute of the Ukrainian Academy of Sciences and taught geophysics at the University of Kiev.

During WWII and the 1943 German occupation, Waclaw Fedukowicz and his wife crossed through Poland, Czechoslovakia and Austria to Germany. Six years later they moved to the U.S., where Waclaw initially was engaged in the manufacturing of gypsum figures. In 1950 he returned to geophysics, with studies in the U.S. and Canada. Four years later he joined the Lamont - Doherty Observatory at Columbia University (NY), engaged in oceanographic geology and geophysics, teaching at New York University, retiering in 1971. His wife was director of an ophthalmic bacteriology laboratory at New York University, Bellevue Hospital.

Waclaw Fedukowicz published many articles and books on seismicity, magnetic anomalies, gravity surveying, mining maping, physical properties of sea water at great depths. He invented techniques for measuring borehole deviations, gravity and magnetic equipment and geophysical exploration. He was a member of several professional American societies, a participating member in the creation of the Academic Russian Groups in the United States.

20. CHARLES AUGUST FELDVEBER / CARL TANNER (*1897, Valga, Estonia, Russian Empire – †1983, California, USA), mining engineer. Emigrated during WW II. California.

Charles was the son of a German farmer living in Estonia, and thus belonged to the Russian Empire. He studied at the St. Petersburg (then Petrograd) Mining Institute in Russia (1915–1918) as opportunities to qualify in this field in Estonia did not yet exist. In 1920, Charles joined the Estonian army and fought for the liberation of Estonia. He then studied at the Royal Technical College and the University of Glasgow (Great Britain). After graduation in 1922 he returned to Estonia. The oil production in Estonia was still in its infancy. Charles Feldveber began his successful career, during which he introduced many new and original methods in the mining industry. He organized training seminars for the mining industry, which later became the Mining School in Jõhvi, Viru County, the first geological survey school in Estonia. Carl was also a lecturer at Tallinn Technical University for six years (1938–44). In 1944, he emigrated during the WWII with his wife and three children. In exile, he lived until 1950 in Germany before settling in the United States (Los Angeles), where he changed his name to Carl Tanner. In the U.S., as an engineer, he participated in the construction of roads and tunnels. He took an active part in the life of the local Estonian community.

21. XENIA G. GOLOVCHENKO (*?1947–52? Liege, Belgium), marine geologist, stratigrapher, geophysicist. Emigrated after the October Revolution and the Civil War –third generation. New York State.

X. Golovchenko (Alexandrov E., 2005)

Xenia's mother, Zinaida Fyodorovna née Kostin, and his father, an industrial civil engineer named Georgy Golovchenko

(*1926 – †2011) from Brest (a town, which, during the period 1915 to 1939 passed from hand to hand, alternately belonging to Russia, Ukraine and Poland). Her parents settled in Prague, and after WWII, moved to Germany then Belgium, Xenia's country of birth, and finally in the US (1954). Xenia went to college in New York, and began higher education at the University of Delaware, majoring in geology at Columbia University (NY). In 1976–77, she taught for two years at the stratigraphy department of the Santiago de Chile University's Geological Faculty, studying the free gas at the base of the gas hydrate zone near Chile (Bangs N.L.B. *et al.* 1993). Upon returning to the United States she entered the Lamont - Doherty geological and oceanographic laboratory magnetism department (Columbia University). In 1981 she engaged in stratigraphy and petroleum geology of coastal and marine basins at Marathon Oil Company, returning to Columbia University in 1986. X.G. Golovchenko published more than 15 books and articles dealing with tectonic and geological maps of the Pacific continental plates and ocean floor, Cenozoic sedimentation in the basin of the Black Bahama, the effects of sea level fluctuations on the Atlantic Ocean continental shelf, the Antarctic and other mountain ridges. At to the present time she is editing geological books.

22. Alexey G. Goncharov (*1958, Shakhty village, Rostov region, Russia), geophysicist, PhD. After WW II. Wyoming.

A. Goncharov Linkedin.com) pub/alexey-goncharov/70/3b5/3b8)

Alexey's parents are the geologists Gennady Goncharov and Svetlana Askoldovna Chirwa. During his school years Alexey already accompanied his father on geological expeditions to various remote areas of the USSR. Their house was frequently visited by prominent geologists, such as the stratigrapher and paleontologist M.S. Mesezhnikov, the petroleum geologist N.G. Chochia, the tectonician A.N. Hramov, etc. Alexey choose to study geophysics, which brought him to the Geophysical Department of the Leningrad Mining Institute after G.V. Plehanov, from which he graduated with honors in 1980, majoring in "Structural geophysics." Alexey taught and was engaged in research on deep seismic sounding at the Department of Geophysics of the Leningrad Mining Institute. In 1989 he presented his thesis on "A seismic model of the mantle transition zone of the lower crust of the Baltic Shield". In 1986–1987 he participated in seismic expeditions of the USSR Academy of Sciences in Iceland.

In 1993 Alexey Goncharov was at the University of Wyoming (USA) on a joint Russian-American project on seismic crustal drilling in the Kola super-deep well area. In 1994 he moved to Australia, hired in the Australian Geological Survey, subsequently Geoscience of Australia, Cambera Area. At the moment he is Principal Research Scientist, Innovation and Specialist Services Group, Energy Division. A.G. Goncharov is mainly engaged in deep crustal studies of the structure and foundation of Autralia's crust. Part of this project included pioneering research on factors regulating the sublimation of hydrocarbons, whose results are now widely used by oil and gas companies. Goncharov is author and co-author of 50 scientific articles and abstracts of scientific conferences. He also participates in Russian joint projects on geophysical studies of the Antarctica continental margins, in relation with the Institute of Geophysics of the Ukrainian Academy of Sciences. He also maintains contacts with Russian oil and gas companies, attracting them to work in Australia and gain access to Australian high technology in geology and geophysics.

23. Paul P. Goudkoff (*1881, Yenisei Province, Russian Empire – †1955, Los Angeles, USA), geologist, paleontologist, petrographer, mineralogist, Ph.D., Professor. Emigrated after the October Revolution – first generation.

P.Goudkoff (VinichenkoP., 2008)

Paul's father was Paul Kozmich Goudkoff (*1850 – †1908) (Berdnikov L.P. 1995), merchant and lord- mayor of the town of Krasnoyarsk. Paul Kozmich was born in Samara province. He was employed as a mechanic in St. Petersburg, and in 1871 he was hired in the Udereysky gold mine in the South Enisei taiga. Paul grew up among the miners and became interested in geology. He was graduated in 1907 from the St. Petersburg Institute of Mines. His ph.D. thesis was on the copper deposits of Akmolinsk, with a dissertation on the volcanic rocks of Turkestan. At the invitation of Professor V.A. Obruchev, he started as a senior laboratory assistant in the Mining Branch of the Tomsk Technological Institute. In 1914, he was a professor in the Department of Geology of that institute. From 1917, as a researcher and professor of geology and petrography of the University of Vladivostok, he taught and guided the exploration for gold and iron deposits in Siberia, Altai and Mongolia (Falk A.U. 1996, 2001). "P.P. Goudkoff was a cheerful and charming man who quickly got on with people. He was loved by his students, friends and colleagues for his intelligence, sociable nature and humor" (Vinnychenko P.Y. 2008). In 1914 he published the monograph "Turkestan". In 1919 he headed the Department of Trade and Industry of the West Siberian Department of the Provisional (White Russian) Government of Autonomous Siberia in Tomsk.

In 1921, P.P. Goudkoff led a delegation to Washington, sent by the Vladivostok Chamber of Commerce, and remained in the United States, not daring to return to Soviet Russia because of his participation to activities of the Provisional Government. He became one of the leading petroleum geologists in this country, was a member of five academies of sciences and scientific societies. Goudkoff was for many years the chief consultant for oil of leading oil companies in the U.S. and Mexico.

In 1922 he became a member of the American Geographical Society, went to New York with his wife and daughter, where he taught courses in Siberian geology and mining at Columbia University. In March 1923, P.P. Goudkoff came to California and engaged in studies of the geology and petroleum potential of San Joaquim Valley. Three years later he opened his own consulting office in Los Angeles, specializing in the study of the microfauna and stratigraphy of the Upper Cretaceous, including that of the Great Valley in California, preparing the groundwork for oil drilling. In 1942 he edited and published data on Costa Rica. He was one of the founders of the Society for Economic Paleontology and Mineralogy. In 1951, his firm joined the Hughes firm and became "Goudkoff and Hughes", where he worked as a consultant until his death. P.P. Goudkoff is the author of about 20 scientific papers mainly published in the Bulletin of the American Association of Petroleum Geologists (AAPG), including the mineralogy and geology of the USSR.

From America he maintained a permanent correspondence with the academician V.A. Obruchev, the only one who ventured to write to him. He died during an operation which was considered non-hazardous.

24. Serguei Goussev (*?1951, Russia), geophysicist, petroleum geologist. Emigrated after WW II. Texas.

S.Goussev (Internet: yatedo.com)

Sergey Gusev graduated in geology and geophysics from the Moscow State University in 1974 and was engaged in Russian geophysics for more than 20 years. During the 1996 to 2006 period he was engaged as a geophysicist in the Geophysical Research Corporation and Development (GEDCO) in Calgary, Alberta (CDN). His activities included the collection, processing and interpretation of data from extensive seismic surveys, geology, remote sensing. Since 2006 he is a consultant senior geophysicist for gravity and magnetism at Fugro Gravity & Magnetic Services in Houston (USA), notably employed in developing geophysical methods for studies of the Mackenzie River delta. At the same time he develops his own service system for petroleum geology.

S.A. Gusev is a member of the Association of Professional Engineers, Geologists and Geophysicists of Alberta (APEGGA), the Society of Exploration Geophysicists (SEG), the American Association of Petroleum Geologists (AAPG), the Houston Geological Society (HGS). He is the author of proprietary technical inventions (2002, 2004), the author or co-author of 16 publications and public appearances related to the magneto-gravitational interpretation of data. In 1997, he developed the technique of data processing known as a "Goussev filtering".

25. Eugene De Hautepick captain / Капитан Евгений Х. де Отпик (* 1880 or 1886 Russian Empire – †after 1929, Adelaide, Australia), geologist.

Captain E. de Hautpick (D. Branagan, 2008)

Eugene de Hautepick descended from a noble French family who left France to settle in Russia. His birth date is uncertain: 1880 (Branagan, 2006) or 1886 (Vallance, 1995). Eugene studied at the School of Military Engineering in Petrograd and published articles on oil, radioactive elements and gold in Siberia and Mongolia (1910–1913). In the period 1914–1916 de Hautepick was an officer in the 8th Army under General Brusilov in Galicia and Romania, where his regiment occupied the Romanian oil wells. He then lived in Odessa in 1920 and left for a year and a half in Constantinople. Records show that he studied at Columbia College in New York and at the Ohio University and subsequently worked in the oil fields of Pennsylvania, Virginia and Ohio (USA). He was a correspondent for the Mining Journal in the UK, where he published several articles on the economic geology of radium. On the recommendation of the Mining Journal in London, the publisher E.B. Scott prompted de Hautepick to go to Australia where there was a demand for oil specialists. In Tasmania, he was warmly welcomed by officials and politicians, but unfortunately not by local geologists. He wrote several articles on the origin of Tasmanian oil, but his colleagues accused him of plagiarism. Eugene de Hautepick (Branagan D. 2006; Tchoumatchenco P. *et al.* 2014) then turned his attention to the Coorong in South-Eastern Australia, where many oil fields had been discovered. De Hautepick guessed that the origin of the oil was to be found in the highly developed peat swamp areas and made drilling recommendations with this intention, subsequently moving to Western Australia. In 1922–1924, he synthetized his work and prepared a general map of petroleum deposits in Australia and then left the country, settling in Paris in 1925. On May 1st 1926 he explained his theory about the influence of microorganisms in the genesis of oil at the French Geological Society. At that time, the geophysical methods are widely used in mining and oil exploration. E. de Hautepick returned to Adelaide in 1927 to present a new radiometric method for the detection of metals and oil (1928, 1929). Captain Eugene H. de Hautepick was one of the most eminent geologists of his time. He is the author of over 50 scientific articles.

26. LOUIS HUSAKOV / LOUIS HOUSSAKOFF (*1897, Kiev, Russian Empire – †1965 New York USA), geologist, paleontologist, paleozoologist. Emigrated before the October 1917 Revolution. New York State.

Louis Husakov was born in Russia in 1889. He arrived in the U.S., possibly with his mother, one year after his father had moved, becoming an American citizen in 1906.

In 1912 his name is mentioned in the list of employees and graduates of Columbia University, King's College. There also is mention of him in the US Army archives, doing service during WW I (1917–18) and WW II (1942).

Louis Husakov lived and worked in Canada and the U.S., notably including the American Museum of Natural History in New York. He studied the fossil fish of Japan and North America (Arthrodira, Dipnoi, Cretaceous Chimeroides, and others), also studied the special instances of modern fish, for which he accompanied the fishermen when fishing. He published his collections from Canada, Syria, Congo, West Indies, Japan and America. He was in correspondence with the famous Russian academician A.P. Karpinsky (writing in 1912).

27. VLADIMIR G. INGERMAN (*1940, Essentuki, Stavropol region, Russia), geophysicist, petrophysicist, PhD., Dr. Sc. Emigrated after WWII.

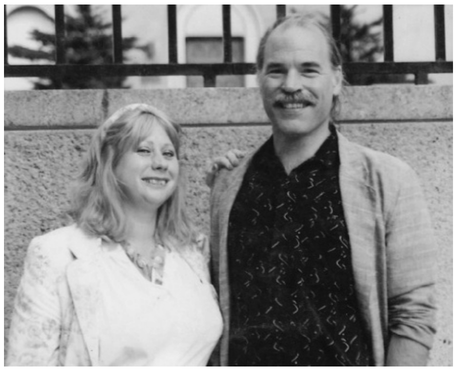
V. Ingerman (Familial archives)

Vladimir graduated in 1961 from the Grozny Petroleum Institute as a geophysicist. In 1962 he headed geophysical expeditions in South Tajikistan. He presented his Ph.D. thesis in VNIIGAZ on the development of oil fields. Later he received the degree of Doctor of Technical Sciences at the Institute of Petrochemical and Gas Industry in Moscow (computerized log interpretation). Between 1969 and 1990, Vladimir worked in Tyumen at various positions from the head of the laboratory SibNIINP to Vice President Zapsibneftegeofiziki.

In 1990 V.G Ingerman was invited by the firm Halliburton and his family moved to the United States. This was the first contract between the employee of Minnefteprom and the American firm. In 1994 he organized and led the corporation AMROS (America Russia) to facilitate the implementation of business between the two countries' oil companies. At the present day he is the owner and manager of AMROS. Vladimir has extensive international experience in evaluation of carbonate reservoirs of hydrocarbons and non-traditional interpretation of well logs: in all areas from the research to their implementation, he worked in Tajikistan, Russia, India, USA, Mexico, Venezuela and Denmark. He currently lives and works in the United States and has published more than 47 scientific publications (books and articles). In his spare time, Vladimir enjoys playing tennis and music. Friends describe him as an outgoing, congenial and friendly person.

28. CRISTINE MARY JANIS (*1950, London, UK), palaeobiologist, zoologist, paleontologist Ph.D., Professor of biology, widow of the late American paleontologist of Russian-Polish origin Jack John Sepkoski. Third generation emigrant before the October Revolution. Massachusetts.

Christine Mary Janis (Personal archives)



Christine Mary Janis with J.J. Sepkoski (Personal archives)

Cristine Mary's great grand-father, Jacob Koslovski, a Polish Jew, immigrated to England in the late 19th century with his family. They adopted the name Jacobs, and later Janis (personal letter, 2012), in memory of the two theater actresses of the family. Her grandmother's family is a mix of Russians, Germans and Lithuanians. Her mother came to England from Estonia in 1938. During her childhood Cristine Mary was fascinated by zoology and it was clear for her that she would follow that way in the future. She graduated from Cambridge University, UK, then majored in vertebrate paleontology and in 1979 received a doctorate in Paleobiology at Harvard University.

Since 1989 C.M. Janis worked as a biology professor at Brown University, Providence, USA. C.M. Janis was married to the late Jack Sepkoski with whom she worked for many years. As a biologist and paleontologist, her interests lie in the ecology, morphology and evolution of the Eurasian large mammals from the past 25 million years, essentially specializing in large herbivorous hoofed mammals, drawing comparisons with United States mammals of the same epoch. She also was interrested in the evolution of the North American fauna from the Miocene savanna. This allowed her to track changes in communities over time, thus provinding information on the rate and mode of climatic and environmental changes.

C.M. Janis also edits the scholarly works of other authors. She was awarded the George Gaylord Simpson on paleontology and Elizabeth H. Leduc Award for outstanding achievements in teaching biology. She also is a member of many scientific societies, has published more than one hundred scientific papers. Cristine Mary Janis has dual citizenship, from the U.S. and UK.

29. Wenceslas S. Jardetzky (*1896, Odessa, Russian Empire – †1962, Elkins, USA) - astronomer, geophysicist , Ph.D., Professor. Emigrated after the October Revolution and the Civil War – first generation. New York.

Wenceslas' father, Sigismund Viktorovich Jardetsky was of a noble Polish family and his mother Maria, née Kudryavtseva was of Russian origin (Ermolaeva N. 1986; Jardetzky O. 1986). In his youth, Wenceslas was fond of music and mathematics, giving preference to the latter for bread-earninig. In 1917 he graduated from the Physics and Mathematics Faculty of Novorossiysk University in Odessa, then, went to Petrograd, where he was hired as an assistant at the Pulkovo Observatory. His first scientific work was devoted to the spectrum of the star Vega.

In 1918–1920, while on vacation in Odessa, and suddenly finding himself in the territory of the White Army, Wenceslas Sigizmundovich took this opportunity to immigrate to Yugoslavia. There he lived in Belgrade, working under the guidance of Professor Milutin Milankovitch, on theoretical and celestial mechanics and theoretical physics. Wenceslas was the secretary of the Russian Research Institute in Belgrade. Becoming a doctor in 1923, he worked from 1926 as associate professor, and later as a Professor in Belgrade University (1929). In 1933, he published in Belgrade his book "Hydromechanics", followed in 1935 by the monograph "Mathematical studies of the evolution of the Earth" and in 1940, "Theoretical Physics". After WW II Jardetsky moved to Graz in Austria, where from 1946 to 1947 he acted as Director of the Institute of Physics and Astronomy, and in 1947–1949 - lectured in Geophysics at the High Technical School in Graz.

In 1949 he moved in the United States with his family, living in New York and doing research at the Lamont - Doherty oceanographical and geological Observatory at Columbia University, studying the propagation of seismic waves in the Earth's crust (Ewing M. *et al.* 1957). From 1951, he has also lectured on mechanics at the Manhattan College. Wenceslas spent much energy in the drafting of scientific journals, which he carried on after retirement, spending the last years of his life in translating Soviet journals for the American Geophysical Union and on a project for closer international relationships in the field of geological sciences.

In his spare time, Wenceslas fond of fencing and football and was a good chess player. In 1927 he married Tatiana Taranovsky, daughter of Professor F. Taranovsky, an historian of Slavic law, who had emigrated from Russia and was working at Belgrade University.

30. Angela S. Jayko (*?1953, USA?), geologist, tectonician, Ph.D. Emigrated after the October Revolution and the Civil War – third generation. California.

A. Jayko (Internet:hgy.cdut.edu.cn)

In 1974–1976 Angela Jayko studied at Humboldt State University in Santa Cruz California, where she received a bachelor's degree and Ph.D. doctoral degree. She is employed at the US Geological Survey, UC White Mountain Reasearch Station, California, and a lecturer at Virginia University, Wellington, New Zealand. A. Jayko concentrates on the effect of regional tectonics on the sedimentation processes and the geographical landscapes (geomorphological processes), over short or for long timescales. She produces maps of tectonically active regions and volcanically active fault zones. In addition, she is engaged in establishing links between tectonics and the ground/geothermal waters and other geomorphologic systems, being also very active in environmental problems. A. Jayko participated in joint projects on tectonically active regions in China. In 2006 she was accepted as a member of the Geological Society of America, GSA, and is author of about a dozen scientific articles.

31. George P. Kanakoff (*1897, Simferopol, Russian Empire – †1973, Los Angeles, USA), paleontologist. Emigrated after the October Revolution and the Civil War – first generation. California.

George Kanakoff descends from a Russian - Tatar family. In 1914 he graduated from Emperor Paul 1st Military Academy in St. Petersburg. In 1915, he specializes in Middle Eastern languages at Kharkov University's Historical-Philological Faculty. During WWI and the Civil War, he was an artillery officer and pilot, escaping from Russia through Turkey in November 1920. Three years later, 26-year-old George arrived from Constantinople to Ellis Island, moving in 1929 to Los Angeles (USA) working as an unskilled laborer.

In the 1950s George Kanakoff studied Cenozoic invertebrate paleontology, publishing in the journal of the Academy of Sciences of Southern California and the Natural History Museum of

G. Kanakoff (Internet: torranceca.gov)

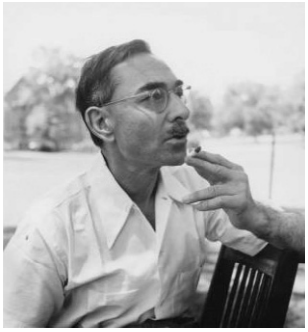
Los Angeles (1953–59). At 1955, in spite of his lack of specialized education, he became the curator of invertebrate paleontology at the Los Angeles National Museum, traveling tirelessly in the field, collecting and augmenting the museum's collection. After retiring in 1966, George Kanakoff (Wilson, 1973) continued to investigate Pleistocene marine life in Southern California. He spoke ten languages and worked as a translator in the State Department. For many years he taught foreign languages, demonstrated superb examples of Russian calligraphy, elevating it to the level of art. He has written numerous articles in the field of philology, military affairs, zoology and paleontology. Until the last days of his life he published in a Russian magazine, helped the poor, kept an interest in theater, culture and science

32. Vitaly Khalturin (*1928, Russia – †2007, Palo Alto, CA, USA), seismologist, PhD., spouse Tatyana Glebovna Rautian. Emigrated after WW II. California, New York State.

Vitaly Khalturin, a seismologist of worldwide reputation, was, in the opinion of his colleagues, a wonderful companion, a cheerful and kind person. Vitaly , graduating in 1951 from the Physics Department of Leningrad State University in Geophysics, worked at the Geophysical Institute of the Academy of Sciences of the USSR until 1992, managing the Garm geophysical station in the village of Garm, Tajikistan, also preparing national senior seismologists.

After moving to the U.S. in 1993, Vitaly Khalturin and his wife entered the Lamont-Doherty Obervatory (Columbia University) with prof. Paul Richards, to study the seismicity of weak underground nuclear explosions, which had not been previously discovered and were unknown to Western seismologists. Vitaly Khalturin himself said: "Paul looked with amazement as Tanya, using a rope loop and a stick (because such large compasses did not exist) defined the epicenter at two stations, without a computer! When after a few years' studies, weak explosions epicenters were located, it turned out that her miss was of no more than 1 km, at a distance of 700 km. Paul was just shocked". Vitaly Khalturin and his spouse then went to the University of California at Berkeley and staged scientific work-shops, signed temporary, often interrupted contracts on translations and consultations. In the last years of his life Vitaly carried-on research, collaborating with American seismologists from Lamont Observatory until 2005. To the Global seismological community, he is known for his research on the seismic records of nuclear explosions, defining the characteristics of the wave patterns at various epicentral distances, assessing explosions's energy and earthquakes.

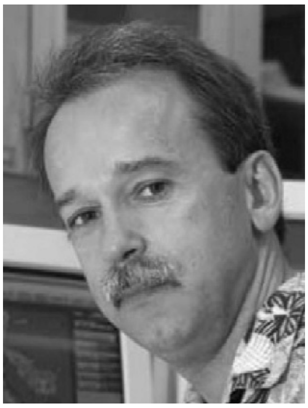
33. Ervand Gevord Kogbetliantz (*1888 Nakhichevan-on-Don, Russian Empire – †1974, Paris), mathematician, geophysicist, Doctor in Physical and Mathematical Sciences, Professor.



E. Kogbetlianz (1944) (Internet:Wikisysop2007, ru.hayazg.info)

Ervand Gevorgovitch Kogbetlyantz was a famous math teacher who worked in Europe, Asia and America. Geophysics was his second passion, by which he left his mark with the invention of the gravimeter, patented in the late 1920s. He was a cousin of the famous poet Marietta Chahinian. Ervand was the son of the merchant Gevorg Melkonyanovitch Kogbetlyantz and Aegina Akovbyan, both of Armenian Gregorian religion. He began his studies at the Faculty of Mathematics at Paris in 1906 (Mnouchine L. *et al*. 2008; Tchoumatchenco P. *et al*. 2014), then he returned to Russia where he settled with his aunt in Moscow. He graduated from the Faculty of Physics and Mathematics at Moscow State University and became assistant professor in 1915. In February 1911, when a student, he presented a request for marriage (students were not allowed to have a family), which was granted. In 1917, in search of work, he went to Ekaterinodar (Krasnodar) in the Kuban, and taught at the University. In 1920, pushed by the Civil War troubles in Ekaterinodar, he moved to Armenia with a professorship at the University of Yerevan. In Yerevan, Ervand Gevorgovitch was caught again by the riots and moved to Paris, engaged in teaching mathematics at the University of the Russian People and the Sorbonne. In 1923 he received the degree of Doctor of Science at Paris University and subsequently developed an interest in geophysics (1930). In 1933 he taught for six years at the University of Tehran, receiving the Order of Iran "For merits in the field of Science". After a short stay in Paris at the CNRS, he left for the United States in 1941 as a professor at the New School for Social Research in New York, being also involved with other universities: Lehigh University in Pennsylvania, Rockefeller and Columbia in New York. In 1945–1946 he was a consultant in geophysics at Standard Oil. Upon retirement in 1968 he returned to France. E.G. Kogbetlyantz extensively published in mathematics and geophysics. He also invented (1918) the three-dimensional chessboard, consisting of six superimposed chessboard levels each containing 88 squares. In this game, the pieces can be moved in both horizontal and vertical directions.

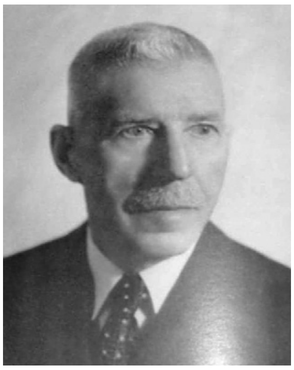
34. Alexander N. Krot (*1959, Russia), geologist, cosmochemist, research professor). Emigrated after WW II. Hawaii.



A. Krot (Internet:psrd.hawaii.edu)

Alexander graduated from Moscow State University. At present he is a researcher at the Hawaii Institute of Geophysics and Planetology at Manoa (Hawaii, USA). He is one of the greatests specialists of meteorites. From their chemical composition, he tracks the origin of the solar system. He contributed to disproove that the Antarctica meteorite ALH 84001, presumably originated from Mars, contained traces of life, contrary to the hypothesis. In it, he found a new 4.5 Gy old mineral which was named after him, the Krotite. Alexander Krot published more than 120 research papers.

35. Ivan Kulaev (*1857, Krasnoyarsk, Russian Empire – †1941, San Francisco, USA), gold mines owner, metallurgist, builder, merchant and financier. Emigrated after the October Revolution and the Civil War – first generation. California

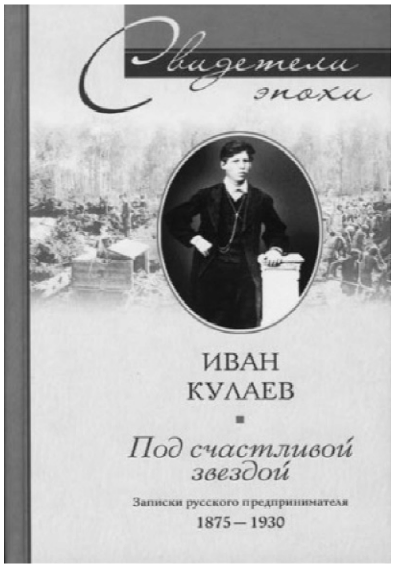


I. Kulaev (Internet:kraevushka.livejourn)

Ivan Kulaev (Kulaev I. 1999; Borsov N. 1947) was the son of a peasant - entrepreneur who was exiled to Siberian penal servitude. At age 16, Ivan started establishing commercial enterprises, becoming a second guild merchant, one of the founders of the Novonikolayevsk-based "Altai factory and industrial company", also founder of the "Russian flour partnership" based in Harbin. Ivan immigrated to China, where he developed charitable activities in Harbin and Shanghai, as well as in Europe and the U.S., providing generous assistance to Russian immigrant students. In 1930 he founded in San Francisco (CA), where he lived for more than 20 years, the "Kulaev Awareness Charitable Foundation",

I. Kulaev and spouse (Internet:museum.nsk.ru)

still active to this day. He invested $ 250,000 to help funding the Krasnoyarsk University, after the fall of Bolshevism. In 1998, this fund presented the State Scientific Library of the Krasnoyarsk region with about 1,000 books authored by Russian emigrants. Kulaev's fund also supports elderly Russian immigrants abroad, as in Bulgaria for Christmas and Easter, when the fund money is spent on food brought to elderly Russian, also including Russian



The book of I. Kulaev (Internet:bookefinder.su

nuns in the Sofia monastery, so they feel remembered and taken care of. I.V. Kulaev published a book describing part of his life in bold pursuit of happiness in the Russian tundra mines, how one day he sunk under the Yenisei ice, how he survived the so-called

Chinese “Boxer Rebellion”, his memories of the Russian-Japanese War, WWI, the revolution, the nationalization of private property, the kidnapping of gangsters ... “As for America ... I can only be happy for our Russian immigrants there. Fate has thrown them into this blessed, sister country were the same Russian spirit prevails, with a feeling of spaciousness and illimited freedom of undertaking. You can adapt to any choice, anywhere, all sectors of activity are open to you. You can grab everything from life that you manage to take. True, the competition is hard, as it used to be in the old days' Russia. A lot of Russians ... in America, and so many figures that created their enterprise with their skills. Many examples of this exist. Former Professor at the Tomsk Technological Institute, Paul Goudkoff opened an office for chemical exploring of oil rocks in the City of Los Angeles, at the center of American oil fields. He worked for several years with two Russian engineers, helping the small American oil owners” (KULAEV I.V. 1999).

36. DIMITRI PAUL KRYNINE (*1877, the Russian Empire – †? 1967–70, USA), engineer, petrographer. Emigrated after the October Revolution.

D. Krynine and son (Big Spring Daily Herald” 1931)

Dimitri Paul Krynine worked as an engineer in the building of the Trans-Siberian railway. In 1909 his family (BATES T. & GRIFFITS J. 1971; FOLK R. & FERM J. 1966), including the young son Paul, traveled to Buenos Aires, where he participated in the construction of railways. In 1917 the family Krynine returned to Russia. Around 1931 Dimitry Krynine (with his son but without his wife) again left Soviet Russia, this time for the United States, in order to teach the mechanics of the Earth at Yale University. His wife Raisa Krynine, the mother of Paul, was only allowed to receive financial help until her death in 1940, but not to join her husband and son. The further life of Dimitri Krynine is closely associated with the life of his son Paul.

37. PAUL DIMITRI KRYNINE (*1902, Krasnoyarsk, Russian Empire – †1964, Pennsylvania, USA), mineralogist, petrographer, PhD., professor, son of Dimitri Krynine. Emigrated after the October 1917 Revolution.

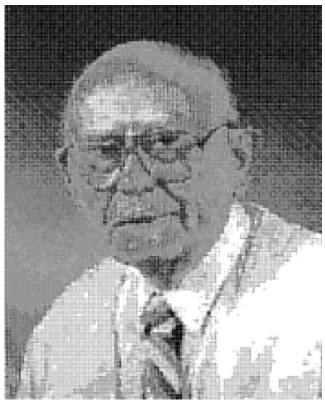
In 1924, Paul Krynine graduated from the Geological Faculty of Moscow State University and thereafter emigrated to the U.S. (BATES T. & GRIFFITS J., 1971; FOLK R. & FERM J. 1966), where in 1927 he graduated from the Faculty of Geology of the University of California. With the “Standart Oil Company of California” he did field work in the tropical jungles of Mexico until 1931. After arriving in the United States Dimitri and Paul, father

P.D. Krynine (The American Mineralogist, vol. 56, 1971)

and son together, were engaged in the petrological study of sedimentary rocks, and together with the mineralogist Adolf Knopf, their mineralogy. In 1936 Paul presented his thesis at Yale University. In 1937, he was appointed professor of geology, head of the Department of Mineralogy at the University of Pennsylvania. As a result of his studies of graywacke, dolomite, limestone and sandstone, he brought forth the so-called “Krynine Classification” (KRYNINE P. 1940–1946), which, together with F.J. Pettijohn's work, (1948) was instrumental in establishing the modern classification of sedimentary rocks.

Paul Krynine was an outstanding researcher, involved in sedimentology, petroleum geology, structural and Quaternary Geology, and in formulating his new theory on the formation of oil traps. His research topics include the geosynclinal sedimentation cycles, the relations between diastrophism and sedimentation in connection with the origin of red rocks. He devoted the last years of his life to the philosophy of science, dealing with the history of geology and of scientific methods in geology. In addition, he was also interested in mathematic geology, Greek philosophy, and spoke several languages. Paul Krynine was an excellent teacher, especially appreciated for his polemical discussions with students and colleagues, and the author of over 75 scientific papers.

38. JOHN A. LEMISH (*1921, Roma, NY, USA – †1998 Eymes, USA), geologist, Ph.D., professor and professor emeritus. Emigrated after the October Revolution and the Civil War –second generation. Utah, Iowa, Michigan



J. Lemish (R. Anderson, D. Bunker, 1998)

John Lemish was born close to New York city in an U.S.- expatriated peasant family from Russia. His parents were Adam Lemish (*1878 – †1957) and Anastasia Lemish (née Kisilevich /? Kisileva). During the years 1943–1945, J. Lemish served in the US Airforce in a B-17 bomber, participating in 29 combat missions over Germany; as a veteran of the war, he was awarded the "Air Medal with Oak Leaves".

Back from the US Airforce in 1945, John graduated as a geologist from the University of Michigan (Bachelor 1947; Master 1948; Lemish J. 1974; Anderson R. & Bunker D. 1998; Raymond R. 1998). In 1955 he presented his PhD thesis on the geology of mineral deposits (Economic Geology). John then worked for three summers as an instructor at the University of Michigan, and along with the U.S. Geological Survey geologists in Utah. In 1955-1959 he was an assistant professor at Iowa State University, majoring in economic and structural geology and geochemistry, becoming associate professor, and since 1962, professor of geology at the Iowa State University in Ames. In 1960, John and his wife Jane Lemish also graduated from the University of Michigan and wrote the book "Jeff Carson, young geologist" (Lemish J. & J. 1960) as a hymn to geology, describing a fictional "hero" of geology.

J. Lemish delt with coal basins, economic geology, sedimentary geology (Diebold F., Lemish J. & Hiltrop C. 1963), oceanography, paleontology, optical mineralogy, structural geology, engineering geology and petrology. In 1991, when he retired, he was awarded the title of "professor emeritus". John Lemish often conducted field trips with students and colleagues from the Geological Society of Iowa, during which repeatedly emerged scientific discussions (Diebold F., Lemish J. & Hiltrop C. 1963).

John Lemish is author of about 20 articles in geological journals. He was a member of the Minerals Council of the Governor of Iowa, a senior member of the American Geological Society (USGS), a member of the Society of Economic Geologists, American Association of Petroleum Geologists (AAPG), the American Institute of Mining Engineers, chairman of the Committee on transfers at the American Geological Institute, was a member of the Russian Academic group (RAG) in the United States. John Lemish died from complications of Parkinson's disease at age 77.

39. Vadim Levin (*1966, Moscow, Russia), geophysicist, seismologist, volcanologist, Ph.D., associate professor. Emigrated after WWII.

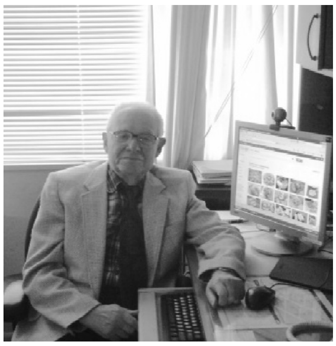
V. Levin (Familial archives)

Vadim Levin graduated in 1988 from the Moscow Institute of Petrochemical and Gas Industry, colloquially called "Kerosina" by the students. He received an engineer - geophysicist degree, specializing in seismic methods for prospecting and exploring minerals deposits.

In 1988 Vadim emigrated to the U.S. and the following he was hired as a laboratory assistant at the Department of Seismologic Research in the Lamont-Doherty Geological Observatory at Columbia University in New York. In 1990 he was a graduate student at the Department of Geological Sciences at Columbia University, where in 1996 he received his Ph.D. in seismology. He was awarded the annual Bruce Heezen Prize for his postgraduate work at Columbia University. After spending seven years at the Faculty of Geology and Geophysics at Yale University, Vadim became an assistant, then an associate professor in the Department of Earth and Planetary Sciences at Rutgers University.

His research interests cover geodynamics, structure formation in the lithosphere, seismology, earthquakes and volcanoes. He often participated in, or processed material from expeditions in many regions of the world, including Iceland, Alaska, the Arctic, Kamchatka, the Northern Apennines, Costa Rica, the Arabian Peninsula and Western Tibet. In collaboration with scientists from around the world, including Kamchatka geologists, he participated in more than 50 publications on the origin and evolution of the continents , plate tectonics and the dynamics of the upper mantle, seismological research methods pertaining to tectonic structures and textures of the Earth, and other related topics.

40. Mark G. Leybson (*1929, Baku, Azerbaijan), geologist, PhD, DSc. Emigrated after WW II. Maryland.



M. Leybson (Personal Archives)

As a child, Mark Leybson was fond of music and learned to play the violin. But who lives in Baku, knows how the oil production dominates over all. This played a role in the fate of Mark. As he says, his professionnal choices were influenced by the proximity of oilfields, the desire to acceed to higher education and an interest in overcoming difficulties. Upon completion of college, he studied at the Industrial Institute in Baku, and then transferred to the Grozny Oil Institute, where he received his Mining Engineer for exploration and development of oil and gas deposits diploma in 1954 with honors. He started his professional activities at the department of theoretical mechanics and underground hydraulics.

In 1957, Mark was invited by the Sakhalin economic council to work in the Sakhaline oil industry and in the Sahalinneft association Central Research Laboratory. He was involved in the physico-chemical properties of oil and reservoirs in Sakhalin, drafting development projects. On these issues he made his first publication. In 1960, Mark was elected as a candidate to the post of senior researcher in the Leningrad Petroleum Institute (VNIGRI), where he was appointed head of the oil and gas resources sectorf. Here he presented his candidate (PhD) and doctoral (DSC) dissertations. In 1988 and 1989 M. Leybson participated in scientific conferences in Pshebram in Czechoslovakia, and in 1990 went on a business trip to Norway to share geological materials. He has published independently and in collaboration 3 monographs and more than 100 scientific articles. Mark Leybson's son and daughter went to the U.S. in the late 80s. This to some extent influenced his decision to move to the US, were in 1992 he took permanent residence in Rockville, Maryland. Despite his age, he first went to college to study the English language, computer science and other subjects. Around 1995 through friends he met with one of the employees of the CERA Company (Cambrige Energy Research Associates). This company was newly established (early 90s) by such major corporations as ExxonMobil, Shevron and Shell, and started business cooperations with Russian oil and gas companies. CERA was attracted to investing by the prospects of the Russian oil and gas industry. As described by Mark: "I felt quite competent in these matters. Periodically, I advised on petroleum geology and on oil and gas production in Russia…. To me personally this was quite interesting, although it was performed on informal and commercial terms". He collected information on the Internet and printed publications, used to consult their extensive knowledge and experience in this area. He had to terminate his participation to this project in 2009, due to age and state of health.

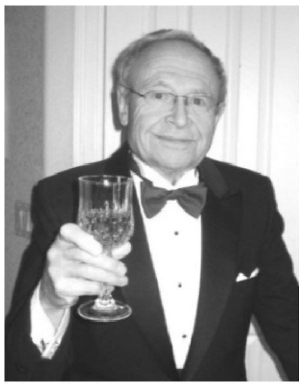
41. Leonid Borissovich Listengarten (*1935, Baku, Azerbaijan), petroleum geologist, PhD, DSc.Emigrated after WW II. Louisiana.

L.B. Listengarten (Personal archives)

Leonid grew up in the highly educated, cultured family of DSc. Professor Boris Moiseevich Listengarten (*1906 – †1982) and the historian Esphira Lvovna (born Belen'kaya) (* 1909 – †1998). His father was a petroleum geologist in Azerbaijan. In 1957, Leonid graduated from the Azerbaijan Industrial Institute with a degree in hydrogeology. In 1964 he presented his PhD thesis, and in 1988 in Moscow (VNIIGAZ), his doctoral thesis on "Methods of exploitation of deep water oil, gas and condensate fields". In the USSR, L.B. Listengarten was head of the Oil Laboratory for offshore fields in Baku, and from 1980 to 1992 was head of the department for the development of oil, gas and gas condensate fields at the "Gipromorneftegaz" institute. He oversaw the development projects of the Caspian Sea Deepwater Guneshli, Chirag and Azeri oil fields. These projects formed the basis for the International Consortium of the Azerbaijan Oil with foreign leadership. Thanks to his contribution, the current annual oil production in Azerbaijan rose to almost 60 million tons. From 1992 to 1994 L.B. Listengarten went to Vietnam as head of the Department of development in the joint Russian-Vietnamese Institute "Vietsofpetro". There he supervised the "The White Tiger" oil field development project located in the South China Sea. He moved to the United States in 1996 due to the ethnic conflict between Azerbaijan and Armenia and Russia's position in this conflict. L.B. Listengarten worked in U.S. oil companies: Petro Energy International, LLC (1997–1999), the NEOppg Corp. Corporation (1999–2000). He mainly engaged in consolidation in case of purchase of the companies, and also in new and improved methods of oil drilling in gas fields. He co-authored several publications in the United States on his results. He participated in a team of specialists for special types of wells in the Gulf of Mexico (Louisiana), Mexico and Venezuela. In Scotland, he also presented a new device to be released in North Sea wells. L.B. Listengarten has over 100 publications in various Russian and international Journals, including books, inventors' certificates and patents. His passion for chess endured of course over the years. Leonid was champion of Azerbaijan, became an International Master of Chess and participated in many championships.

L. Listengarten - International Master of Chess (Personal archives)

42. Vadim A. Litinsky (*1929, Petrozavodsk, Russia), mining engineer and geophysicist, PhD. Emigrated after WW II (1979); Colorado.



V. Litinsky (Personal Archives)

Vadim's father was Arpad Szabados (*1887 – †1966), a Hungarian communist who took an active part in the 1918 Hungarian

Revolution. He was sentenced to 13 years in Hungary Penitentiary and in 1922 was exchanged for Hungarian prisoners of war and thus moved to Russia. He spent five years in the Solovki camp, after which he worked as an economist in Petrozavodsk, Moscow and Kazakhstan. After returning to Hungary in 1947, he was a legal adviser in Soviet-Hungarian companies. Vadim's mother was Nina Litynska (*1886 – †1977), an accountant in Petrozavodsk. Vadim wanted to be a journalist, but instead became a geophysist under the influence of the hydrogeologist Alexander Alexandrovich Alexin.

In 1953, Vadim Litinsky graduated with honors from the Geological Department of the Leningrad Mining Institute, majoring in "Mining engineer- geophysicist". He received a Ph.D. degree in 1972 at Moscow State University in the department of Prof. V.V. Fedynsky. He worked at the Leningrad Research Institute of Arctic Geology (now Institute of Oceanographic Geology) for 28 years. Engaged in diamonds exploration in northern Yakutia, for the first time in the world, he used high-precision magnetic survey, kappametry (measurement of magnetic susceptibility) and metallometry for the exploration and delineation of kimberlite pipes. In 1963, as the chief engineer of the Polar high-latitude air expedition he led the airborne gravity and magnetic surveys of the USSR eastern Arctic seas, established drifting ice bases, conducted a gravimetric survey of the New Siberian Islands in the Bering Sea and the Kara Sea. Applying the universal isostatic gravity reduction instead of the traditional Bouguer reduction, he could establish the existence of a large 80 km thrust of the Verkhoyansk Range over the Preverhoyansk foredeep, which greatly increased the potential reserves of hydrocarbons in the trough.

In 1979, V.A. Litinsky with his wife and 12 year old son emigrated to Vienna on an Israeli visa, then in Rome, and in 1980 arrived in New York (USA). Vadim quickly found a job as a senior geophysicist at EDCON company based in Denver, Colorado, where for more than six years he performed geological interpretations of gravimetric and magnetic data at sea, in the U.S., Africa and Asia, developed calculation techniques for estimating the depth of magnetized bodies and sedimentary basins from gravity data. From 1986 until his retirement he worked as a consultant and translator for an English and two American oil companies in Western Siberia, Kazakhstan and Kyrgyzstan. Vadim Litinsky was a member of the American Geophysical Union (AGU), American Association of Petroleum Geologists (AAPG) and the International Society of Exploration Geophysics (SEG). The results of his work (over 50 articles) were published in Russian, American and British journals.

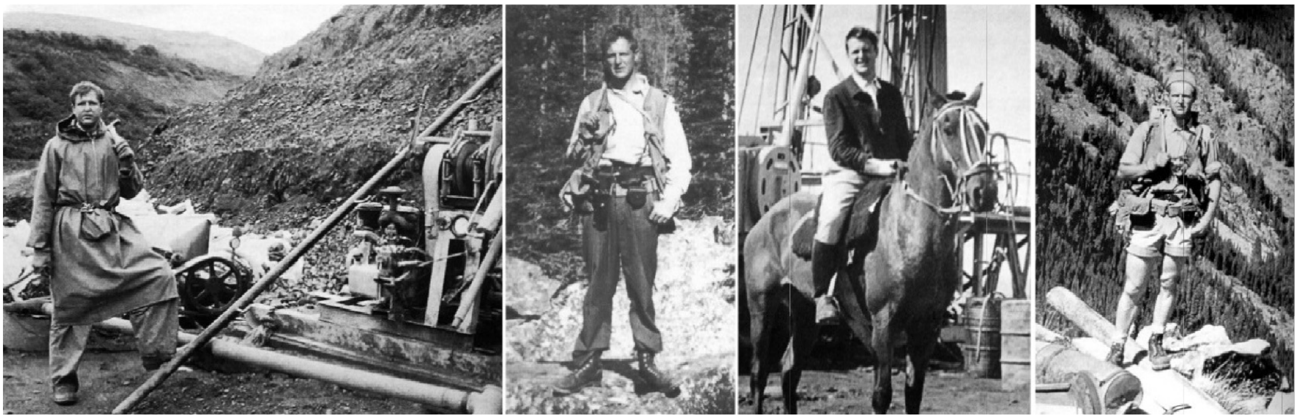
43. Prince Nikita D. Lobanov-Rostovsky (*1935, Sofia, Bulgaria), geologist and economist, honorary Doctor of Arts, Academician, Maecenas of art. Emigrated after the October Revolution and the Civil War – second generation. Alaska, Montana.

Nikita Lobanov - Rostovsky descends from Rurik princes, founder of Ryussia, and is a direct descendant of Yaroslav the Wise, Vladimir Monomakh, Yuri Dolgoruky, etc. Nikita's father, Prince Dmitry Ivanovich Lobanov - Rostovsky (*1907 – †1948) was an accountant. His mother was mother Irina Vyrubova (*1911 – †1957). His father's family moved to Bulgaria in order to escape the terror following the October Revolution in Russia. After graduating from a Bulgarian school in 1953 he succeeded with his mother to move to France, thence to England. He has a Bachelor's degree in geology, from the University of Oxford, a Master of Economic Geology from Columbia University in New York (1962) and a master's degree in accounting / banking from NYU.

Nikita participated in geological field work in Patagonia and North America (Alaska, Montana, etc.), and later in Africa and other countries. He also held senior positions in Banks in America and England, in combination with geology. From 1964 he prospected for oil in Argentina, mercury deposits in Tunisia and Alaska, iron in Liberia, nickel in Venezuela, and diamonds in the Kalahari Desert in South Africa.

Prince Nikita Lobanov-Rostovsky as field geologist in the USA (Lobanov-Rostovsky, 2010)

In recent years, N.D. Lobanov - Rostovsky participated in the funding of a position for a lecturer in Organic Chemistry at Oxford's Christ Church College, in the name of his favorite professor Paul Kent. He also donated funds for the creation of a Faculty of Planetary Geology at Oxford University, the first lecturer in Planetary geology being Dr. D. Porcelli. Nikita Lobanov – Rostovsky is an avid collector of Russian theater and decorative art from the beginning of the XX century. He posseses a unique collection of 150 Russian avant-garde artists (about 1,000 pieces), repeatedly bringing his collection throughout the world exhibitions. He is an Honorary Doctor of the St. Petersburg Academy of Arts and of the "International Information Academy" accredited to the UN in Geneva, winner of the prestigious award Ludwig Nobel, the Russian Government order of Friendship for his contribution to the preservation of historical and cultural values of Russia. He is a member of numerous scientific and cultural societies in different countries. Lobanov is the author of numerous publications on geology as well as banking and Russian art.



N.D. Lobanov-Rostovsky at Vitosha Mnt., Bulgaria (photo P. Tchoumatchenco)

44. Alex (Alexander E.) Malakhoff (*1940, Moscow, Russia), geophysicist, oceanographer, volcanologist, tectonician, PhD, Honorary Doctor of Science (DSc. Hon.), Professor. Emigrated after WW II. Hawaii.

A. Malahoff (Internet: youtoube.com)

After the death of his father during WWII, in 1949 the Malakhoff family, consisting in Alexander, a 9 year old boy, his mother, grandmother and brother emigrated to New Zealand. He studied at the University of Victoria, earning a mastership in geophysics (1962), and two years later a PhD in Hawaii (USA). He then engaged for a long period of time in airborne geophysics in the Hawaii area, at the University of Hawaii's Undersea Research Laboratory. He also engaged in submarine deep diving for underwater exploration of volcanoes and the unique hot springs thermophilic life. In 2002, he returned to New Zealand as executive director at the Institute of Geological and Nuclear Sciences. Alex Malakhoff is an internationally recognized expert in underwater volcanism, marine engineering geology, tectonics and underwater mineralogy. He did more than 200 dives, also engaged in scientific vulgarisation with public movies about underwater volcanism and university teaching. His studies led him to envisage that life on Earth probably originated around volcanoes, probably underwater ones, with a constraint on adequate temperature conditions.

Alex Malakhoff is an amazingly educated, courageous and friendly person, a performing researcher , practitioner, skilled organizer and author of numerous scientific publications. He is Honorary Doctor of Science from the University of Victoria and a recipient of the Moore Medal Award for his achievements in the field of oceanography, geophysics and marine engineering, member and the Royal Geological Society of New Zealand, the Society of Exploration Geophysics, Geological Society and Geophysical Union, and many other scientific associations.

45. Ilya Mamantov (*1914, Tartu, Estonia (Livonia lips.), Russian Empire – †1991, Richardson , USA), geophysicist, Dr., Professor of Russian and modern history. Emigrated after WW II. Texas.

Ilya Mamantov was born in a Russian family in Jurev (St. George, now Tartu), Estonia.When he was seven his family moved to Latvia. In Riga, he received a geological formation (Necrolog, 1991). In 1944 Ilya Mamantov was in the flow of refugees and displaced to a camp in Bavaria (Germany). In 1951 he found a job as a production scheduler in the Lion Match Company in New York. A year later, he was engaged as a seismologist and from 1955 held positions at the Donnally Geophysical Company, Dallas, and in other American oil companies. In 1965 he also was a professor of Russian language at the University of Texas.

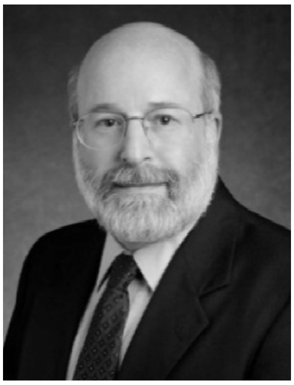
I. Mamantov is a member of the Society of Exploration Geophysicists of which was at a time chairman. After retirement he continued to teach Russian at the Southern Methodist University in Dallas.

46. Sergey S. Marchenko (*? 1960, Russia) Ph.D., associate professor. Emigrated after WW II. Alaska.

S. Marchenko (Internet: gi.alaska.edu)

In 1985, S. Marchenko graduated in theoretical mechanics engineering at the Institute of Agriculture. He worked for about four years in the city of Alma-Ata (Kazakhstan), at the same time attending a course at the Moscow Institute of patent examination. In 1989 moved to the Yakut Institute of the Permafrost. In 1991, he received a degree in mathematical modeling of the permafrost in the Moscow University Geological Faculty. In 1999 he presented his Ph.D. thesis on physical geography with specialization on "Geocryology and Glaciology" in Moscow. In 2003 S. Marchenko was invited at the University of Alaska, Fairbanks, in the Geophysical Institute for studies on Snow Ice Permafrost where he currently holds the position of professor-researcher. His activities in the United States cover the evolution of the hydrogeology and permafrost of Northern Eurasia and as part of international projects on permafrost survey. Sergey Marchenko is co- leader of the Working Group for mapping and modeling of the spacio-temporal dynamics of the permafrost in mountainous regions at the International Permafrost Association (IPA). He is an expert on "Mountain Permafrost" of Central Asia at the Global Observing system for the interaction of Climate and Permafrost in the Arctic and sub-Arctic regions (GCOS). In 2006 he also participated in archaeological studies in the Altai for the preservation of Scythian tombs from the global melting of ice and permafrost. S. Marchenko is a member of the American Geophysical Union (AGU), the US Permafrost Association and the European Geosciences Union (EGU). He co-authored abroad a number of papers on the above subjects.

47. Stephen Marshak (*1955, Rochester, USA), geologist, tectonician, PhD, Professor. Emigrated before the October Revolution - thirth generation emigrant. Illinois, New York.



Stephen Marshak (Internet:news.illinois.edu)

Stephen's grand-parents, Harry and Rose Marshak, emigrated to the U.S. from Minsk (Belarus), fleeing the pogroms. In Minsk, Harry and Rose had lived in the Jewish ghetto and had only received religious education. Arriving in New York, they could only get simple jobs: Rose was a seamstress, and Harry seller. During WWII, Stephen's father, Robert E. Marshak (*1916 – †1992) was involved in the Manhattan project and was later a lecturer at the University of Rochester, New York, Stephen's city of birth.

In 1976, Stephen Marshak received a bachelor's degree in Geology at Cornell University in New York, followed three years later by a master's degree in Geology from the University of Arizona in Tucson. Returning to New York, he worked for four years on a Ph.D. thesis, which he presented at Columbia University. Since then, S. Marshak teaches at the University of Illinois at Urbana-Champaign, in 1999 becoming head of the Department of geology. In parallel, he also taught at the Federal University of Ouro Preto and at the University of Sao Paulo in Brazil, at the Geological and Oceanographic Observatory Lamont - Doherty (New York), the University of Adelaide in Australia and the University of Leicester in England. His research interests include Proterozoic tectonics of the Brazilian shield, where he did field research, Phanerozoic continental tectonics of North America, structural geology in fold-and-thrust belts. Stephen Marshak is the author of about 55 scientific articles on regional structural geology, author or editor of five textbooks and general public books, including general geology, the basic methods of structural geology, earth structure, tectonics of the planets, that each belong to the best textbooks in these fields. Marshak has received numerous awards in recognition of research and teaching activities, including a medal from the Australian Journal of Earth Sciences, several awards for teaching at the University of Illinois. He is an active member of the Geological Society of America, assistant editor on geology, a member of the Tectonophysics Editorial Board.

48. Donald (Don) Arthur (Arturovich) Medvedev (*1958, the Livonia, USA), geologist, tectonician, petroleum geologist. Emigrated after the October Revolution and the Civil War – thirth generation emigrant; Texas, Michigan

Don Medvedev (Internet: AAPG. Org)

Donald is a descendant of immigrants from Russia. He was born in the family of Barbara Medvedeva (*1930) and Arthur Medvedev (*1925 – †1991), a graduate from the University of Michigan in 1947. Donald was educated in the United States and Canada: he obtained a bachelor's degree in 1981 at the University of Michigan in Detroit (USA), and a master's degree three years later at Queen's University in Canada. In 1987 he obtained a doctorate in structural geology (Ph.D.) at Princeton University Faculty of Geology and Geophysics, New Jersey (USA).

Donald Medvedev started in the oil and gas company ARCO in Plano, Texas, in exploration. He stayed with the company for 13 years. In 1994–99 he also taught at the University of Michigan. In 2000, Donald Medvedev accepted an offer from Chevron in Perth area, Australia, as a research consultant in industry, oil and energy. As a tectonics specialist, D. Medvedev was involved in the varying relationships between tectonic folds, faults and fractures, producing their geometry in 3D using computer-aided design.

For 29 years he was a structural geologist in the Geoscience Community. In 2010-2011 he received awards from the American Association of Petroleum Geologists (AAPG) for his contributions to the knowledge of oil and gas reservoirs He also is a member of the Geophysical and Geological Society of America. He wrote several papers on tectonics, including on he co-authored with the geology and geophysics prof. David V.Willschko on the tectonic mechanics and stress distribution of the Northwestern outskirts of the Southern Appalachian foothills.

49. Baron George von Mohrenschild (*1911 Mozyr, Russian Empire – †1977, USA), petroleum geologist, businessman in the oil industry, Ph.D. Emigrated after the October Revolution.

G. von Mohrenschild (Bettman/Corbis, 1964)

George's father, Baron Serge Alexandrovich von Morenshild, was a russified wealthy German nobleman. Shortly after the Russian Revolution, he was arrested by the Bolsheviks for anti-communist activities and sentenced to life exile in Siberia. In 1921 he and his family managed to escape to Poland.

George graduated from the Polish military academy in 1931, and in 1938 received a PhD in the field of international trade at the University of Liege in Belgium, and then moved to the United States. In 1939 he was hired by the Humble Oil, co-founded by Prescott Bush. In 1945, von Morenshild received a master's degree in "Geology and exploitation of the petroleum deposits"at the University of Texas. After the Second World War he moved to Venezuela for the Pantepec Oil Company belonging to William F. Buckley's family. In 1952, he moved to Dallas, where he worked for the oil millionaire Clint Murchison and joined the Dallas Petroleum Club. In 1957 G. von Morenshild worked for the "CVOVT, Cuban-Venezuelan Oil Voting Trust Company". As a an oil specialist, he traveled around the world, and also taught geology at the University of Texas.

After a long private journey to Mexico and Central America, George von Morenshild and his wife returned to Dallas. Around 1962, he met with the family of Lee Harvey Oswald whose wife, Marina born Prusakov, originated from Belarus, the same country as von Morenshild. Lee Harvey Oswald later became famous as the murderer of President John F. Kennedy (November 1963). In June 1963 George and his wife moved to Haiti. In 1977, he was teaching French in Dallas. Beeing harassed by U.S. security because of his links with Kennedy's murderer Oswald, von Morenshild fell into a deep depression. It is assumed that he committed suicide by shooting himself in the mouth in a hotel in Palm Beach, Florida, although his wife has always denied this likelihood.

50. Siemon William Müller (*1900, Blagoveshchensk, Russian Empire – †1970, California, USA), geology, paleontology, stratigraphy, structural geology, Ph.D., Professor. Emigrated after the October Revolution and the Civil War – first generation. Nevada, California, Alaska, Maryland

Siemon Müller(Internet:udel.edu)

Müller's father arrived in Russia from Denmark, being employed at the telegraph office and as a teacher. During the October Revolution, 17 year old Siemon entered the Naval Academy in Vladivostok. Realizing the danger of belonging to the White army, he fled to Shanghai, where he could be hired by an American company, and learned English. In 1921, he enlisted in a ship's crew and sailed to the United States. There he graduated from the Oregon State University in 1927, majoring in geology. He pursued his studies at Stanford University, specializing in paleontology and stratigraphy under James Perrin Smith's supervision. S. Müller received a master's degree in 1929 and his doctorate in 1930, with a thesis on the Triassic stratigraphy of Western Nevada. He married Vera Vilamovska, also of Russian origin.

S. Müller became a lecturer and later a professor at Stanford University. He enthusiastically taught courses in historical geology, paleontology, stratigraphy, permafrost and the geology of California, conducted geological excursions with students, being one of the most popular professors at Stanford University. During WWII, Siemon Müller undertook permafrost studies in Alaska for the needs of the U.S. Army, wearing an officer's uniform without shoulder-piece, meaning he was not directly serving in the Army. He made a great contribution to the knowledge of permafrost, but his main interest was the study of fossil fauna and flora and its use for interpreting the origin and geological history of the Late Paleozoic and Mesozoic sedimentary rocks of the western United States. Two decades of cooperation with the Henry J. Ferguson of the U.S. Geological Survey made a great contribution to the study of the Maryland Western Cordillera. As a young man in the late

1930s, he was an adviser to the U.S. Geological Society, a member of the Guggenheim in Austria, and in the 50–60s was a member and then president of the Paleontological Society, and a trustee of the California Academy of Sciences.

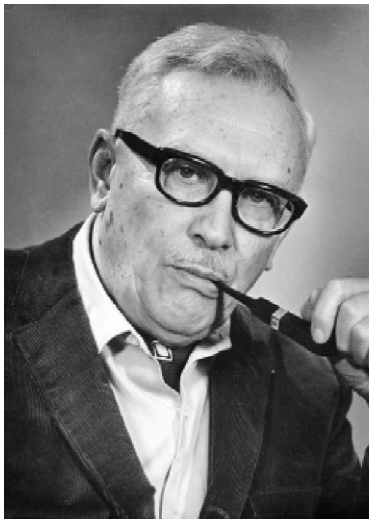
51. Artem Romaevich Oganov (*1975, Moscow, Russia), crystallographer, Ph.D., Dr. habil., Professor. Emigrated after WW II. New York.

A.R. Oganov (Personal archives)

Artem Oganov has been interested in science since childhood. At 4 he became interested in chemistry, at 7 attended lectures at the Polytechnic Museum and conducted chemical experiments at home, which fortunately did bring any significant "disaster". At age 11 he became interested in mineralogy and soon began to follow expeditions, which determined his future career. In 1992 Artem graduated with honors in high school and enrolled at the Faculty of Geology, Moscow State University. He received five Soros Fellow, also received two Shubnikov scholarships, Vinogradov and Lomonosov. In 1996, during the month long program at the University of Milan in Italy Artem mastered the technique of quantum- mechanical calculations and learned Italian during the course. He also speaks English, French and German. In 1997 he graduated with honors from the Moscow State University in crystallography. He devoted his thesis to the theoretical modeling of the structure and properties of aluminum silicates. In 1998, with a President's Scholarship for abroad studies, Artem Oganov moved to the UK, in prof. David Price's team at University College, London, and presented his Ph.D. thesis on "Computer simulation studies of minerals", afterwards engaging for a year as a junior researcher . In 2003 Artem accepted an interesting proposal to create and lead a research group at the Zürich Polytechnic Institute (ETH Zürich, Switzerland), where he presented a doctoral habilitation thesis on "High Pressure Crystallography" in 2007. Since 2008 he is a Professor in the State University of New York at Stony Brook (USA), where he teaches and conducts research.

A. Oganov has published more than 100 scientific papers on crystallography, mineralogy, geophysics, theoretical physics of condensate matter, has discovered a number of new mantle minerals (mineral "post- perovskite" = $MgSiO_3$ and a high-pressure phase in $CaCO_3$ and $MgCO_3$), created a new method for the prediction of crystal structures and the search for new materials, the winner of many awards and honors, including the Latsis award, awards from the European Mineralogical Union, the European Union of Geosciences , the London Geological Society, etc. A. Oganov maintains active ties with Russian scientists and from 2006 is an associate professor at Moscow State University. According to the independent business magazine FORBES Russia, Artem Oganov belongs to the ten most successful Russian scientists of our time.

52. Vladimir Joseph Okulitch (*1906 , St. Petersburg, Russian Empire – †1995, Canada), paleontologist, Ph.D., Professor. Emigrated after the October Revolution and the Civil War – first generation. California, Hawaii.



V.Okulich (Internet:digitalcollections.ubc.ca)

Vladimir was born in a family of Siberian Cossacks, the son of agronomist engineer Joseph Konstantinovich Okulitch - Okashi (*1871 – †1949). His father often traveled abroad for familiarizing with European experience in agriculture in order to use it in Siberia. He traveled in 1919 to the United States as a diplomatic representative of Admiral A.V.Kolchak, represented until 1923 the White Russian government in the United States, Britain and France. After the Civil War, he lived in Yugoslavia (1923–1926), engaged in the export of timber, later settling with his family in British Columbia (Canada).

Vladimir Okulitch graduated from the University of British Columbia Faculty of Geology in 1932 with a Master in Engineering Geology. Later he studied at McGill University in Montreal, two years later presenting his doctoral thesis. After 10 years of research at Harvard University in the United States, Vladimir Okulitch became an assistant professor of paleontology at Vancouver University in 1949, staying for 22 years professor of paleontology and stratigraphy. In the years 1953-1959 he headed the Geological Department of the University, and later Dean of the geological-faculty (1963) (Okoulich V. 1971; Joukovsky A. 1995). As dean, V. Okulitch launched many university research projects, including project telescope on Mount Kobau. He conducted much geological research in Eastern Canada and in the Cordillera of western Canada. He was also invitated to lecture at the Universities of Southern California and Hawaii. V. Okulitch was a member of numerous Canadian and American geological and scientific societies. He published more than 60 papers, including monographs, devoted mainly to Cambrian and Ordovician invertebrate paleontology. Vladimir was known as a photographer and refers to photography as an art, for which he received numerous awards at exhibitions. He was also fond of astronomy. In 1934 he married Susanna née Kuhar, with whom he had two sons. Their son Andrew followed his father and became a geologist – second generation white emigrant, working in Canada.

53. Felix Persits (*1937, Moscow, Russia), geophysicist, Ph. Emigrasted after WW II. Colorado.

Felix Persits (Personal Archives)

In 1962, Felix Persits graduated from the Geophysical Department at the Moscow Geological Exploration Institute (MGRI), specializing in rare and radioactive elements. In 1978 he presented his PhD thesis.

In USSR Felix Persits has been exploring for oil and uranium in Kazakhstan with “Spetsgeofizika” and the Kazakhstan Institute of Mineral Resources (VIMS), also searching for bauxite, gold and diamonds in Central Asia, the Timan , Urals and East Siberia. He supervised airborne geophysical surveys at the Central Research Institute of Geological Prospecting for Base and Precious Metals (TSNIGRI) and the Research Institute “Zarubezhgeologiya”, also being engaged in the development of algorithms. He traveled as a consultant for those companies and institutions to Mongolia, Canada and the United States. In 1972, during an airborne geophysical survey for bauxite on the Timan Ridge, Felix survived a plane crash.

Moving to the U.S. in 1993, he experienced some hardships, as part of his family (including his sick mother) was still in the USSR, while only the uncertainty of the future had forced him to take this step. Only in 1998, his family finally could piece together and their lives become normal in Denver. His choice of Denver is not accidental, since it is one of the main centers of the U.S. Geological Sciences and the beautiful nature of Colorado is hard to even describe. In addition, being a skier with a 45 years’ experience, he was close to many major ski resorts in Colorado. In 1993 F. Persits worked mainly on episodic projects with the American physicist D. Cooper. Three years later he entered the U.S. Geological Survey (USGS) in Denver. He joined the new project “Assessment of the world’s resources of oil and gas“ which was organized to perform with the use of modern methods of computer mapping and database management. Persits Felix was invited to participate in the geographic information systems (GIS). The project produced a system of data analysis and maps of the world on any petroleum province running on UNIX, and later on PCs. The second focus of his work was the production and publication of digital geological maps on CDs covering countries and continents such as Africa, the former Soviet Union, the Arctic, Iran and Bangladesh, spreading thousand copies throughout the world. He co-authored about 12 international scientific papers with American colleagues.

54. Sergei Pisarevsky (*1953, Leningrad, Russia), physicist, geophysicist, paleotectonician, paleogeographer, PhD, Dr. Sc., research assistant professor. Emigrated after WW II. Florida (periodicaly).

S. Pisarevsky (Personal archives)

Sergei Pisarevsky, the son of an engineer and a nurse, graduated from the Faculty of Physics, Leningrad University in 1976, specializing in the physics of the Earth. Within six years he presented his thesis on the “Investigation of the fine structure of the paleomagnetic field in order to build a detailed magneto- stratigraphic scale”. In Russia, he worked at the Petroleum Institute in Leningrad (VNIGRI), author or co-author of over 140 publications. On fieldwork Sergei was often in the vast expanses of Eastern Siberia. From 1995 to 1997 he periodically worked at the University of Aarhus in Denmark, the Lund University in Sweden and the University of Florida in Gainesville (USA). Sergei was invited in Australia in 1998 as a visiting researcher at the University of Western Australia (Centre for tectonic studies), where he received a permanent position. From 2006 to 2010 he also worked at the University of St. Francis Xavier (New Scotia, Canada) and the University of Edinburgh (Scotland), collaborated with the University of Helsinki (Finland), the University of Geosciences in Beijing (China), also collecting field data in Norway and India. His main interests are paleomagnetism and its relationship with geology and tectonics, plate tectonics and Precambrian paleogeography. On these subjects he authored or co-authored about 80 scientific papers in international journals. Since 2002 he is in care of the global paleomagnetic database (Pissarevsky S. *et al.* 2013). Sergey also participated in the preparation of illustrations for the popular science book “The Big Picture Book” (John Long, Brian Choo), presenting the modern theory of global paleogeography. It won the Australian Award for outstanding achievement in the creation of educational literature and as the best guide for students. He also participated in the design of "Ground Dinosaurs" at the Royal Park in Perth, Australia (Kings Park): some of his reconstructions in the form of bronze plates where installed at the Wana Park.

Sergey participated in collaborative research projects overseas and with Russian institutions, collaborating on the Precambrian Siberia with the Irkutsk Crustal Institute. He currently is a senior research fellow at the University of Western Australia and the Curtin University of Technology, member of many international scientific societies, recipient of several awards for scientific and popular science work.

55. Inna Vitalievna Poiret (*1890, Samarkand, Turkestan, Russian Empire – †1959, Washington, DC, USA), geologist, petrographer. Emigrated after WW II. Alaska.

Inna was born in the family of the Russian Imperial Army lieutenant colonel, the Frenchman Vitaly Poiret (*? – †1902) and a Russian mother, Maria Ivanovna Poiret. It is known that the Poiret settled in Russia after the 1812 war. After her father's death the family lived in Leningrad. Having completed her studies at the Leningrad Mining Institute with a specialization in lithology and petrography, Inna engaged in a scientific career (1911). At the outbreak of WWI in 1914, Inna Poiret engaged as a nurse in the ranks of the 1st Battalion of the Petrograd female rifles. In October 25, 1917 she participated in the unsuccessful defense of the Winter Palace, the last residence of the Provisional Government. In 1919 she persued her scientific career. In 1930 she was a senior geologist at the Leningrad Hydrogeological Trust, writing a number of scientific papers. In March 1935 Inna Poiret was convicted and sent with her mother to Ufa for 5 years.

I.V. Poiret then left the Soviet Union during WWII and settled in the United States (circa 1959). She dealt with the permafrost at the US Geological Survey, publishing a number of scientific articles. Inna Poiret was a member of the American Institute of Mining Engineers, the Geological Society of America and the Association of Women Geographers.

56. Constantin A. Prokopov / Konstantin A. Prokopoff (*1887?, Esentukskaya stantia, Russian Empire – †1972, San Francisco, USA), mining engineer, oilman, Professor. Emigrated after the WW II.USA.

Constantin Prokopov came from a Terek Cossack family. In 1910 graduated from the Mining Institute and was assigned to Geolkom since 1913 as an associate geologist, specializing in oil exploration and in regional stratigraphy. On behalf Geolkom he participated in the geological field studies in Siberia and the Kuban region, participated in the description of sections of the Mesozoic and Cenozoic, and was engaged in the stratigraphy of these deposits. In the Udel steppe in Stavropol province he studied the fauna; in 20 – 30s in the Pre-Caucasus he has refined and detailed the stratigraphic scheme of the subdivision of the Neogene, published some papers in the Notices of the Mining Institute. His final work "The new Grozny Oil District" (1915) finally cemented a new strategic direction for the Russian oil industry; in 1916 Novogroznensky oilfields already given 51 million tons of oil, i.e. 50 % of total oil production in the Grozny district.

The "case Geolkom" in 1929 held a total of 32 people sentenced to various punishments. Ten defendants, including Constantin Prokopov gave on bail and were released after completion of the case for lack of prosecution. But the materials on five defendants, including Constantin Prokopov were marked for inclusion in other cases. Subsequently, Constantin Prokopov worked in NGRI and in 1934 was sent from Moscow to Leningrad. He participated in the exploration in the North Caucasus and the Kuban, where he first found the Devonian fauna in the bedrock. In years 1938–41 he again conducted geological studies in the Stavropol region. C. Prokopov probably got abroad during the World War II, and he went to the U.S. and was a professor at several universities, and in his spare time writing books about the Cossacks.

57. Nikola P. Prokopovich (*1918, Kiev, Ukraine – †1999, Sacramento, CA), engineering geologist, geochemist, Dr.rer.nat. Emigrated after the WW II. California.

N. Prokopovich (Internet: lib.ucdavis.edu)

Nikola graduated from the Faculty of Geology of the University of Kiev. In autumn 1941 Prokopovich was on occupied territory. The German command ordered to clear Kiev from the civilian population, and so it was in 1943 among the refugees went to the West, from which Russia has not returned. After the war, he first lived in the French zone of South-West Germany, enrolled in graduate school at the Faculty of Geology Tubingen University in which he defended his doctoral thesis. In the U.S., he moved in 1950, moonlighting at odd jobs, worked at the University of Minnesota, and then got a job as a geologist in the Bureau of Land-Reclamation, U.S. Department of the Interior in California and conducted research in various fields of geology, and land reclamation. He developed some new techniques, such as mathematical calculation determining the degree of subsidence in the design of channels in California, which was laid in the foundation of the project irrigation canal San Louis to irrigate 1.4 million hectares of land in the Central Valley for urban and industrial needs of California.

Nikola Prokopovich (Morrison D. & Phillips L. 2011) further worked as a geologist in the Bureau of Reclamation Mid- Pacific Region in Sacramento. He liked to work in the field and found solutions to many complex geotechnical problems associated with the design and construction works in the Mid- Pacific region of the State of California. He participated in many international congresses, symposia and conferences, earning wide popularity among professionals, was the author of more than 150 technical papers and abstracts, actively worked to 74 years of age. Recognizing the merits of N. Prokopovich the U.S. Interior Secretary awarded him commendation, nominal silver medal and a silver mark to wear in his buttonhole. Part of printed works N.P. Prokopovich was transferred to the technical library of the Ural Branch of the Russian Academy of Sciences in Ekaterinburg.

58. Rhoda Rappaport (*1935, New York, USA – †2009, New York, USA), historian of geology, Ph.D., Professor. Emigrated after the October Revolution and the Civil War –second generation. New York.

R. Rappaport (M.Whalen, Vassar College, 9.5.2011)

R. Rappaport (Prof. J. Challey, Vassar College, 16.6.2011)

The parents of Rhoda Rappaport emigrated from Russia in the beginning of the revolution - in 1917, and three years later, through Central Europe, arrived in the United States. In 1961 she graduated, and came to the history department of Vassar College, and in 1964 he defended a Ph.D. thesis in history from Cornell University. Her specialty was the early history of geology in Europe and especially geology XVII and XVIII centuries in France, " when the geologists were historians " - from the time of Hooke , Leibniz, and Fontenelle to Lavoisier , Werner and Cuvier. She wrote about the proper understanding of the role of paleontological remains, meaning mineralogy (especially in France), and the reliability of different information about the Earth's past. Her work activity covers half a century, and during the last 40 years, she worked as historian and until his death was a Distinguished Professor at Vassar College in New York.

59. Vladimir E. Romanovsky (*?1950, Barnaul, Russia), geologist, PhD., Professor. Emigrated after WW II. Alaska.

V.E. Romanovsky (Internet: sciencepoles)

In 1975, Vladimir Romanovsky graduated from the Geological Faculty of Moscow State University with a specialization in geophysics and in 1982 defended a master's thesis. In 1985 in Moscow, Vladimir received a second university degree - in mathematics. Upon graduation, he worked at the Moscow State University, doing geo-chronology and geophysics. In the USSR, Vladimir worked in Kazakhstan, on the Black Sea , in the Baikal-Amur region , Western Siberia, northern Yakutia and from Moscow State University in Mongolia.

In 1992, Vladimir Romanovsky - Specialist Earth Cryosphere began his scientific career in the Geophysical Institute, University of Alaska Fairbanks, UAF, which in 1999 received a professorship, Head of the Laboratory of permafrost , directs the work of students and graduate students. The second dissertation V.E. Romanovsky done at the University of Fairbanks, to give in 1996 U.S. doctoral degree (Ph.D.).

For outstanding achievements in scientific research in 2011 he was awarded the University "Usibelli Award". In the realm of his research interests and belong to the scientific and practical aspects of environmental and technical problems associated with the ice and permafrost. This is a problem in the field of soil physics, thermodynamics, heat and mass transfer flow associated with permafrost, subsea permafrost, seasonal permafrost soils and seasonal snow cover. Romanovsky worked except Alaska and in Iceland, Greenland and the Canadian Arctic. He also develops mathematical methods (analytical and numerical modeling) in geology and geophysics. Romanovsky participates in joint Russian-American research project on the Arctic shelf, is president of the Society of permafrost and the U.S. member of the International Society of permafrost, a member of the American Polar Research Board, a member of the American Geophysical Union. He - the author or co-author of three books and over 160 scientific articles.

60. Joseph Rudolph (*1897, Russian Empire – †1953 ? Indiana, USA), geologist. Emigrated after the October Revolution and the Civil War – first generation. Utah, New Mexico, California, Oklahoma and Texas.

Rudolph Joseph emigrated from Russia to the USA and worked in the mining industry in Ontario (Canada), in the states of Utah, New Mexico and California in the United States, in the oil business Oklahoma and Texas, consultant geologist in Houston (Texas), where he was searching for and mining. After arriving in Houston, Texas, it was first adopted as an engineer in a company „Lockwood and Andrews." A year later, Joseph Rudolf looking for an opportunity to work in geology and began as a geologist working with John C. Myers, a consultant from Houston, and this worked for a few years. In 1928 he wrote a paper on the nationalization of natural resources in different countries - Britain, Australia and Africa (Rudolph J. 1928). Rudolph Joseph was a member of the American Association of Petroleum Geologists (AAPG).

61. AnatolY I. Safonov (*1897, Russian Imperia – †1987, Sacramento, USA), structural and petroleum geologist. Emigrated after the October Revolution and the Civil War – first generation. California.

When the family came to America, could not be determined. In the 30s of the 20th century, Anatoly Safonov was already in the United States and worked in Geology (Consulting Geologist Sacramento). In 1937 he wrote an article on the structure of the Ural Mountain, published by Cornell University. In 1939 he published a note in America in memory of the famous Russian scientist Ivan Mikhailovich Gubkin (*1871 – †1939), a geologist, engaged in Russian regional structural geology of the Volga and Ural regions. At 1947 Anatoly Safonov was a member of the American Society of Petroleum Geologists (AAPG). In 1953 he worked and published together with the geologist Paul Goudkov, which in 1951 merged his company with the firm of Hughes entitled "Goudkov and Hughes". At 1958 A. Safonov formally belonged to the firm Brazos Oil & Gas Co., but practically was vice president of Sacramento Petroleum Association.

Anatoly worked in California, in the Sacramento Valley, and called it a paradise for geologists, because a in relatively small area geologist faced with such a variety of geological structures. He studied the structure of the facies of the rocks, the geological structure, the stratigraphy and the tectonic mainly of the Cretaceous sediments, published as author and co-authored numerous geological papers.

62. Serge A. Scherbatskoy (*1908, Buyuk Dere near Constantinople, Turkey – † 2002, Paris, France), geophysicist, oilman, Ph.D. Emigrated after the October Revolution and the Civil War – first generation. New York, Oklahoma

The father of Serge – the Russian diplomat Alexander I. Scherbatskoy (*1874 – †1952) was born in Reval (Estonia) and was diplomat in Japan, Brazil, Uruguay, Paraguay, Chile, United States, served as the third secretary of the Russian embassy in Constantinople (Turkey). Serge was born there. The father was going to enter in the Kerensky government, but after his fall, he went to Berlin. After the Revolution, the family lived first in Germany, and since 1927 in France.

S. Scherbatskoy, Smithsonian Institution (invention.smithsonianm.org)

Sergei Tsherbatskoy was very talented, fluent in French, English, German and Russian languages, graduated from the Sorbonne in Paris and holds a PhD in physics. In 1929, a few months before the financial crisis, Serge Scherbatskoy moved to the United States. From 1929 to 1932 he worked at Bell Laboratories Building, Manhattan, in New York and some other engineering firms. In 1936 Serge joined the Seismograph Services Corporation, which has developed new equipment and participated in drilling for oil. The company was one of the first U.S. companies to use nuclear physics for oil exploration. Around this time, he met Mary Ellen Dunham, they were married in 1938 and they had four children and seven grandchildren. In 1944 S. Scherbatskoy developed a portable radiation detector and led the group for uranium in the Great Bear Lake in Canada. In 1948 Serge founded the firm of geophysical measurements (GMC) in Tulsa, Oklahoma. During this time he worked on the development of GIS technology, "Well logging is a systematic process of studying the entire length of the borehole with tools capable of measuring physical properties of rocks traversed and present them graphically" (logging). Around 1980 he was appointed director of special projects and continued his work on the development of measurement -while-drilling and directional drilling for oil and gas: "Measurement While Drilling" (MWD) and "Logging While Drilling" (LWD). S. Scherbatskoy patented more than 200 inventions in the field of technical exploration and production of oil, a rich collection of documents on the development of geophysics in the drilling, which was donated by his children to the Museum of Modern Physics and the American Petroleum Institute. In 1985, the U.S. Patent Office officially called his work „the work of an outstanding American inventor." Serge Scherbatskoy died at the age of 94.

63. Anatol James Schneider (OV) (*1894, Ekaterinburg, Russian Empire – †1987, San Francisco, USA), geophysicist, seismologist, tectonician, Ph.D., Professor. Emigrated after the October Revolution and the Civil War – first generation. Washington, Maryland, California.

Anatol Shneider is born in Ekaterinburg. In the U.S., Anatol Shneider graduated in Seattle in 1944, since 1945 he worked as a geophysicist at the Geological Survey in Washington, and from 1946 - seismologist at Johns Hopkins University. In his young age Anatol became famous in almost all America . Known is the story about him from the time of nuclear tests in 1946. "Anatol J.

Foto A. Schneider (ov) - epitaph on the tombstone
(Internet: russianmuseumsf.org)

Schneider, seismologist, stated on 10 June 1946, in San Francisco, that there was great danger of cracking the Earth's surface with atomic bombing by the danger of climate changes occurring throughout the world. It was the underwater bombing that was to be the most feared. "(library.antiquatis.org)." In San Francisco newspapers nearly panicked the crews of three Bikini-bound press and observer ships. They headlined a warning from Anatol J. Schneider, "seismologist" at Johns Hopkins University, that the explosion would swamp every ship and leave no survivors. Hopkins authorities promptly announced that Schneiderov was only a student and "of Soviet origin," and that his views were not those of the university. "NEWSWEEK: JULY 1, 1946). In 1948 Anatol defended at Columbia University his PhD dissertation. The scientific works of Shneider (mostly from the 50s of the 20th century) have been on the theory of the expansion of the Earth, the Earth's core and stability temperature boundary with the mantle, the forces of attraction in the world, the problems of asteroseismology. He led a group of scientists who together with the Russian researcher K.P. Stanyukovich engaged in alternative theories of gravity in the world of nature, including causing great controversy and is often attributable to the metaphysics of quantum theory of gravity. Already in 1943, while still a student, he published an article about gravity because of its influence on the seismicity and tectonics of the Earth. In 1954 he wrote an article about the nuclear explosions and the ozone layer of the Earth. In addition, he also published his translations of scientific articles from Russian.

Anatol Shneider was a regular correspondent and literary associate to the newspaper " Russian Life" in Washington, a member of the International Union of Geodesy and Geophysics (UGGI), repeatedly until the mid- 60s was based on reports and in international symposiums on seismology .

64. Jack John Sepkoski Jr. / J.J. Sczcepkowski (*1948, Presque Isle, Maine, USA – †1999, Chicago, USA), paleontologist, Ph.D., professor, foreign member of the Polish Academy of Sciences. Emigrated before the October Revolution – third generation. South Dakota, Montana and Wyoming.

The grand father of Jack John Sepkoski - Jan Sepkoski was born, according to some information , in Ukraine , in town Malin, Zhytomyr region, and was with Polish origin. In 1913, as 19 -year-old boys, he emigrated to the United States and participated in the First World War on the American site. Jack John Sepkoski was born in America (Foote M., Hopson J.A. 1999); he studied geology at the University of Notre Dame in Indiana, and received his PhD doctorate in 1977 at Harvard University, Massachusetts, USA. The topic of his doctoral dissertation was the Upper Canbrian Stratigraphy and Paleontology of South Dakota, Montana and Wyoming. Then he became interested in mathematical modeling in geology. Sepkoski has taught since 1974 at the University of Rochester, and since 1978 - in the University of Chicago, where he remained until his death in 1999.

Jack Sepkoski (Acta Palaeontologica Polonica, 44/2; 1999)

Jack John Sepkoski studied models of taxonomic diversity of marine organisms of the Vendian period and Phanerozoic, reducing them to simple demographic models: after long periods of low-level taxonomic diversity followed by periods of rapid development, search through the massive loss of organisms. Thus, the idea of periodicity of life on Earth has helped to link mass death of organisms with possible extraterrestrial phenomena. The study of Sepkoski mass death of organisms was carried out together with his University of Chicago colleague David M. Raup: they set reduction degree of dead organisms during the Phanerozoic and the apparent periodicity of 26 million years during the late Phanerozoic. Despite the fact that the mechanism of periodic death is not yet fully understood, statistical processing of the data proves this periodicity.

J.J. Sepkoskin was proud of his Polish ancestry. His wife was paleobiologist Cristina Maria Janis with which he conducted numerous collaborations. For his contributions to paleontology, in 1998 he was elected in 1997 a foreign member of the Polish Academy of Sciences, He was awarded numerous international awards, including in 1983 after Charles Shuchert Award from the Paleontological Society. Jack John Sepkoski died at the age of 51. In his honor, the American Paleontological Society has created a grant for paleontologists of the former Soviet Union and of the Eastern Bloc countries.

65. Alexei Skrilov/ Алексеј Иванович Скрилев (*1894, Zlatoust , Russian Empire – †1979, USA), engineer land surveyors. Emigrated after the October Revolution and the Civil War – first generation. USA.

Alexei was born in Kuban, where his father served as a railway technician. It is called the Kuban Cossacks (the Kuban Cossacks – are the indigenous inhabitants of the the right bank of Kuban River and Azov region). Even as a child he lost his father and a cousin took him to be raised, moving with them from place to place. Only occasionally he could visit his mother and sisters. In Chelyabinsk, Alex graduated from the parish school, in Kursk and

Pskov - studied in middle schools for land surveyors. At the end he was appointed to serve in the Grodno land committee. At the beginning of World War I enlisted in the army and was promoted to officer. After the October Revolution in November 1917, he came from the Rumanian front in vacation to the Kuban and joined the squad of esaul K.L. Bardizh, then the white army of General Kornilov.

In 1920 he was evacuated to Serbia. After graduating from Belgrade Geodesic Academy, he served in public office, and later in private practice in the specialty. In 1924 he married the Hungarian Elizabeth Murai (*1904 – †1991). During the WW I, the area belonged to Yugoslavia, was occupied by the Hungarians. It so happened that twenty years later, during World War II, Alexei Ivanovich with the whole family came to Germany, lived in the camp Schleißheim for displaced persons. In October 1949 Alex went to the USA, where the first time made a living by simple physical labor, and later worked as an engineer - surveyor. He edited a book on the life of the Cossaks (Gubarev G.V. 1968). In the 60s, his sons Nicholas and Valerian successfully started his scientific career: Nicholas (*1929) became an economist, and Valerian Alekseevich Skrilov (1925) hid determined to serve the Standard Oil Company, where he specialized in water treatment of waste oil and other contaminants.

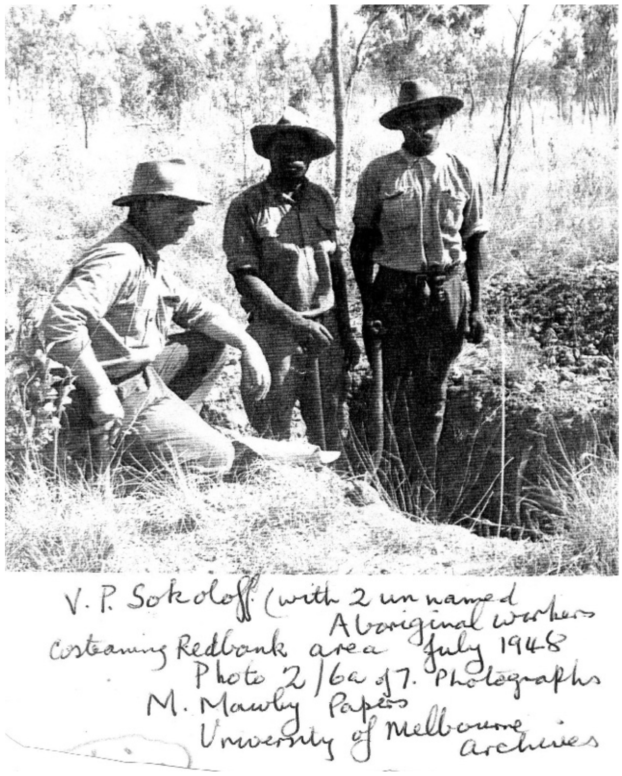
66. Leonid S. Smirnoff (*1937, Leningrad, Russia – †1991, Denver, Colorado, USA), geologist, PhD. Emigrated after the WW II. Alaska

L.S. Smirnoff (Archives VNIGRI, Russia)

Leonid Smirnov was born shortly before the Second World War and survived the famine in Leningrad blockade, was evacuated to the North Caucasus. After the war he returned to Leningrad and in 1958 graduated from the Mining Institute with a specialization in sedimentology, and worked as a geologist at the All-Union Research Geological Institute (VNIGRI), in 1970 he defended his Ph.D. thesis, has been developing methods to search for stratigraphic and lithologic traps for oil and gas on the basis of paleogeographic and lithological analysis, in northwest Caucasus, Western Siberia, the Polar Urals and Timan-Pechora province, published 20 articles in Russian. Russian colleagues say that he was confident and very purposeful person, liked to play football.

In 1976, he as a political refugee with no family (in Russia survived his wife and daughter) moved to the U.S. and worked mainly in Alaska, where he was prospecting and exploration of oil fields. He also taught at the University of Toronto and was considered an expert on „Arctic oil." He died in Denver at age 54 from cancer of the blood. Suggestions that the geological party, with his participation, has been exposed to radiation during the geological work in the Polar Urals, and Leonid Smirnov was the last member of the party who died from this terrible disease.

67. Vladimir P. Sokoloff / "Pete" (*1904, Tomsk, Russian Empire – †1995, Largo, Florida, USA), geologist, petroleum geologist, mineralogist, geochemist, physicist, Ph.D. Emigrated after the October Revolution and the Civil War – first generation. Maryland.



V.P. Sokoloff - on field research (D. Branagan, 2007)

It is not known when he came to the U.S., but most likely, after the October Revolution with his family, and later took U.S. citizenship. Already in 1933 V.P. Sokoloff studied geochemical research and implementation of the achievements of Russian geochemical schools in the U.S. and Australia (Branagan 2007). In 1937 he defended his thesis at the University of California at Berkeley. In 1943 Sokoloff worked in the US Geological Survey. His first report, "The search in the "Wallaroo-Moonta" 1948 in Broken Hill told about " Zinc Corporation ". He discovered in 1948 by geochemical (metallometric) works a zone with increased metal content, but, unfortunately, with low economic value, but laid the foundation for the application of geochemistry in exploration in Australia, make work more profitable. Since 1949, V.P. Sokoloff studied field search of gold in Western Australia, and in 1950 left the USGS due to weak interest for mass geochemical field work and went to work at Johns Hopkins University in

Baltimore, combining work with teaching at Johns Hopkins University, Isaiah Bowman School of Geography, Baltimore (Maryland). Here Sokoloff started to apply the metallometry in Archeological research.

In the period 1953–1956 in Israel he made a summary of the country's mineral resources for the American Geological Society, participated in archaeological work on the King-Solomon copper mine "Timna", where it was proved that these mines were not developed during the reign of King Solomon. In 1954, he probably studied humus soil for the Geographical Institute of Istanbul University. After returning from Israel since 1956 V.P. Sokoloff became a consultant to the U.S. Geological Survey and the oil company Shell, 1965 - consultant in Conzinc-Riotinto, in 1966 eight years in translation and editing of foreign (including Russian) geological literature in the American Geological Institute. After retirement, he moved to Miami and attended the Society of Engineers of the metallurgical industry in Florida. V.P. Sokoloff was a member of the Geological Society of Washington and the Cosmos Club and by nature - a sociable person and an interesting conversationalist.

68. Viacheslav Nicolas Sovinsky (*1894, the Russian Empire – †1962, Houston, USA), cartographer, geologist. Emigrated after the October Revolution and the Civil War – first generation. Texas.

Vyacheslav Sovinsky comes from a noble family, the son of Captain of the Navy, graduated from the Marine Corps in 1914, served in the Siberian Fleet, participated in the Civil War on the side of the White Army in the East with Admiral Kolchak. Vyacheslav emigrated from Russia to Bulgaria and then in 1923 made his way to the United States. Probably there he received a geological formation.

V.N. Sovinsky participated in the creation of the first, successful and still not repeated geographical map "Millionth Map of Hispanic America" - map of South and Central America on a scale 1:1.000.000 compiled based on the standards established by the International Geographical Union. Some of the group remained in the service of the Geographic Society for more than thirty years "(Tierney J.A. 1962; Pinther M. 2002). Then he worked as a geologist in Texas, studied the cyclic sedimentation in salt dome structures on the Mexico Gulf Coast, for the purposes of petroleum geology, studied the saliniferous groundwater, and worked on the geology of North America.

69. Taisia Maximovna Stadnichenko (*1894, village Taganash Dzhankoy area of Crimea, Russian Empire – †1958, Washington, DC, USA), geologist and geochemist, Ph.D. Emigrated after the October Revolution and the Civil War – first generation. Colorado?, Alasca.

Taisia graduated from middle school in Vladivostok and from the St. Petersburg University and received a geological formation. In 1917 was sent on an expedition by Geolkom to Sakhalin, and from 1919 to 1922 worked in the Far East. After the First World War, she came to the U.S. as a translator and a representative of the Russian peace mission; in 1922–1925 worked as a teacher of chemistry at Vassar College, then until 1931 - an assistant at the National Research Council and the American Petroleum Institute. In 1931 Taisia Stadnichenko received American citizenship and entered the US Geological Survey (USGS), has worked there with the scientist Charles David White (1862–1935), and worked there until his death in 1958. Taisia Stadnichenko studied the origin and condition of coal, oil, carbonate slates, including in Alaska , examined the effect of metamorphism of source rocks. She studied the problems of coal geochemistry and distribution of the chemical element germanium (which was very important for the production of transistors) and other trace elements in coal and oil, their economic value. She has published several articles on these topics, including posthumously in collaboration with Peter Zubovic and Nola B. Sheffey.

Anna Jaspers wrote about her: „Thaisia never lost his enthusiasm, helping others, especially young people, who accompanied her on her academic path, where there was a friendship around the world " (Jespersen A. 1959). In 1950 Taisia Stadnichenko was a member of the Geological Society of Washington, the Cosmos club, the Society of woman geographers.

70. Alexander Alexander Stoyanow (*1879 Zheleznovodsk on the Black Sea, Russian Empire – †1974, Los Angeles, USA), geologist, paleontologist, DSc. Emigrated after the October Revolution and the Civil War – first generation. Arizona.

In all probability, Alexander Stoyanow came from a Bulgarian family, who had left the Turkish Empire at the XIX century after the Russian campaign over the Balkan of General Field Marshal Ivan Dibich - Zabalkansky. The interests of the young Alexander to rocks, minerals and fossils (Lee Ch.A. & Schroter G.A. 1977; Mount J.D. 1990) influenced his decision to become a geologist. In 1899 he graduated from the University St. Vladimir in Kiev; in 1901 - received a Master of Science degree at Moscow University, and in 1904 - degree in mining engineering at the Mining Academy in Petrograd. In 1906 he defended his doctoral thesis at Moscow University and in the same year entered assistant at Russian Academy of Sciences in St. Petersburg. His numerous works, included the study of gold and non-metallic source rocks in northern Persia , the Caucasus, the border areas with China, and Saur and Tarbagat mountains and the Irtysh River basin . He studied the stratigraphy of Ararat, oil and rock structures northwest Caucasus. One time he led geological expedition in China, studying Chinese gold-bearing rocks in the mountains Quen moons. During the First World War, he continued to search for oil in Kurdistan and in Eastern Turkey, near the sources of the rivers Tigris and Euphrates. A.A. Stoyanow was an active member of the Russian Mineralogical and Paleontological Society.

His career in Russia ended in 1917, when he and his family emigrated to Finland on the ice of the frozen Lake Ladoga. His American colleague and friend, Dr. Charles Shuchert, Yale hired him and A.A. Stoyanow was doing research for his paleontological site of the Swedish island of Gotland. In 1921, on the instructions of Sinclair Oil Company he spent working in the Malay Archipelago. In 1923 Stoyanow became a professor at the University of Arizona in the United States; at 1927 began working as a geologist in the Arizona Bureau of Mines. He made an invaluable contribution to the study of Paleozoic and Mesozoic stratigraphy of Arizona. Since 1950, for 24 years he worked simultaneously at Caltech (California Institute of Technology) and at UCLA (University of California, Los Angeles), studying with students its rich collection of Paleozoic and Mesozoic fossils. This collection is now in the Natural History Museum of Los Angeles County, California.

During the 60s prof. A.A. Stoyanow was in correspondence with the Bulgarian paleontologist Dr. T.G. Nikolov, whom he advised on fossil ammonites in the Lower Cretaceous rocks of Bulgaria. Prof. Stoyanow wrote that he loves working with the students and this supports him young. He actively participated in the scientific activity of the Geological and Paleontological Society of America, was a member of society Sigma Xi. He has authored more than 30 scientific, mainly paleontological publications, most of which are leading to researchers around the world.

71. George Theokritoff (*?1930 Oxford shire, United Kingdom), paleontologist, Ph.D., Professor. Before the October Revolution. Vermont, New Jersey, Massachusetts.

George Theokritoff: 1990 (Internet: villanova.edu)

George Theokritoff was born in England, in the family of the Russian Archdeacon Vladimir Ivanovich Theokritoff (*1881 – †1950). Vladimir sang in the choir in the chapel at the Russian Embassy in London, and after the revolution remained in the UK. Later served as a priest, rector of the Russian church in London.

In London, George Theokritoff graduated as a geologist and paleontologist, studied the Ordovician and Silurian fauna Galway and Mayo in Ireland (diploma thesis). He defended his PhD thesis on the material of the eastern part of New York State and west-central Vermont. He has taught at colleges and universities in England, Canada and the United States.

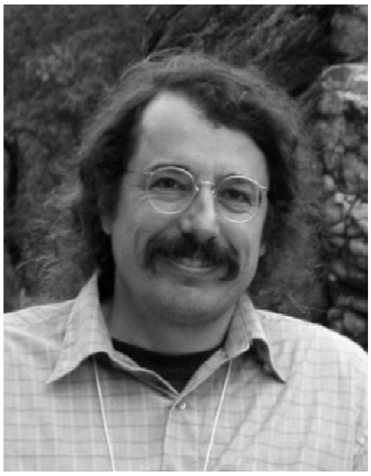
Sometime between 1951 and 1961 he worked not only in London but also in the Museum of Comparative Zoology at Harvard University in Cambridge (USA), University of New Jersey, and others. Since 1967 he has his academic career at the university Rutgers in the United States. He studied the Cambrian fauna (including trilobites) of Massachusetts, proved the similarity of the Paleozoic fauna of Ireland with the fauna of Massachusetts in the United States, Greece,Turkey, Finland and elsewhere. He also developed the theoretical foundations of the life on Earth, taking into account and including the philosophical aspect of this problem. On this occasion, he wrote articles together with his wife Elizabeth Ann Theokritoff, born Briere, (e.g. Theokritoff G. & Theokritoff E. 2002), who had a theological education, and having received his doctorate at Oxford (England), work as theological scholar.

After 27 years of work as a university professor George Theokritoff, retired in 1994. After retirement, he made geological

Dr Theology E.A. Theokritoff (Internet: iesdistance.org.ua)

excursions in Ireland, England, Scotland, Greece, Turkey and Finland, which, as he puts it, a good effect "on blood pressure and morale in general."

72. Basil Tikoff (*1965, USA), structural geologist, tectonician, associate professor. Emigrated after the October Revolution and the Civil War –third generation white emigrant. Wisconsin.



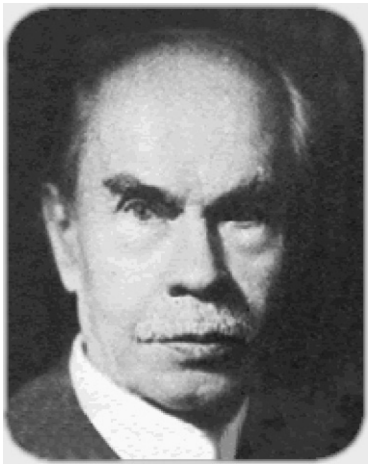
Basil Tikoff (Photo: Mrs. Maitri)

The grandparents of Basil Tikoff were ethnic Greeks living in Sevastopol, as their ancestors had for a generation or two before they moved to the Crimea from Northern Turkey. It is known that in the XIX century to the Crimea came a few thousand Greek refugees from the Ottoman Empire. The grandparents of Basil emigrated from Russia during the Civil War. The parents of Basil - cardiologist Gerasim E. Tikoff (*1933) and Edith Tikoff (*1937), both born in the United States and live in Chicago.

Basil himself received bachelor's degree in physics at Ohio in 1987 and a Ph.D. in geology and geophysics from the University of Minnesota in 1994; he worked first at the University of Minnesota. B. Tikoff is now since 1998 professor of structural geology and tectonics of the University of Wisconsin, Madison). Basil is engaged in the field of quantitative geology, using a combination of field studies, geophysics, physical (analog) and quantitative models to understand the spatial breach of the Earth's crust in three dimensions. Basil Tikoff teaches structural, historical and regional geology constantly goes with students at geological field trips.

Since the beginning of the XXI century, he is working on several projects: "The process of introducing of the granitoids and precipitation processes in magmatic arcs" in the United States and New Zealand (California, Idaho, New Zealand, Minnesota); "Deformation of rocks of the lower mantle in Australia"; "Deformation and primary flow traces ultra-metamorphic rocks "in Norway, New Zealand and New Caledonia"; "Global tectonics of the western United States ", etc. and is co-authors of many papers on the tectonics of the region – Bonamici C.E. *et al*. (2011), Gage J.R. *et al*. (2011), Titus S.J. *et al.* (2011), etc.

73. Innocent P. Tolmachoff (*1872, Irkutsk, Russian Empire – †1950, Pitsburg, USA), geologist, paleontologist, Dr., Professor. Emigrated after the October Revolution and the Civil War – first generation. Pennsylvania.



Tolmachoff (Internet: carnegiemnh.org)

Innocent Tolmachoff graduated from Physics and Mathematics Faculty of St. Petersburg University in 1897. He trained for several months petrography in Leipzig with prof. F. Tsirkelya and in Munich paleontology with Professor K.A. Zittel. In 1897 he was an assistant for two years at the Department of Geology at the University Yuryev, then appointed curator of the Geological Museum of the Imperial Academy of Sciences. Acquainted to work with Academician A.P. Karpinskys Innocent married his daughter Eugenie.

I.P. Tolmachev worked in Altai, Kuznetsk Alatai and the Yenisei province. In 1904, the Imperial Geographical Society seconded him in region of Turukhansk to prepare geological and geographical expeditions to study Yenisei and Anabara rivers (the basin River Hatangi). Since March 1909 Tolmachev directs annual Chukotka expedition from the mouth of the Kolyma River to the Bering Strait along the coast of the Arctic Ocean, which they performed on horseback, sled dogs and deer. In 1914 Tolmachov is scientific secretary of the created on his initiative at the Academy of Sciences the Polar Commission. In 1918 he was trying to avoid political pressure, went to Siberia professor of geology and mineralogy at the Agronomy Institute in Omsk.

In 1922, the Yale University professor Charles Schuchert recommended to the Director Avinoff the Professor I.P. Tolmachev as curator and Tolmachev moved to the United States. In 1922–1945 years – he is Curator of invertebrate paleontology, geology and mineralogy of the museum Carnegie in Pittsburgh. At the same time he is teaching paleontology at the University of Pittsburgh. During his stay at the Carnegie Museum in Pittsburgh (Pennsylvania), he has published 68 articles on a wide range of issues, from the geology of Siberia to the Cenozoic foraminiferes. In America, he was also engaged with the problems of the petroleum potential. I.P. Tolmachev - author of numerous articles published in Russia, Sweden, Switzerland and the USA. Under his leadership, students and graduates of the University of Pittsburgh assembled important collections of Western Pennsylvania and neighboring states. I.P. Tolmachev resigned from the post of curator of invertebrate paleontology section in 1945.

74. Count Ivan A. Tolstoy (*1923, Baden-Baden, Germany), marine geophysicist, acoustics physicist, mathematician, Ph.D. Emigrated after the October Revolution and the Civil War –second generation. New York State.

LANDS *of* EXILE

IVAN TOLSTOY

Archives M. Wiazemsky

Ivan is successor of the ancient princely family Tolstoy. Ivan's mother was Maria Pavlovna Shuvalov (*1894), and father - Andrey Dmitrievich Tolstoy (*1892 – †1963), who was born in Kiev and died in New York. In his book "Lands of exile" Ivan Tolstoy very colorfully describes his fate. Summary of the book: "Russian boy who was born in Germany, parents fled the Bolshevik revolution, growing in France, experiencing the Second World War against Germany and two occupations, runs through the mountains to the south of Switzerland, returns to Paris after the liberation, moved to the United States. There makes a successful career in science professor at several universities, emigrated to England and eventually visited - poured in Scotland. Life of Ivan Tolstoy was colorful and rich, sometimes contemplative and thoughtful – sayd he in an interview with Russian newspaper in Vladivostok during the Gorbachev era. The journalist described him as a true citizen of the world.

In France, Ivan Tolstoy graduated from the Sorbonne, then studied at Columbia University in the United States, where he received a Master of Geology in 1947, and three years later defended his thesis in geophysics (Ph.D.). Ivan Andreyevich Tolstoy and William Maurice Ewing in 1950 for the first time explained the occurrence of seismic T- waves. In Tolstoy ‘s 1953–67 worked as a researcher and director of the Hudson Secretary -ray lab at Columbia University in the U.S. Later he became a professor at Columbia University, has taught at several universities. He wrote in 1981 the biography of the physicist James Clerk Maxwell, creator of the theory of electromagnetic fields.

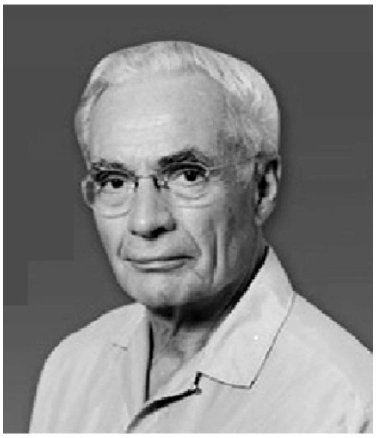
Initially, he worked as a marine geologist - geophysicist with the British structural geologist John Frederick Dewey. These studies laid the foundation of the theory of plate tectonics. In the late 40s he studied the topography and hydrography of the north Atlantic and Mid-Atlantic Ridge, participated in ocean expeditions. Now I.A. Tolstoy is known among his colleagues as a specialist in marine acoustics and applied mathematics. Becoming a physicist acoustician, he participated in the development of the theory of electromagnetic waves (Very Low Frequency, VLF). I.A. Tolstoy is a consultant in acoustics and applied mathematics for the study of underwater phenomena important to control submarines and shelf development. Ivan Tolstoy lived from about 1979 in Scotland.

75. Maya Ivanovna Tolstoy (*1967, New York, USA), marine seismologist, geophysicist, oceanographer, Ph.D., daughter of Ivan Andreyevich Tolstoy. Emigrated after the October Revolution and the Civil War – third generation white emigrant. New York State.

Maya Tolstoy (Personal archives)

In 1988, Maya Tolstoy received a master’s degree in University of Edinburgh, Scotland, and in 1994 - PhD in Scripps Institution of Oceanography, La Jolla, U.S.A., where she started his professional work. Since 1998, Maya Tolstoy worked as a researcher at the research institutes Lamont-Doherty Earth Observatory Columbia University. Maya - continuer the business of his father and spend a significant portion of time in the ocean expeditions to all oceans of the world (more than 27 expeditions), including under water. Together with other scientists of the institute is engaged in Maya Tolstoy surveillance and monitoring of earthquakes in the Mid-Atlantic Ridge, exploration and study of underwater volcanic eruptions in the Atlantic and Pacific oceans. This work - helps scientists understand the geological processes of formation of mid-ocean ridges and the impact of earthquakes and eruptions on the biological communities that live on the sea floor. M. Tolstoy - co-authored over 25 scientific papers on marine seismic data. In 2005, Maya can be seen in James Cameron’s “Aliens of the Deep” , where it is a group of scientists studying the mid-ocean ridges and submarine fauna.

76. Victor V. Vacquer (*1907, St. Petersburg, Russian Empire – †2009, La Jolla, CA, USA), physicist, electrical engineer, geophysicist, oceanographer, Ph.D., Professor Emeritus. Emigrated after the October Revolution and the Civil War – first generation. California.



V. Vacquer (Internet: ucsdnews.ucsd.edu)

Victor Vacquer parents escaped from Russian during the winter of 1920 and got to Helsinki (Finland), and then moved to France and from there in 1923 - in the United States. Victor received a degree in electrical engineering from the University of Wisconsin in 1927 and in physics in 1929.

Victor V. Vacquer worked for more than 70 years in science, was a professor at Scripps Institution of Oceanography in California (USA). He has worked in the field of geomagnetism in marine geology, engaged, including the development of new instruments and geophysical modeling. V.V. Vacquer is the inventor of the magnetometer for the aeronautical and marine magnetic survey, which led to the discovery of magnetic anomalies on the sea floor. His models play an important role in the formation of the theory of plate tectonics. He also made a major contribution to the geothermal research on seabed. He wrote several books and articles on these topics. Colleagues, who met with him at meetings on geothermics in Czechoslovakia, remember his soft but precise and unusually insightful comments.

V.V. Vacquer has received numerous awards for his pioneering work in the field of geophysics: the medal “Wetherill” of the Franklin Institute, the medal of John Adam Fleming of the American Geophysical Union, the award of the Fessenden Society of Exploration Geophysicists, the Alexander Agassiz medal of the U.S. National Academy of Sciences for his contribution to the study of geomagnetism, and tectonics. Victor Vacquer died at age 101.

77. Nicolas Varlamoff (* 1910, Don Region, Russian Empire – †1976 New York, USA), mineralogist Emigrated after the October Revolution and the Civil War – first generation. New York State.

Nicholas was born in a Cossack family, in the village between the Volga and the Don. When he was 10 years old, he and his parents fled from the Bolsheviks on horseback across the border. Around 1923 they lived in Belgium. In 1934, Vladimir received a first degree in mining engineering in the University of Liège, and two years later he graduated from the Faculty of Geology of the University. He began his career in Belgium, where he worked at the plant for the extraction of building materials.From 1934 to 1960 he worked Explorers in Zaire (then – Belgian Congo) (VARLAMOFF N. 1954), Rwanda and Burundi, Madagascar and other African countries. He was searching for deposits of rare metals, diamonds, coal, limestone and cement raw materials. In his work he applied methods and metallogenic study the propagation of mineral deposits, depending on the geological evolution of the continents, was a supporter of the theory of catastrophism. De Dicker in 1947, he conducted analytical work collected Varlamov collection set a new mineral species holomorphic rare cassiterite, calling his name Varlamov - "Varlamoffite".

In 1960, Nikolai Varlamov was forced to flee with his family from the Congo by rebellion against the indigenous population of the Belgian administration. For two years he worked in Chile , studying minerals in the desert attacks. From 1964 to 1975 he served as adviser to the United Nations (UN) in New York on mineral exploration in Africa and Madagascar. In 1971–73 Varlamov has described pegmatites of Central and West Africa , their relationship with the granites, as well as the dependence of mineralization faulting African platform .

N. Varlamov lectured at Queens College in New York (ALEXANDROV E.A. 1975): and is the author of 43 articles, mainly on deposits of rare metals. During his lifetime Varlamov held senior chief engineer and director of mining companies, owned four languages, including Swahili, was a member of the Académie Royale des Sciences d'Outre Mer and seven geological and engineering societies.

78. IMMANUEL VELIKOVSKY (*1895, Vitebsk, Russian Empire – †1979, Princeton, USA), cosmogeologist, doctor, science fiction writer. Emigrated after the October Revolution and the Civil War – first generation. New York.

I. Velikovsky (Internet: jimpoz.com)

Immanuel Velikovsky, one of the most interesting and best-known theoritician in cosmogeology and the origin of the solar system, is born in Belarus. He published his theories in the form of popular books available in a wide range of reader that has brought them a lot of popularity, especially in the west. Immanuel came from a wealthy family of the famous scientist - Hebraist (scientist studying the Hebrew language, writing, history, culture) Simon Yehiel Velikovsky (*1859 – †1937) and Bella Grodenska. Immanuel studied law and ancient history at the University of Moscow, medicine - in Moscow and Kharkov University, and received his medical degree. Moved in 1921 to Germany, he worked in the Berlin hospital „Charité"and in Zurich (Switzerland). In Germany, he founded the Berlin scientific journal "Scripta Universitatis", where Albert Einstein became editor of mathematics and physics. From 1924 to 1939 he worked as a doctor and psychoanalyst in Palestine. In 1939 Velikovsky and his family went to New York (USA), where he remained in connection with the outbreak of the Second World War. In America, he maintained close friendships with Albert Einstein, with whom they discussed their theories. Velikovsky formulated aspects of his own cosmo - geological theory of catastrophism, widely known, but rejected by many scholars. According to I. Velikovsky, the solar system was formed gradually, planets colliding with one another, and changed orbit. He believes that the last great cataclysm in the solar system occurred during the history of the humanity, proving that with the similar myths in all ancient religions. I. Velikovsky - author of science fiction books „Worlds in Collision", "The years of chaos", "Earth in the coup"(1950–1955), etc. and in them, he put forward his cosmological hypotheses.

79. GEORGE M. VESSELAGO (*1892, Kronstadt, Russian Empire – †1971, Menlo Park, California, USA), engineer in oil company. Emigrated after the October Revolution and the Civil War – first generation. State of Pennsylvania.

Veselago George graduated from the Marine Corps in 1911, was promoted to midshipman, became an officer in the operational headquarters of the Black Sea Fleet, and participated in the First World War. In 1915, during the Dardanelles operation, he was a liaison officer at the headquarters of the chief of the Allied squadron. As commander of the destroyer "Jarky" on the Black Sea Fleet , was dismissed at the request of the revolutionary sailors . In 1918 he collaborated with the new government, serving in leadership positions of the fleet in Murmansk. Since October 1918 G. Veselago was under investigation of the White Army as an "agent of the Soviet power." With the help of the U.S. mission in 1919, he left Murmansk, moved to France, where he represented the Kolchak government. In January 1920, he emigrated to India, then to Mexico, and later moved to the U.S., where he lived in Philadelphia, worked as an engineer and manager. In 1921–1925 serves in the Cortez Oil Corporation, in 1926–1954 works as engineer in the firm Day and Zimmerman, in 1954–1964 - in the company of Edward N. Hay and Associates, Inc. During the Second World War was lieutenant of the reserve of the American Navy. We have no more information about him.

80. BASIL B. ZAVOICO (*1899, St. Petersburg, Russian Empire – †1975, USA), petroleum geologist. Emigrated after the October Revolution and the Civil War – first generation. Oklahoma, Texas, California, Louisiana, Michigan and New York.

B. Zavoico (AAPG Bulletin)

The great-grandfather of Basil was Admiral Zavoico (*1810 – †1898), a Ukrainian born in Poltava , known in Russia, especially in Kamchatka and Amur, as hero of the defense of Petropavlovsk-Kamchatsky, and Governor of Kamchatka. The father of Basil was Vasily Stepanovich Zavoico (*1844), and the mother - Sofya Zavoico, died in St. Petersburg. Basil studied at the Moscow Institute of Technology, and in 1917 he emigrated with his father and brother Stepan (his mother had already died) in the United States. Basil continued his studies at MIT. During his life (Grandall K. 1976) he lived and worked as a geologist in many U.S. states: Oklahoma, Texas, California, Louisiana, Michigan and New York. Upon graduation, he worked for four years as geologist in the Sinclair Oil Company. The next eight years advising businesses on geological and economic issues. In 1929 he published the results of research on the geology and water supply of the city of Oklahoma. Since 1936 he is geologist and economist in the oil department of the Chase National Bank. Since 1943 held the post in the administration of petroleum industry of wartime, then until 1960 he was a consultant. Also after 1937 Bazil Zavoico collect and analyze data on the oil fields of the USSR, releasing in America regular status summaries of exploration and production of oil and gas in the Soviet Union. B. Zavoico was member of several American oil and geological professional societies, an active member of the Society of Russian engineers in the United States.

Conclusions

We have information for 81geologists of Russian origin, which are working or work in the United States of America. N.B. Periods of emigration: [1] – before the October revolution or their descendants; [2] – between the October revolution and WW II or their descendants; [3] – after the WW II.

Acknowledgments

We are grateful to Olga Dietl (Stuttgart, Germany) who helped us very much during the preparation of the Russian variant of the text for the geologists of Russian origin working all over the world.

Reference

Alexandrov E.A. 1975. Nicolas Varlamoff. An Appreciation. Varlamoff Nicolas. Curriculum vitae (typescript). – *Engineering and Mining Journal*, 1975.

Alexandrov E.A. 2005. The Russian in the North America, DrSc. Nikolay Prohorovich Prokopovich. -

Alexandrov E.A. Souvenirs (manuscripts, letters): Correspondance with A.F. Lebedev; Biographic vocabulary “Jardetsky Oleg Vyacheslavovich”.

Alexandrov E.A. 1980. Waclaw S. Fedukowicz. //Notes on the RAS in US (New York), vol. XIII.

Anderson R.R. & Bunker D.J. 1998. John Lemish (1921-1998). *Journal of sedimentary Research (SEPM),* 68/1.

Banjac N. & Dulić I. 2010. The influence of the Russian emigrants on the development of the Geology in Serbia. – 15th Congress of the Serbian geologists, Belgrade, 6-29. 05. 2010. *Zbornik Radova*, 736 (in Serbian).

Berdnikov L.P. 1995. P.K. Goudkoff. The all Krasnoyarsk power. Notes on the history and the local direction and the self-direction (1822-1916). – *Facts, events, people*. Krasnoyarsk.

Borsov N.V. 1947. Ivan Vasil’evich Kulaev: kul’turno-biograficheskii ocherk. Fond im. Kulaeva, San Francisko (In Russian).

Branagan D. 2008: Captain Eugene de Hautpick: a Russian ghost in Australian mining and geological history? *Proceeding of the Royal Society of Victoria*, 120, 1.

Branagan D., Gostinopolsky V. & Tchoumatchenco P. (in preparation). Geologists of Russian origin worked in Australia, New Zeeland, and Oceania – or Australia and Oceania? or in the Southeast Pacific region.

Branagan D., Tchoumatchenco P., Torrens H. & Whittaker A. (in preparation). The geologists of Russian origin from the British Isles.

Carter C., Churkin M. Jr *et al*. 1973. Biostratigraphic record extended to Early Silurian or Ordovician in western Brooks Range. *U.S. Geological Survey Professional Paper*, 850, 63–64.

Churkin M. Jr. 1971. Western boundary of the North American continental plate in Asia. *Bull. Of The Geological asociety of America*, 83/4: 1027–1036.

Diebold F.E., Lemish J. & Hiltrop C.L. 1963. Determination of calcite, dolomite, quartz and clay content of carbonate Rocks. *Journal of sedimentary Research (SEPM),* 33/1: 124–139.

Dunn P.J. 1983. Dwornikite. *In*: P.J. Dunn & M. Fleischer (eds.), *New Mineral Names*. *American Mineralogist*, 68: 642–645.

Ermolaeva N. 1986. Jardetsky Venceslas Sigizmundovich. *In*: The Russian diaspora. The golden book of the emigration (in Russian).

Ewing M., Jardetsky W. & Press F. 1957. *Elastic waves in layered media.* McGraw Hill Book. company, New York.

Fedukowicz W.S. 1975. Autobiography. Manuscript.

Foote M. & Hopson J.A. 1999. In memorian. J. John Sepkoski Jr. (1948-1999). *Acta Palaeontologica Polonica,* vol. 44, 2, 235–236.

Gubarev G.V. 1968. Dictionary of the Cossaks. A.I.Skrilov (edit.), Vol. II, San Anselmo.

Gul R. 1962. N.E. Efremoff.- N.Z. (Novyi zhurnal), New York, 69.

GRANDALL K.G.: Basil B. Zavoico (1899-1975). *AAPG Bull*., vol. 60, 5, 889.

In memoriam to Inna Vitalievna Poiret. – NRS, New York, 1959.

JARDETZKY O. 1986. Professor Wenceslas S. Jardetzky (1896-1962). *Acta geophysica polonica,* vol. 14 (in Polish).

JESPERSEN A. 1959. Taisia Maximovna Stadnichenko. – *The Geochemical news*, 15, 1959.

JOUKOVSKY A. 1995. On the bright memory of Vladimir Josifovich Okoulich. – *Vesnik rukovoditelya ORUR. October;* 431.

FOOTE M. & HOPSON J.A. 1999. In memorian. J. John Sepkoski Jr. (1948-1999). *Acta Palaeontologica Polonica,* vol. 44, 2.

KHILYUK L. & CHILINGAR G.F. 2006. On global forces of nature driving the Earth's climate. *Environmental Geology*, 50, 899–910.

KULAEV I.V. 1999. *Under a happy star. Souvenirs*. Moscow; 296 p. (in Russian).

LEE CH.A. & SCHROTER G.A. 1977. Memorial to Alexander Stoyanow 1879-1974. – *Geol. Soc. Am. Memorials*, v. 6.

LEMISH J. & J. 1960. *Jeff Carson, yung geologist.* 211p.

LEMISH J. 1974. Curriculum vitae. Archives of the Ass. Russ.-Amer. Scholary in the USA.

LOBANOV-ROSTOVSKY N. 2010. *Epoch. Destin. Collection*.- M., Russkyi put.

MANUCHAROVA N. 2008. Gorge Chilingar: If we will found petrol or gas in Armenia – this will be a great plus for us. *Novoe vremya* (in Russian).

MILTON C., EVANS H.T. JR. & JOHNSON R.G. 1982. Dwornikite, (Ni, Fe) $SO_4 \cdot H_2O$, a member of the kiserite group from Minasragra, Peru. – *Mineral. Mag.*, 46: 351–355.

MOUNT J.D.1990. Alexander A. Stoyanow (1879-1974), Pioneer Arizona geologist: A biographical bibliography. *Geoliterary Bulletin*, vol. 4, no. 3,

MORRISON D. & PHILLIPS L. 2011. That sinking feeling: Nikola Prokopovich papers on land subsidence and hydrocompactionm in California. – *University of California, Davis.*

Necrolog. 1991. Ilya Alexandrovich Mamantov. – NRS, New York.

OKOULICH V. I. 1971. Autobiography notes.

RAYMOND R.A. 1998. John Lemish (1921-1998). Geological Society of Iowa.

RUDOLPH J. 1928. *On the nationalization of natural resources, its forms and stages of development in different countries*. – University of Wisconsin, Madison.

Russian scientists – researchers of the Middle Asia. 1961. Romanovsky Genadyi Danilovich, v. 4, Tashkent, Gosizdat Uzbek SSR (in Russian).

SCHULTZ, C. 1962. Goudkoff, Paul Pavel (1880-1955). In: Biographies of geologists. Materials for the study of the history of geology, prepared in Geology 851, a seminar in the history of geology 1953 to 1958. *First Supplement. Columbus, Ohio: Ohio State University, Dep. of Geology*, 66.

TCHOUMATCHENCO P., DIETL O., DURAND DELGA M., WIAZEMSKY M., PETROUSSENKO S., BRANAGAN D., BANJAC N., DULIĆ I., YANEV Y., GOLONKA J., CZARNIECKI S., STANEK J., WITHTAKER A., TORRENS HEW, DIMOV G., GRADINARU E., LISSENKO-CEHLAROVA I. 2014 (in preparation). *Geologists of Russian origin in the world: destiny and contribution in the science. Scientific-encyclopaedic collection on the history of the geology*. – Sofia (in Russian).

TIERNEY J.A. 1962. Viacheslav Nicolas Sovinsky (1894-1962). *AAPG Bull., vol.* 46, 10.

VALANCE T.G. 1995. Database prepared from card index of Valance by D.F. & C.D. Branagan for the Earth Sciences History Specialist Group. *Geological Society of Australia*,

WILSON E.C.: Eulogy for George P. Kanakoff. – Typescript, March 15 1973.

Annex

Participation of the geologist of Russian origin in the different states of US

Alabama: 0
Alaska: 9 - Michael Churkin Jr.[2], Vadim Levin[3], Prince Nikita D. Lobanov-Rostovsky[2], Sergey S. Marchenko[3], Siemon William Müller[2], Inna Vitalievna Poiret[2], Vladimir E. Romanovsky[3], Leonid S. Smirnoff[3], Taisia Maximovna Stadnichenko[2];
Arizona: 4 - Alexander Andronikov[3], Irina Andronikova[3], Alexander Belousov[3], Alexander Stoyanow[1];
Arkansas: 1 - Edward John Dwornik[2];
California: 18 - Irina Artemief[3], Boris V. Brajnikov[2], Michael Churkin Jr.[2], Charles August Feldveber / Carl Tanner[3], Paul P. Goudkoff[2], Angela S. Jayko[2], George P. Kanakoff[2], Vitaly Khalturin[3], Ivan Kulaev[2], Siemon William Müller[2], Vladimir Joseph Okulitch[2], Nikola P. Prokopovich[3], Joseph Rudolph[2], Anatoly I. Safonov[2], Anatol James Schneider (OV)[2], Victor V. Vacquer[2], George M. Vesselago[2], Basil B. Zavoico[2];
Colorado: 4 - Vadim A. Litinsky[3]; Felix Persits[3]; Leonid S. Smirnoff[3]; Taisia Stadnichenko[2]
Connecticut: 1 -Dimitri Paul Krynine[2].
Florida: 3 - Waclaw Stanislavovich Fedukowicz[3], Sergei Pisarevsky[3], Vladimir P. Sokoloff[2];
Georgia: 0
Hawaii: 3 - Alexander N. Krot[3], Alex (Alexander E.) Malakhoff[3], Vladimir Joseph Okulitch[2];
Idaho: 1 - Vladimir Davydov[3];
Illinois: 1 - Stephen Marshak[2];
Indiana: 1 - Joseph Rudolph[2];
Iowa: 1 -John A. Lemish[2];
Kansas: 0
Kentucky: 0
Louisiana: 2 -Leonid Borissovich Listengarten[3]; Basil B. Zavoico[2];
Maine: 1 - Jack John Sepkoski Jr. / J.J. Sczcepkowski Jr.[1];
Maryland: 4 - Mark G. Leybson[3], Siemon William Müller[2], Anatol James Schneider (OV)[2], Vladimir P. Sokoloff[2];
Massachusetts: 0
Michigan: 4 - Boris Avdeev[3], John A. Lemish[2], Donald (Don) Arthur (Arturovich) Medvedev[2], Basil B. Zavoico[2];
Minnesota: 0
Mississippi: 0
Missouri: 0
Montana: 3 - John Aleinikoff[2], Prince Nikita D. Lobanov-Rostovsky[2], Jack John Sepkoski Jr. / J.J. Sczcepkowski[1];
Nebraska: 1 - Max Eliash (Eliashevich)[2];
Nevada: 1 - Michael Churkin Jr.[2];
New Hampshire: 0
New Jersey: 1 - George Theokritoff[1];
New Mexico: 1 - Joseph Rudolph[2];
New York: 18 - Jacob L. Delevsky[1], Nicholas Antonovich Efremov[3], Waclaw Stanislavovich Fedukowicz[3], Xenia G. Golovchenko[2], Paul P. Goudkoff[2], Louis Husakov / Louis Houssakoff[1], Wenceslas S. Jardetzky[2], Vitaly Khalturin[3], Ervand Gevorg Kogbetliantz[2], Stephen Marshak[2], Artem Romaevich Oganov[3], Rhoda Rappaport[2], Serge A. Scherbatskoy[2], count Ivan A. Tolstoy[2], Maya Ivanovna Tolstoy[2], Nicolas Varlamoff[2], Immanuel Velikovsky[2], Basil B. Zavoico[2];
North Carolina: 0
North Dakota: 0
Ohio: 1 - Captain Eugene H. De hautpick[2];
Oklahoma: 5 - Alex Mark Alexander[2], Max Eliash (Eliashevich)[2]; Joseph Rudolph[2]; Serge A. Scherbatskoy[2]; Basil B. Zavoico[2];
Oregon: 0
Pennsylvania: 6 - Alexander Belousov[3]; Captain Eugene H. De hautpick[2], Ervand Gevorg Kogbetliantz[2], Paul Dimitri Krynine[2], Innocent P. Tolmachoff[2], George M. Vesselago[2];
Rode Island: 0
South Carolina: 0
South Dakota: 1 - Jack John Sepkoski Jr. / J.J. Sczcepkowski[1];
Tennessee: 0
Texas: 11 - Paul S. Dvorkovich[1,2], Stephen I. Dworkin / Steve Dworkin[1], Max Eliash (Eliashevich)[2], P.V. Ingerman[3], S. Marchenko[2], Donald (Don) Arthur (Arturovich) Medvedev[2], Baron George von Mohrenschild[2], Joseph Rudolph[2], Viacheslav Nicolas Sovinsky[2], Basil B. Zavoico[2];
Utah: 2 - John A. Lemish[2], Joseph Rudolph[2];
Vermont: 2 – John Aleinikoff[2], George Theokritoff[1];
Virginia: 1 - Stephen Eugene Dwornik[1];
Washington: 6 - Stephen Eugene Dwornik[1], Edward John Dwornik[2], Inna Vitalievna Poiret[2], Anatol James Schneider (OV)[2]; Taisia Maximovna Stadnichenko[2], leonid s. smirnoff[3];
West Virginia: 1 - Captain Eugene H. De Hautpick[2];
Wisconsin: 1 - Basil Tikoff[2];
Wyoming: 2 - Serguei Goussev[3], Jack John Sepkoski Jr. / J.J. Sczcepkowski[1].

N.B. Periods of emigration: [1] – emigrated before the October revolution or their descendants; [2] – emigrated after the October Revolution and the Civil War and their descendants; [3] – emigrated after the WW II.

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The abstract must be concise, not more than 200–250 words, and should be informative, stating the results presented in the article rather than describing its contents. Inclusion of references in the abstract is not recommended.

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AGER, D.V. 1963. *Principles of Paleoecology*. 318 pp. McGraw-Hill, New York.

OWEN, E.F. 1962. The brachiopod genus Cyclothyris. *Bulletin of the British Museum (Natural History)*, *Geology*, 7 (2): 2–63.

RABRENOVIĆ, D. & JANKIČEVIĆ, J. 1984. Contribution to the study of Albian near Topola. *Geološki anali Balkanskoga poluostrva*, 48: 69–74 (in Serbian, English summary).

SMIRNOVA, T.N. 1960. About a new subfamily of the Lower Cretaceous dallinoid. *Paleontologicheskii Zhurnal*, 2: 116–120 (in Russian).

SULSER, H. 1996. Notes on the taxonomy of Mesozoic Rhynchonellida. *In*: COOPER, P. & JIN, J. (eds.), *Brachiopods*, 265–268. Balkema Press, Rotterdam.

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ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА
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