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Cover page: The remains of *Doliostrobus taxiformis* in the Late Eocene marl of Socka beds from Dobrna area (Slovenia). (Šoster et al., paper in this issue, photo: Aleš Šoster)

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Nekrolog

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Mineral composition of sediments underlying the Velenje lignite seam in the P-9k/92 borehole (Slovenia)

Mineralna sestava talninskih plasti velenjskega lignitnega sloja v vrtini P-9k/92

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Abstract

The paper presents the results of granulometrical, geochemical and mineralogical characterisation of sediments underlying the Velenje lignite seam as drilled through the P-9k/92 borehole in the central part of the Pliocene intermontane Velenje Basin. This study of differently lithified sediments/sedimentary rocks is based on analyses of 32 samples from 21 core intervals at the depth of 562.6–580.0 m (end of the borehole). Grain size was analysed on 12 samples, 24 samples were investigated geochemically, while mineral composition was obtained with X-ray diffraction (XRD) on 23 samples, and optical microscopy was performed on 7 samples. Granulometry of very low lithified samples revealed that they are mostly clayey silts (>85 % of the silt fraction), only two are silty sands and one is pebbly/rubbly sandstone. Well-lithified clastics are all sandstones cemented by calcite, siderite and/or marcasite. Geochemical analysis indicated that most samples are SiO_2 + Al_2O_3 rich (>60–80 %). Some sediments, mostly at the base of the profile, are enriched in Fe_2O_3 and inorganic C both indicating the presence of siderite. At the top of the profile, thin limestone and gravelly sandstone beds contain a high CaO content and have high loss on ignition (LOI). Qualitative XRD analysis and microscopy showed that all clastic sediments consist of quartz, kaolinite and muscovite/illite. Feldspars occur sporadically, mainly in sands and sandstones. Gypsum was found in some samples of siltstones. Pyrite occurs only in a sample of limestone at the top of the profile. Also marcasite was found only in one sample.

Izvleček

V članku predstavljamo rezultate granulometrične, geokemične in mineraloške opredelitve talninskih plasti lignitnega sloja, prevrtanega z vrtino P-9k/92, v osrednjem delu pliocenskega intermontanega (medgorskega) Velenjskega bazena. Raziskava različno litificiranih sedimentov oziroma sedimentnih kamnin obravnava 32 vzorcev iz 21-ih jedrnih odsekov v globini 562,6–580,0 m, to je do končne globine omenjene vrtine. Granulometrično je bilo analiziranih 12 vzorcev, geokemično 24, mineraloško z rentgensko difrakcijo (XRD) 23 vzorcev in mikroskopsko 7 vzorcev. Granulometrična analiza je pokazala, da so zelo slabo litificirani različki večinoma glinasti melji (>85 % frakcije melja), le dva sta bila meljasta peska in eden prodnati do gruščnati pesek. Mikroskopsko preiskani dobro litificirani klastiti so vsi peščenjaki, cementirani s kalcitom, sideritom ali markazitom. Geokemična analiza je pokazala za večino vzorcev prevladujočo SiO_2 + Al_2O_3 (60–80 %) sestavo. Zlasti v spodnjem delu profila je izstopajoča vsebnost Fe_2O_3 in anorganskega C, kar nakazuje prisotnost siderita. V zgornjem delu profila se pojavljata plasti apnenca in prodnato gruščnatega peščenjaka, ki sta nosilki visoke vsebnosti CaO in imata znatno žaroizgubo (LOI). Kvalitativna XRD analiza je pokazala, da vse preiskane vzorce sestavljajo kremen, kaolinit in muskovit/illit. Glinenci nastopajo večinoma v peskih in peščenjakih. V nekaj vzorcih meljev in meljevcev je bila določena sadra. Pirit je bil določen le v plasti apnenca v zgornjem delu profila, v najglobljem vzorcu peščenjaka pa je bil določen markazit.

Introduction

The Velenje lignite seam is up to 100 m, extremely even up to 165 m thick. It occurs approximately in the middle of the Pliocene to Pleistocene intermontane Velenje Basin (Fig. 1) which is filled with lacustrine, marshy and fluvial clastic sediments in a thickness of more than 1000 m (Fig. 2). The lignite is an ortho-lignite by rank, mostly xylite-rich, and of medium to low grade by its ash (mineral matter) content. The Velenje Basin and the lignite seam – its geometry, tectonics, petrology, inorganic and organic geochemistry, paleofloristic assemblages, genesis, quality, and reserves – have been thoroughly described and discussed in the following key works from the 1960s onwards: Drobne (1967), Šercelj (1968, 1987), Brezigar (1987), Brezigar et al. (1987, 1988),

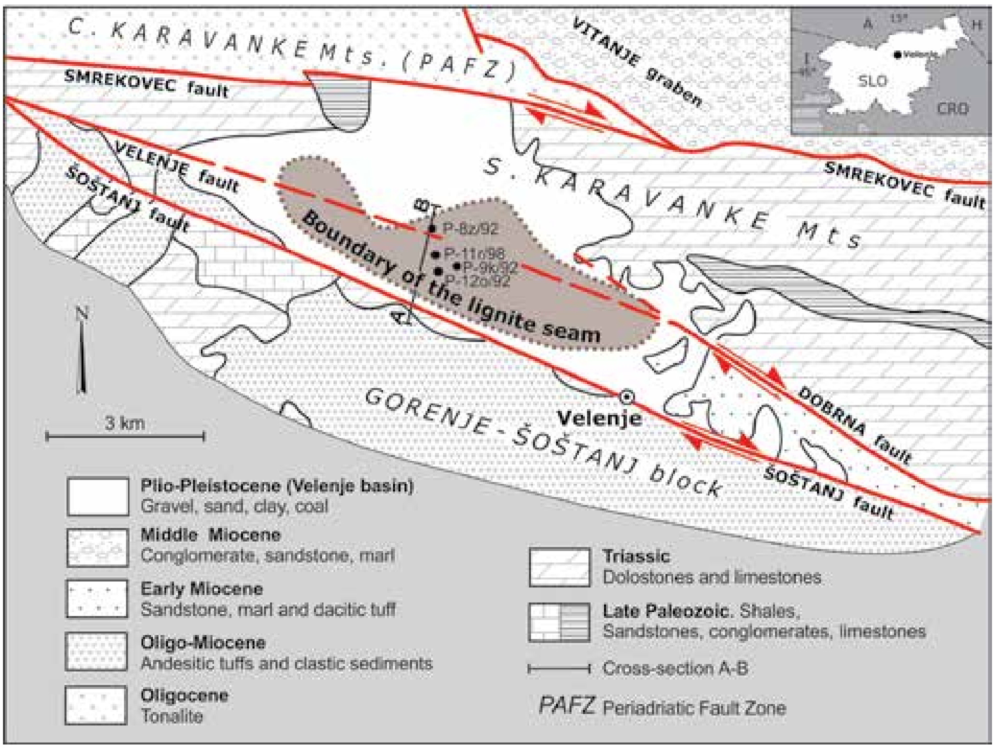

Fig. 1. Geological map of the lignite-bearing Velenje Basin (simplified after Brezigar, 1987, and Brezigar et al., 1987). Note the position of the P-9k/92 borehole and A-B cross-section shown in Fig. 2.

Sl. 1. Geološka karta Velenjskega bazena (poenostavljeno po Brezigar-ju, 1987 in Brezigar-ju et al., 1987). Prikazan je položaj vrtine P-9k/92 in prereza A-B na Sl. 2.

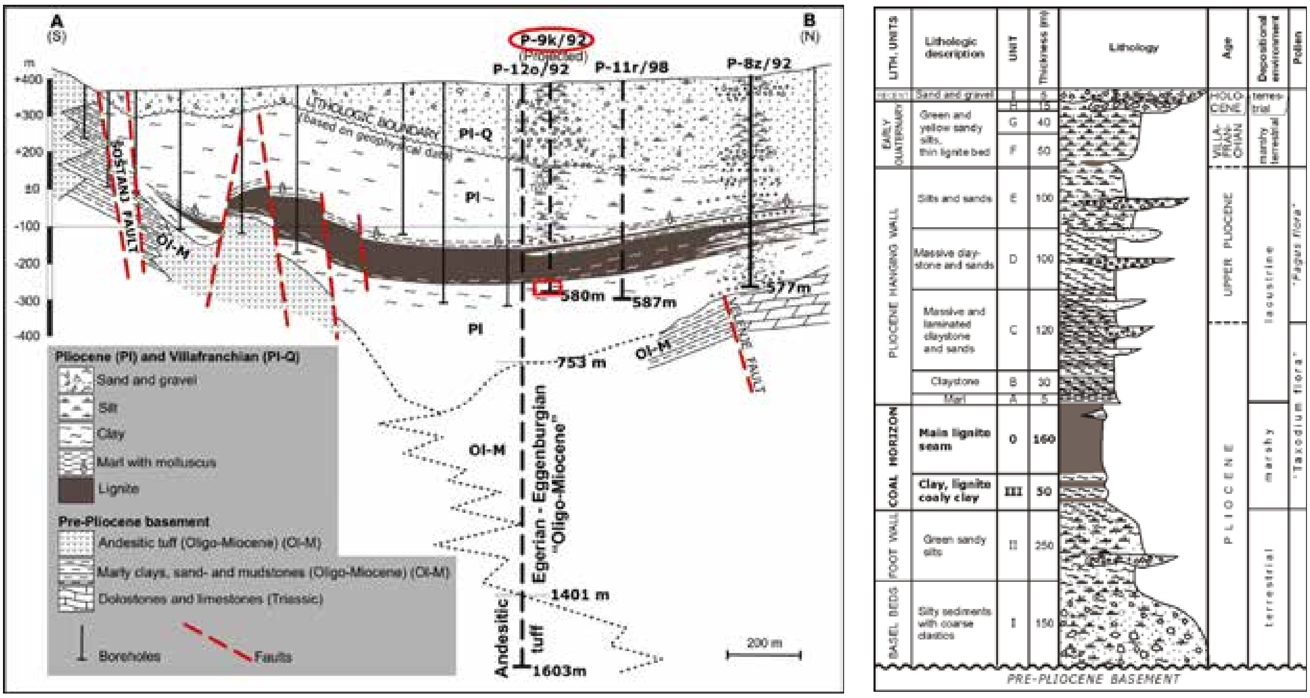

Fig. 2. Left: Geological cross-section A-B – adapted after Brezigar's (1987) profile 3-3'. Basic geological facts along the P-12o/92 are summarised from Veselič et al. (1993). Note the position of the lignite underlying sediments in the studied P-9k/92 borehole. Right: Representative litho-stratigraphic column of the Pliocene and post-Pliocene sedimentary fill of the Velenje Basin (after Brezigar, 1987).

Sl. 2. Levo: Geološki prerez A-B – prirejen po Brezigar-jevem (1987) profilu 3-3'. Podatki za globoko vrtino P-12o/92 so povzeti po Veselič-u et al. (1993). Prikazan je položaj talninskih sedimentov pod lignitnim slojem v vrtini P-9k/92. Desno: Značilni stratigrafski stolpec pliocenske in postpliocenske sedimentne zapolnitve Velenjskega bazena (po Brezigar-ju, 1987).

Pezdič et al. (1998), Veber (1999), Vrabec (1999), Vrabec et al. (1999), Bruch (in Hemleben, 2000), Markič et al. (2001), Bechtel et al. (2003), Veber & Dervarič (2004), Markič (2006), and Markič & Sachsenhofer (1997, 2010). Rock-mechanical methods of measurements, properties and modelling were introduced and studied by Ribičič (1985, 1987), Žorž et al. (1984), Kočar et al. (1988, 1989), Likar (1995), Psakhie et al. (2000, 2001), and Zavšek (2004). Basic questions concerning dewatering of different aquifers above and within the lignite seam have been mostly solved in the 1970s and 1980s (Veselič, 1985; Veselič et al., 1993). Hydrogeochemistry and the origin of

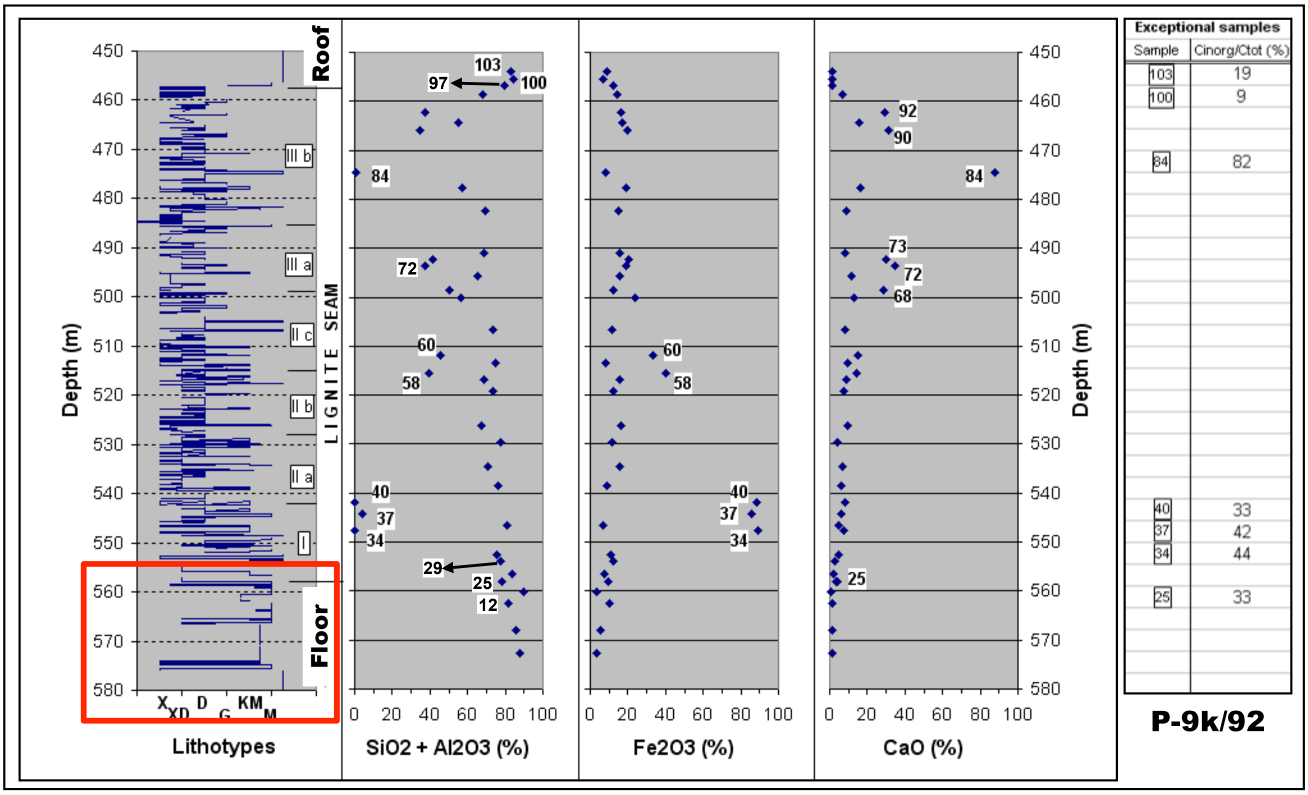

Fig. 3. Lithotype log of the lignite seam and contents of the main element oxides in the P-9k/92 borehole (Markič, 2006). The studied lignite underlying sediments at the depth of 560–580 m are marked as "floor".

Sl. 3. Litotipnost velenjskega lignitnega sloja in vsebnosti oksidov glavnih prvin v vrtini P-9k/92 (Markič, 2006). Talninski sedimenti, obravnavani v tem prispevku, so označeni kot "floor".

groundwaters were studied by Mali & Veselič (1989), while the monitoring of water drainage was summarised by Fijavž (2002). Zapušek & Hočevar (1998), Pezdič et al. (1999), Žula et al. (2011), Likar et al. (2008), Likar & Tajnik (2013) studied gas (mostly CO_2) adsorption/desorption properties of different lignite lithotypes, whereas the chemical composition of the lignite gasses (sampled in the mine), their origin and dynamics were thoroughly analysed, described and interpreted (especially using stable isotopes) by Kanduč & Pezdič (2005), Kanduč et al. (2003, 2011), Lazar et al. (2014). Even though it has been carried out for a long time already, a systematic study in how to degasify the lignite seam more successfully has been intensified in the recent years (Jamnikar et al., 2015). Most recently, monitoring and modelling of gas dynamics during exploitation in the Velenje lignite seam has been studied and published by Si et al. (2015a, 2015b). In their study, the Velenje lignite served as a general case for monitoring and modelling gas dynamics within ultra-thick coal seams during the mining process of multi-level longwall top caving. The most recent hydrogeological study was about groundwater/surface-water interaction based on geochemical and stable isotopic investigations (Kanduč et. al., 2014).

The aim of this paper is to present the results of petrological and mineralogical investigations of sediments that underlie the Velenje lignite seam in the P-9k/92 borehole (Fig. 3) located in the centre of the Velenje lignite-bearing Basin. This borehole was chosen because it is a key borehole in which the lignite has been thoroughly studied petrologically (Markič & Sachsenhofer, 1997, 2010), geochemically (Bechtel et al., 2003; Markič, 2006), and in the very close vicinity (in P-11r/98 – see Figs. 1 and 2) also paleobotanically (Bruch – in Hemleben, 2000).

Lithological, mineralogical, and geochemical investigations presented in this paper have been carried out by the first author of this paper in the frame of her B.Sc. Thesis work at the University of Ljubljana – Department of Geology (Čeru, 2013). Before that, petrological characterisation of the lignite underlying sediments had not attracted any special interest. The reason was probably that the lignite underlying sediments (also termed "footwall" or "floor" sediments) were not problematic from the coal-mining point of view. It was only Brezigar (1987) who published that the footwall sediments consist of clays/claystones, coaly clays, silts/siltstones, sands/sandstones, and also of gravels at the base. The thickness of the entire sedimentary fill between the pre-Pliocene sediments and the lignite seam is from a couple of metres to 450 m, depending on the position within the basin and the tectonic displacement of the pre-Pliocene basement, respectively. The pre-Pliocene basement is composed of a wide spectrum of carbonate, siliciclastic, volcaniclastic and magmatic rocks, from Paleozoic to Miocene in age (Mioč & Žnidarčič, 1976; Mioč, 1978; Brezigar et al., 1988) (Figs. 1 and 2). These rocks gave the sedimentary material that filled the basin. The southern hinterland of the Velenje Basin is mostly built up of volcaniclastic deposits of prevailingly andesitic and subordinately dacitic composition (also known as the Oligocene andesitic tuff) of the Smrekovec Volcanic Complex (Kralj, 2013). Areas to the north of the basin are composed of Triassic limestones and dolostones (Mioč & Žnidarčič, 1976), and further to the north of the Oligocene tonalite of the Central Karavanke Mountains (Faninger, 1976).

The bottom part of the sedimentary fill is characterised by coarse clastics, which grade upwards into finer clastics, and finally to clayey silts/siltstones, organic matter-rich and coaly mudstones, mineral-rich lignite and lignite.

Published information about mineralogical composition of the Velenje lignite underlying sediments is very scarce. In the overview study of non-metallic raw materials in the Šalek Valley only Štern et al. (1988) described the so-called "white footwall clay". It occurs in the northern periphery of the Velenje Basin above the "dolomite (Triassic) threshold", where the lignite seam lies close to the carbonate basement. The clay – in fact silty clay – is of the illite-kaolinite type, composed mainly of quartz, muscovite/illite, kaolinite, and feldspars. The thickness of the "white footwall clay" is variable, 12.7 m at most. According to Štern et al. (1988) it could be used as a ball clay but it lies too deep underground to be economically exploitable.

The "white clay" is not present in our studied profile because it is situated in the centre of the basin, quite far from the dolomite threshold.

Studying coal's underlying sediments in coal mines is in most cases primarily important from the rock-mechanical point of view because mine workings often run at least partially in such "coal's footwall" strata. Among the rock-mechanical parameters, load capacity, strength, and possibility of swelling are the most crucial ones. They are primarily dependent on the degree of lithification, tectonic deformations, water content, and mineral composition. Montmorillonite- (Na, Ca, Mg clay-mineral) bearing clays are especially undesirable due to their expanding behaviour in the presence of water. In many cases of coal deposits, mudrocks are the predominant lithology of strata just below a coal seam. They most often represent a final stage of the fining upwards sequences which preceded the development of peat-forming environments. In the time of biomass deposition, coal underlying sediments influenced the geochemistry of the standing waters. The type and abundance of dissolved chemical elements, salinity, acidity (pH), the redox potential (Eh), and the activity of bio-organisms governed processes of either precipitation or leaching of special chemical elements or minerals as well as processes of biochemical transformations of the organic matter during the early peatification/coalification process, known as the biochemical stage of coalification (Stach et al., 1982; Diessel, 1992; Taylor et al., 1998). The topography just before the development of a peat-forming environment probably also governed the distribution of different types of biomass, e.g. wet versus dry forest swamps, bush moors, fens, moss and grass lands.

The authors are aware that the extent of the studied sediments in the P-9k/92 borehole is quite small in relation to the whole complex of the lignite underlying sediments. However, number of archived samples (25) and the interval studied (the depth of 560–580 m), were the most optimal in relation to available samples from some other wells (P-12o/92, P-8z/92, and P-11r/98).

Sampling and analytical methods

Our study of the lignite underlying sediments from the Velenje P-9k/92 borehole is based on collection, macroscopic description, granulometry, optical microscopy of standard thin sections, X-ray diffraction (XRD) and geochemical analysis of 32 samples. They were collected from 21 core-samples, representing 0.2–2.0 m long intervals (Fig. 4, Tab. 1). Prior to the beginning of this research, the samples were archived for almost 20 years in PVC bags in the rock samples depository of the Geological Survey of Slovenia. Core samples 1–21 were treated as whole samples (if homogeneous), or divided into two or three sub-samples (if heterogeneous) and marked with "a", "b", and "c". The types of analyses are given in Tab. 1.

The chosen samples were macroscopically described and photographed (see results and Fig. 5).

The 12 compact but not lithified samples which were easily split into smaller fragments by hand, then gently crushed in an agate mortar and/or disintegrated by drowning into water for 48 hours, were granulometrically analysed with the laser diffraction particle size analyser Analysette 22. The following groups of fractions were separated: <0.002 mm (clay), 0.002–0.063 mm (silt), 0.063–2 mm (sand), and >2 mm (gravel). Three of the 12 samples, which were coarse grained, were also manually dry sieved and separated into the following fractions: <0.125 mm, 0.125–0.25 mm, 0.25–0.5 mm, 0.5–1 mm, 1–2 mm, 2–4 mm, and > 4 mm.

Well-lithified 7 samples were saw-cut (if visible, perpendicular to bedding) and prepared as thin sections for optic microscopy in transmitted light. Each sample was carefully petrographically described (Čeru, 2013), while its mineral composition was defined semi-quantitatively. In this paper, specific lithologic types are outlined and presented as groups of samples. Representative mineral compositions are described in detail and presented as microphotos in Plates 1–5.

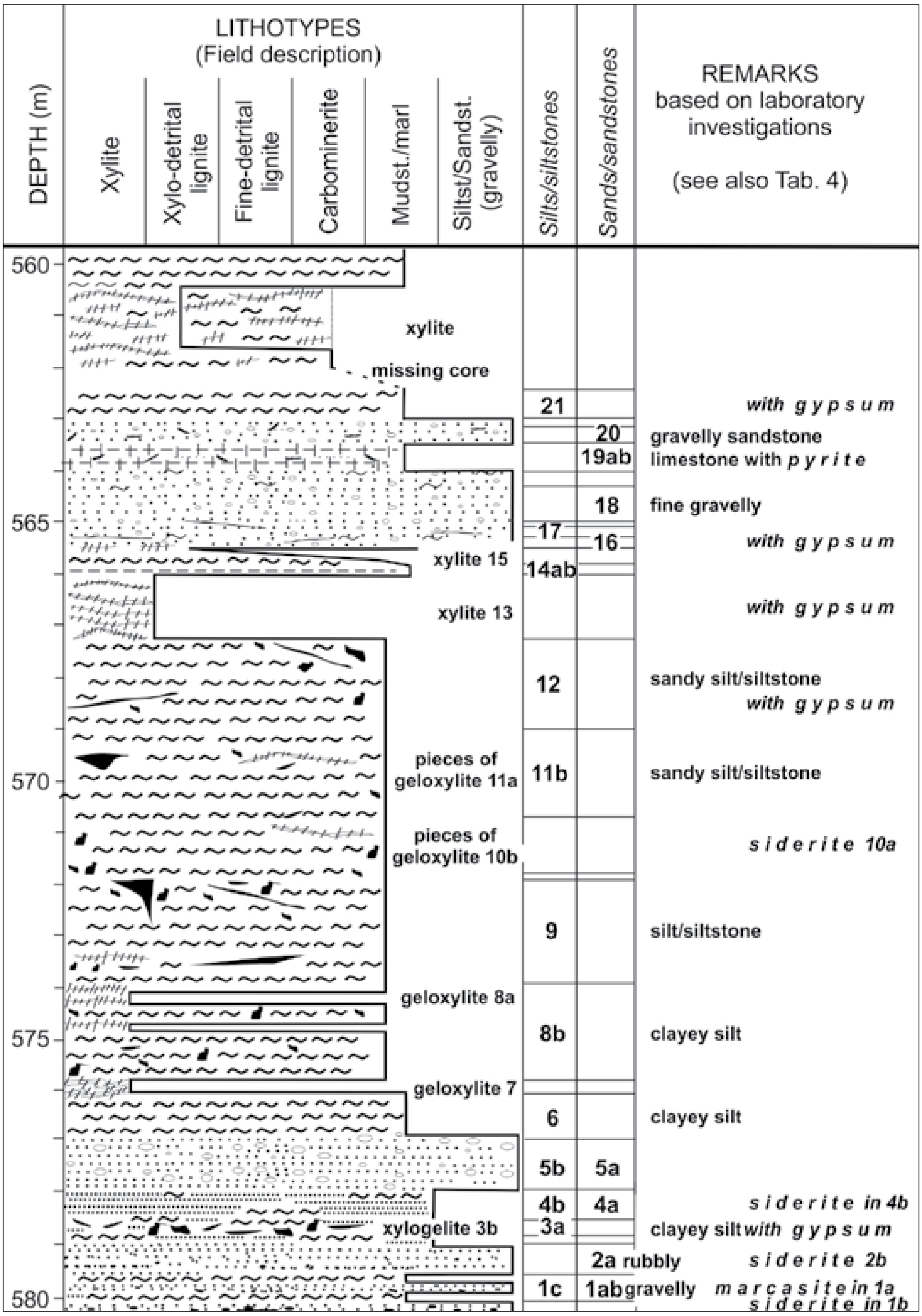

Fig. 4. Lithotype log and sampling of the lignite underlying sediments in the P-9k/92 borehole.

Sl. 4. Litotipnost in vzorčenje talninskih sedimentov v vrtini P-9k/92.

For the XRD analysis, 23 samples were pulverised. Each sample weighted ca. 50 g. Pulverizing was done by milling in a Co/W ring mill. The XRD was carried out at the Department of Geology – University of Ljubljana on the PHILIPS PW3710 Difractometer at the voltage of 40 kV, electric current of 30 mA, and the CuKα wavelength of 1.54060 Å. The X'Pert HighScore Plus programme and the PAN-ICSD data basis were used for the XRD qualitative estimation of the mineral composition. Identification of minerals was done according to Brindley & Brown (1980) and Moore & Reynolds (1997).

The same samples as for the XRD and one additional sample, all weighting ca. 10 g, were prepared also for geochemical analysis. Inductively coupled plasma/atomic emission spectrometry (ICP/AES) was used to determine the main oxides, whereas ICP/MS (mass spectrometry) was applied to determine trace elements. The total sulphur (Stot.) and the total and organic carbon (Ctot., Corg.) were determined with Leco. The difference between Ctot. and Corg. is considered as the inorganic carbon (Cinorg.). The loss on ignition (LOI) was determined on the basis of the weight loss

Table 1. Types of analyses of 32 samples from the lignite underlying sediments in the P-9k/92 borehole. Samples are from 21 depth intervals, which are 0.2 to 2.0 m long. Shaded are lignite samples, which were described only macroscopically.

Tabela 1. Vrste analiz 32-ih vzorcev iz 21 globinskih intervalov talninskih sedimentov v vrtini P-9k/92. Dolžina intervalov 0,2–2,0 m. Osenčeni so vzorci lignita, opisani le makroskopsko.

Sample	Depth (m)	Macroscopic description	Granulometry	Optical microscopy	Geochemical analysis	XRD analysis
21	563.00 – 562.60	x			x	x
20	563.50 – 563.15	x		x	x	x
19b	564.00 – 563.60	x			x	x
19a	564.00 – 563.60	x		x	x	x
18	565.00 – 564.35	x	x		x	x
17	565.30 – 565.10	x	x		x	x
16	565.50 – 565.30	x	x		x	x
15	565.80 – 565.50	x				
14b	566.00 – 565.80	x	x		x	x
14a	566.00 – 565.80	x	x			
13	567.35 – 566.00	x			x	x
12	569.00 – 567.35	x			x	x
11b	570.75 – 569.00	x			x	x
11a	570.75 – 569.00	x				
10b	571.75 – 570.75	x				
10a	571.75 – 570.75	x		x	x	x
9	573.95 – 571.95	x			x	x
8b	575.85 – 573.95	x	x		x	x
8a	575.85 – 573.95	x				
7	576.05 – 575.85	x				
6	577.00 – 576.05	x	x		x	x
5b	577.95 – 577.00	x	x		x	x
5a	577.95 – 577.00	x	x		x	x
4b	578.55 – 577.95	x	x		x	x
4a	578.55 – 577.95	x		x		
3b	578.85 – 578.65	x				
3a	578.85 – 578.65	x	x		x	x
2b	579.50 – 578.90	x		x	x	x
2a	579.50 – 578.90	x			x	
1c	580.00 – 579.50	x	x		x	x
1b	580.00 – 579.50	x		x	x	x
1a	580.00 – 579.50	x		x	x	x

on heating at 1000 °C for 1 hour. Geochemical analysis was done in the ACME Laboratories in Vancouver (Canada) according to their well-established procedures (Acme Labs Schedule & Fees, 2012 – Groups 4A and 4B, and 2A for Leco).

Results and discussion

Macroscopic description

The macroscopic appearance of the main lithologic varieties from the lignite underlying sediments in the Velenje P-9k/92 borehole is presented with photographs in Fig. 5.

Photos 1–4 (samples 1c, 6, 9, 17 – see Fig. 4 for position) represent compact clayey silts. The most compacted is sample 9 (photo 3), but we did not succeed in preparing a thin section of it. However, it was also too lithified to be disintegrated for granulometric measurements, as we did with the other three samples (1c, 6, 17).

Photo 5 (sample 10a) shows siderite (cut view at the bottom) covered with geloxylite (surface view), and photo 6 (sample 2b) is siderite concretion within sandstone. Very similar to sample 2b is sample 4a.

Photo 7 (sample 1a) is a gravelly sandstone. It was sawn through and a thin section was prepared.

Photos 8, 9 and 10 (samples 5a, 18 and 16) show compact silty sands (samples 5a and 16) and a gravelly sand (sample 18). All three samples were disintegrated in water and granulometrically analysed both by dry sieving and the laser analyser.

Photos 11 and 12 (samples 19b and 20) both show lithified slightly gravelly sandstone composed of quartz, feldspars and clay (kaolinite). The sandstone is calcite-cemented. It reacts with diluted HCl.

Fig. 5. Photographs of characteristic lithologic varieties: Photos 1–4 (samples 1c, 6, 9, 17): compact clayey silts; Photo 5 (sample 10a): siderite coated with geloxylite; Photo 6 (sample 2b): siderite concretion within sandstone; Photo 7 (sample 1a): gravelly sandstone; Photos 8, 9, 10 (samples 5a, 18 and 16): compact silty sands (photos 8 and 10) and a gravelly sand (photo 9); Photos 11 and 12 (samples 19b and 20): lithified slightly gravelly calcite-cemented quartz sandstones.

Sl. 5. Fotografije značilnih litoloških različkov: Foto 1–4 (vzorci 1c, 6, 9, 17): kompaktni glinasti melji; Foto 5 (vzorec 10a): siderit, obdan z geloksilitom; Foto 6 (vzorec 2b): sideritna konkrecija v peščenjaku; Foto 7 (vzorec 1a): prodnato-gruščnati peščenjak; Foto 8, 9, 10 (vzorci 5a, 18, 16): kompaktni meljasti pesek (foto 8 in 10) in prodnato-gruščnati pesek (foto 9); Foto 11 in 12 (vzorca 19b in 20): litificiran prodnato-gruščnati kremenov peščenjak s kalcitnim vezivom.

Concerning the term “sediments” as used in this paper for the “lignite underlying sediments” we suggest to the reader to keep in mind that we are discussing about Neogene lithology, which is mostly considered to be composed of sediments, not sedimentary rocks. In the broad literature, as well as colloquially, we normally encounter to terms such as “Tertiary sediments”, “Neogene sediments”, “sediments of the Pannonian Basin” etc. The reason for the term “sediments” in these cases is the fact that the Neogene lithologies are generally not yet “totally” cemented and lithified as are “true sedimentary rocks” from Mesozoic and older geological formations, for example. Strictly speaking, the term “sediment” is restricted only to designation of a loose material, e.g. clay, silt, sand,

Table 2. Granulometric composition of samples which were easily disintegrated. Siltstone samples 1c–17 are listed from the lower to the upper part of the lithologic column in Fig. 4.

Tabela 2. Granulometrična sestava kompaktnih vzorcev, ki jih je bilo mogoče z lahkoto dezintegrirati. Vzorci meljevcev 1c-17 so navedeni po litološkem stolpcu (sl. 4) od spodaj navzgor.

Sample	CLAY <2 µm (%)	SILT 2-63 µm (%)	SAND 63 µm-2 mm (%)	GRAVEL >2 mm (%)	Particle size distribution classification	Sedi-ment name
17	13.82	85.53	0.65	0	slightly clayey silt	Clayey SILTS
14b	6.57	92.09	1.34	0	very slightly sandy slightly clayey silt	
14a	18.42	81.41	0.17	0	slightly clayey silt	
8b	14.76	85.24	0	0	slightly clayey silt	
6	14.36	84.52	1.12	0	very slightly sandy slightly clayey silt	
5b	12.63	85.97	1.40	0	very slightly sandy slightly clayey silt	
4b	14.84	84.64	0.52	0	slightly clayey silt	
3a	16.22	83.78	0	0	slightly clayey silt	
1c	27.20	71.21	1.59	0	very slightly sandy clayey silt	
18	1.86	23.79	51.69	22.66	gravelly silty sand	Silty/ grav. SANDS
16	1.82	28.11	69.40	0.67	very slightly clayey silty sand	
5a	5.09	36.32	57.79	0.80	slightly clayey silty sand	

or gravel. When loaded under succeeding sediments, losing air and water, and becoming less porous, "sediment" transforms to a "compact material". If such "compact materials" can still be disintegrated in a laboratory by hand, by gentle crushing (with no fracturing of mineral grains), and/or finally by drowning in water for some tens of hours, we can still call such materials "sediments". Therefore, we apply the term "sediments" to all materials which were granulometrically investigated by dry sieving or by the laser diffraction method, whereas we use "-stones" for materials from which we were able to prepare thin sections. The materials in between, which could neither be sieved nor thinly sliced, we arbitrarily designate as a "sediment/-stone", e.g. silt/siltstone etc.

Granulometry

As already mentioned, granulometry was carried out on samples of compact but not yet cemented and well-lithified sedimentary materials. Results are given in Tab. 2. In the set of samples 1c to 17, the silty fraction highly predominates with a share of more than 80 %. The sandy fraction is negligible, it is below 2 %. The clayey fraction is below 20 %. The only exception is sample 1c with 27 % of the clay fraction. In general, all samples from 1 to 17 in Tab. 2 are clayey silts.

Samples 5a and 16 are silty sands with negligible (<5 %) clay and gravel fractions.

Sample 18 contains a considerable gravel fraction (23 %). It was not the only gravelly sample in the whole suite, but other gravelly samples were more lithified, thus not suitable for the sieving analysis, but for preparing thin sections.

In the gravelly fraction, rounded and angular grains are distinguished, the first termed as "pebbles" and the second as "rubbles". If only grain size is discussed, both extreme grain shapes are unified under the term "gravel".

Granulometric composition of the sediments in Tab. 2 is additionally presented in triangular diagrams in Figs. 6 and 7.

A large proportion of silt, clay and organic matter indicates a dominantly low-energy depositional environment. Furthermore, on the basis of low sorting and asymmetric grain-size distributions (Čeru, 2013, p. 83) a short transport of these sediments can be presumed. On the other hand, coarse-grained sedimentary rocks reflect intense events and increased fluvial input of terrigenous material from the south and also from the north into the sedimentary basin.

Geochemistry

In this paper we take into consideration only the bulk geochemical analysis, which includes the determination of oxides of the main rock-forming elements such as Si, Al, Fe, Mg, Ca, Na, and K, plus Loss on Ignition (LOI), Ctot. and Corg. The results of the geochemical analysis are presented in Tab. 3 in which samples are grouped according to their main outstanding geochemical characteristics, that is: samples with increased Fe_2O_3 contents, increased CaO contents, increased $SiO_2 + Al_2O_3$ contents, and samples with outstanding organic matter content.

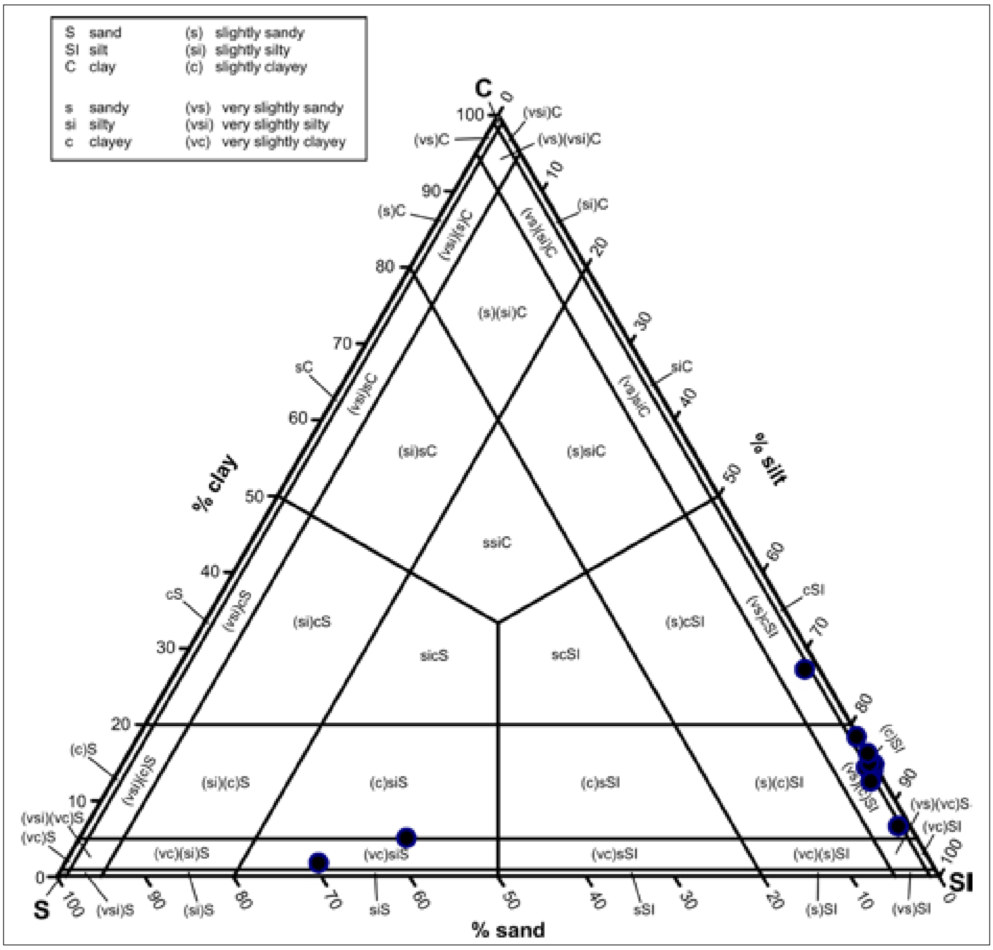

Fig. 6. Triangular diagram Sand-Silt-Clay (after Blott & Pye, 2012) showing a predominance of the clayey silt composition of the granulometrically investigated samples. Two samples are silty sand.

Sl. 6. Trikotni diagram pesek–melj–glina (po Blott & Pye, 2012) za granulometrično preiskane vzorce. Večina vzorcev je glinasti melj, dva pa sta meljasti pesek.

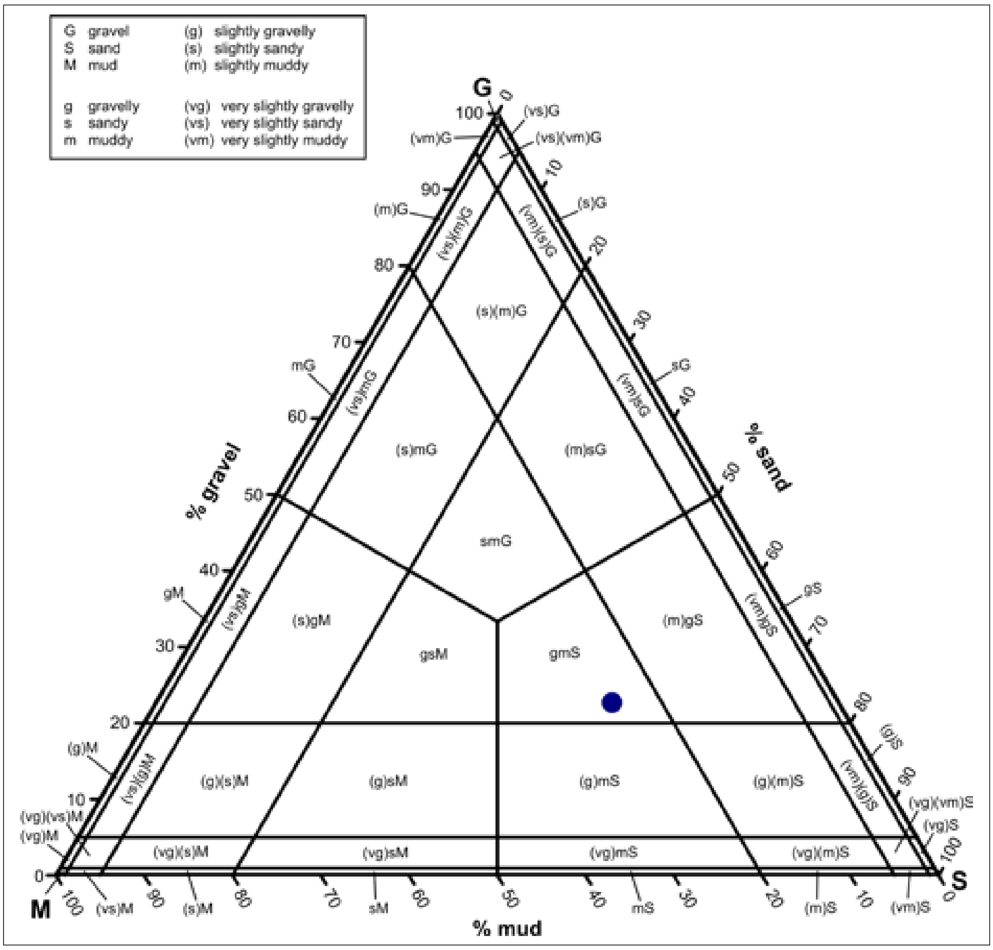

Fig. 7. Triangular diagram Mud-Sand-Gravel (after Blott & Pye, 2012) showing the granulometric composition of sample 18, which is gravelly muddy sand.

Sl. 7. Trikotni diagram mulj-pesek-prod prikazuje (po Blott & Pye, 2012) sestavo vzorca 18, ki je prodnato muljasti pesek.

Table 3. Basic (main elements) geochemical analysis of investigated sediments in the lignite underlying sediments of the P-9k/92 borehole, and geochemically distinguished groups of samples.

Tabela 3. Osnovna geokemična analiza preiskanih vzorcev talninskih sedimentov pod lignitnim slojem v vrtini P-9k/92 in geokemično ločljive skupine vzorcev.

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	LOI	Ctot	Corg	Groups of samples
	%	%	%	%	%	%	%	%	%	%	
1a	49.2	8.6	19.3	0.3	0.6	1.4	1.3	18.8	0.2		**High Fe_2O_3**
1b	52.8	10.4	15.6	1.1	1.8	1.2	1.6	14.6	3.8	1.4	
2b	11.7	3.2	48.7	0.7	3.6	0.3	0.4	29.2	9.3		
4b	35.8	12.2	20.3	2.0	3.3	0.4	1.5	23.6	7.1	3.7	
10a	4.9	2.8	49.2	1.4	4.3	0.1	0.4	35.5	12.1	5.6	
19a	15.0	5.4	6.5	0.8	35.7	0.1	0.7	34.6	11.1		**High CaO**
19b	51.4	9.3	0.8	0.5	17.6	1.2	1.9	16.7	4.1		
20	52.1	9.3	0.7	0.5	17.1	1.2	1.9	16.6	4.1		
1c	56.8	22.3	1.9	1.3	0.3	0.5	3.0	12.8	1.9		**Prevailing $SiO_2 + Al_2O_3$**
3a	50.1	22.4	2.5	1.4	0.4	0.5	2.9	18.8	4.5	4.4	
5a	61.6	17.7	2.6	1.0	0.5	0.8	2.1	12.5	2.3		
5b	71.4	14.6	1.7	0.5	0.3	1.3	1.9	7.3	0.6		
6	56.6	21.8	2.1	1.1	0.4	0.5	2.5	13.9	2.5		
8b	57.7	20.7	1.8	1.0	0.9	0.4	2.6	13.8	2.8		
9	46.2	21.6	1.7	1.2	0.5	0.4	3.1	24.2	9.2	9.2	
14b	50.3	23.2	1.7	1.2	0.4	0.3	3.0	18.7	4.9		
16	66.8	14.8	1.9	0.2	0.1	0.3	3.6	11.5	1.4		
17	50.4	20.6	2.8	1.0	0.4	0.3	2.6	20.7	5.2		
18	71.3	15.4	1.1	0.3	0.4	1.5	3.3	6.0	0.2		
21	38.1	14.7	3.9	0.9	0.7	0.4	2.0	38.5	14.1	14.1	**High LOI and C Corg = Ctot**
11b	32.8	16.7	5.1	1.1	1.1	0.3	2.2	39.4	17.9	17.9	
12	17.9	8.5	2.7	0.7	0.9	0.3	1.0	64.0	30.3	30.3	
13	21.3	11.3	1.5	0.9	1.0	0.3	1.3	58.1	29.1	29.0	

It is evident from the data in Tab. 3 that most samples (1c–18) belong to $SiO_2 + Al_2O_3$ rich sediments, composed mainly of quartz and kaolinite.

The composition of organic matter-rich sediments with outstanding LOI (~ 40–65 %) and Corg. (~ 15–30 %) can be considered as a normally expected composition of sediments under a lignite (or coal) accumulation. In coal-bearing sequences, the content of organic matter often starts to increase already in the under-coal strata. It correlates more or less tightly with fining upwards trend in the grain size of the clastic sediments.

The intervals (samples) with increased Fe_2O_3 content, remarkable Cinorg. content and low S content indicate siderite. Siderite ($FeCO_3$) forms in more oxidative conditions than pyrite or marcasite (FeS_2). It is highly probable that environmental conditions were more oxidative in pre-peat (lignite) forming environments than later in the true swamp environment. More oxidative conditions in presence of siderite have also been confirmed with the cerium (Ce) anomaly (Čeru, 2013).

CaO-rich samples are typically from the upper-most part of the investigated profile. CaO enrichment shows an influence of carbonate-enriched inflowing waters. The carbonate influence was also one of the key factors during the peat-to-lignite diagenesis of the Velenje lignite (Markič, 2006; Markič & Sachsenhofer, 2010).

Mineral composition as studied with XRD analysis of powdered samples

The qualitative mineral composition of the majority of samples (23; without lignite) was interpreted using the XRD method on pulverised samples. The mineral composition and textures were studied supplementary with conventional optical microscopy, the results of which are presented in a separate chapter. The collected diffractograms of the XRD analysis are given in Fig. 8. The obtained mineral composition of samples is presented in Tab. 4. The interpreted diffractograms revealed the presence of the following 9 minerals: quartz (Qz), feldspars (Fsp), kaolinite (Kln), gypsum (Gp), siderite (Sd), muscovite/illite (Ms/Ilt), marcasite (Mrc), calcite (Cal), pyrite (Py).

Quartz is present in all samples with the most characteristic diffraction pattern at the d-spacing value of 3.34 Å (Moore & Reynolds, 1997). In general, quartz is mostly of terrigenous origin and is brought by a river or wind transport

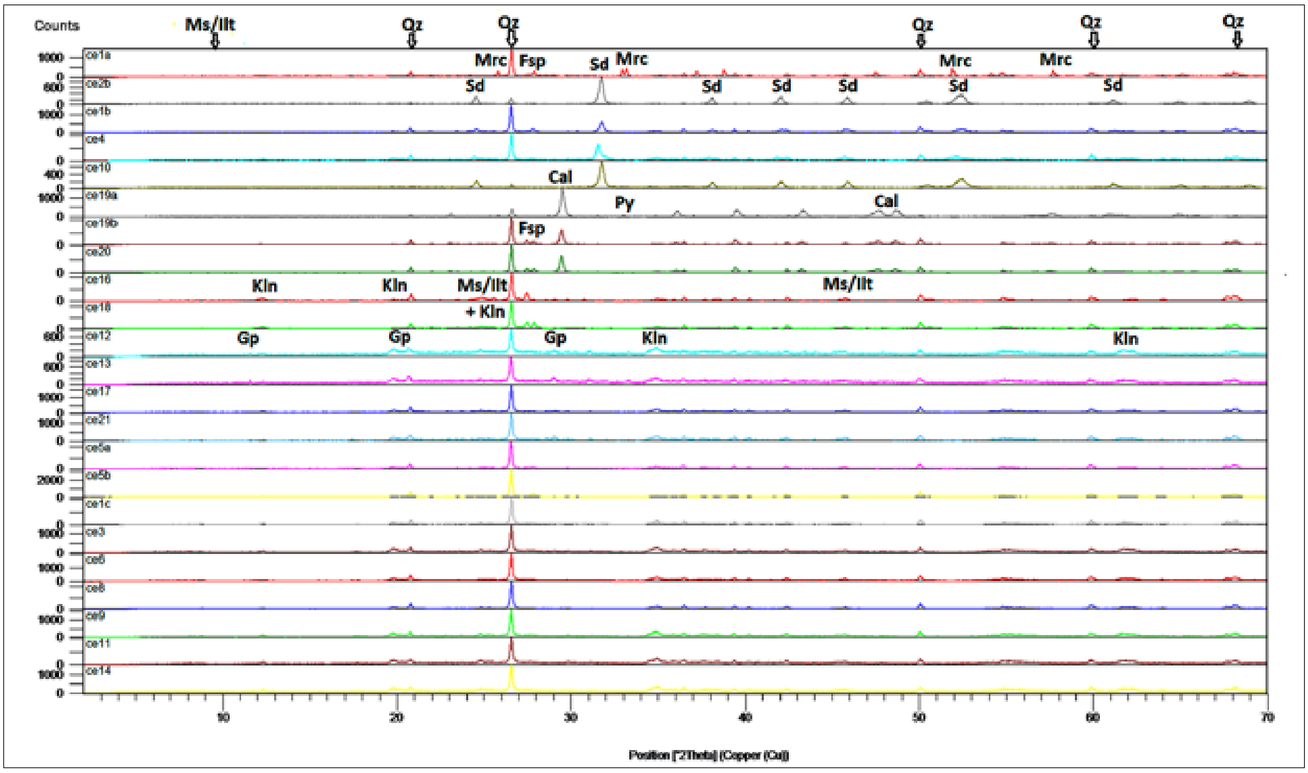

Fig. 8. X-Ray powder diffraction patterns for all analysed samples. Marked are characteristic peaks of determined minerals (Qz-quartz, Ms/Ilt- muscovite/illite, Mrc-marcasite, Fsp-feldspars, Kln-kaolinite, Gp-gypsum, Cal-calcite, Py-pyrite). Interpretation was made for each sample separately on its own diffractogram.

Sl. 8. Rentgenogrami rentgenske praškovne difrakcije vseh analiziranih vzorcev z označenimi značilnimi ukloni določenih mineralov (Qz-kremen, Ms/Ilt- muskovit/illit, Mrc-markazit, Fsp-glinenci, Kln-kaolinit, Gp-sadra, Cal-kalcit, Py-pirit). Interpretacija je bila izvedena za rentgenogram vsakega vzorca posebej.

into a depositional basin (Taylor et al., 1998; Renton, 1982).

Feldspars, predominantly occurring in coarse-grained sediments, are also of terrigenous origin. Their presence is the result of occurrences of lithic grains. Microscopic observations confirmed the presence of both plagioclases and K-feldspars.

Clay minerals also represent a terrigenous material as a result of weathering of silicates such as feldspars and mica and as a result of alteration of volcanic rocks, respectively. On the other hand, they could also have been formed authigenically, i.e. chemically within a sedimentary basin (Ward, 1989; Taylor et al., 1998). In most coals, for instance, clay minerals form the most common constituents of the mineral matter (Gluskoter et al., 1981; Taylor et al., 1998; Velde, 1995; Ward, 2002), among which kaolinite and illite are the most abundant (Renton, 1982; Ward, 2002). Only these two clay minerals were determined by the XRD analysis in our study in almost all samples.

Muscovite/illite was determined by the most characteristic diffraction peak at the d-spacing values of 9.9–10.1 Å (Brindley & Brown, 1980). Muscovite/Illite was recognised in most of the samples, except in coarse-grained sediments, siderite concretions and sedimentary rocks with calcite. Muscovite and illite were not distinguished by the XRD, so the tag muscovite/illite is used in the results. Only small amounts of muscovite mineral within coarse-grained sediments were recognised under optical microscope; therefore we assume that almost all samples contain higher amounts of illite, especially fine-grained samples.

Kaolinite was determined on the basis of the characteristic diffraction from the basal plane (001) at 7.15 Å (Brindley & Brown, 1980). Kaolinite occurs in significant amounts in all samples, except in the siderite concretions and limestone.

Fine-grained clastics are made up of quartz, kaolinite and muscovite/illite. A few samples also contain small amounts of gypsum. Marcasite was determined only in a sample 1a (gravelly sandstone) by the XRD and microscope, where it represents an authigenic mineral. A small amount of pyrite was recognised only in sample 19a (limestone). Thin section petrography showed that sample 20 (lithic feldspar quartz sandstone) also includes small amounts of framboidal pyrite, which is partly replaced by Fe-hydroxides. Calcite was determined only in three samples in the upper part of the profile (limestone and gravelly sandstones). Siderite and calcite were determined by the XRD and also by optical microscopy. Siderite occurs in sandstones (three samples) and in a clayey silt (one sample). It can only be formed if the activity of the sulphide ion is low. Siderite indicates the freshwater environment (Renton, 1982).

On the basis of the XRD analysis, 23 samples were divided into 8 groups with similar mineral composition (Tab. 5). The mineral composition of fine-grained clastics significantly differs from coarse-grained clastics. Silts and siltstones are composed essentially of quartz and clay minerals. Only a small number of samples contains a small amount of gypsum, while the coarse-grained clastics also contain feldspars (lithic grains) and cementitious minerals belonging to calcite, siderite and marcasite. Carbonate minerals (calcite, siderite) and marcasite are authigenic in origin. Siderite concretions within coarse-grained clastics are made up of quartz and siderite.

Petrographic composition and texture of the well-lithified samples

Samples of well-lithified (cemented) sediments representing rocks were investigated using optical microscopy of thin sections to get more detailed insight into their mineral composition and texture. Only 7 samples were suitable for this kind of study. Three groups of lithologic varieties were distinguished: 1) well-lithified coarse-grained sandstones, 2) calcite-rich sedimentary rocks, and 3) siderite-rich concretions. Mineral contents were estimated semi-quantitatively in plan-view percentages.

Well-lithified slightly gravelly sandstones (samples 1a, 1b)

According to the mineral composition sample 1a was determined as feldspar quartz lithic sandstone and sample 1b as quartz lithic sandstone. Both of them are slightly pebbly to rubbly, exhibiting homogeneous clastic texture with similar mineral assemblages but different degree of cementation, either with marcasite (1a) or siderite (1b). They occur in the lowest part of the analysed profile (Fig. 4).

Sample 1a is composed of minerals and lithic grains (65 %), marcasite cement (15 %) and pores (20 %). Sandstone is poorly-to-moderately sorted, containing detrital grains of various sizes (0.1–2.8 mm), which are mainly subangular-to-subrounded. Lithic grains, quartz, feldspars, clay minerals and some opaque minerals were identified. The most common are various lithic grains, among which dominate rock fragments of volcanic origin with phenocrysts in microcrystalline to cryptocrystalline matrix (Pl. 2, fig. 3). The intersertal texture with plagioclase laths is visible (Pl. 1, fig. 2; Pl. 2, fig. 2) and also hyalophitic and trachytic texture (Pl. 1, figs. 6a, 6b) occur in some volcanic lithic grains. Grains of metamorphic and sedimentary origin (0.8–1.4 mm in size) are rarer and are represented by low-grade metamorphic rocks (Pl. 1, fig. 1; Pl. 2, figs. 6a, 6b), cherts (Pl. 1, fig. 5) and quartz sandstones (Pl. 1, fig. 4). Quartz is second to lithic grains in abundance. It occurs both as monocrystalline and polycrystalline grains with mean size of 1 mm (Pl. 1, figs. 3a, 3b). Feldspars represent a very low content of all detrital components and are mainly sericitised or/and kaolinised. Grains of K-feldspars (Pl. 1, fig. 3a) are more common than plagioclase.

Pore spaces of the sample 1a sandstone are filled almost entirely by marcasite cement, in some places also by chlorite and brown-coloured Fe-oxy-hydroxides (Pl. 2, figs. 1a, 1b). An interstitial clayey matrix can be either detritial or authigenic –the determination of their origin is unreliable. Euhedral grains of marcasite are concentrated in some places (Pl. 2, fig. 4). Marcasite also occurs as a corrosive cement in lithic grains (Pl. 1, fig. 6a; Pl. 2, fig. 6a). Pl. 2, fig. 5 shows chalcedony with radially oriented quartz fibers.

Sample 1b consists of 40 % minerals and lithic grains, 50 % siderite cement and 10 % pores. The sandstone is moderately sorted and the grain size of detrital grains is in the range of 0.02–3 mm, mainly 0.1–0.2 mm. Subangular quartz grains are smaller than rounded rock fragments (Pl. 3, figs. 1a, 1b). Monocrystalline quartz with grain size varying from 0.02 to 1.6 mm is a major component of terrigenous grains. A small amount of quartz belongs to the polycrystalline grains with mainly straight and infrequently sutured grain boundaries. Feldspars are sparse and represent less than 5 % of all terrigenous components.

Table 5. XRD mineral composition of lithologically grouped samples – summarized from Tab. 4.

Tabela 5. Rentgensko določena mineralna sestava litološko združenih vzorcev – povzeto iz Tab. 4.

Samples and lithology		XRD mineral composition
1c, 4b*, 6, 8b, 9, 11b, 14b	SILTS and SILTSTONES	quartz, kaolinite, muscovite/illite, siderite*
3a, 12, 13, 17, 21	SILTS and SILTSTONES with gypsum	quartz, kaolinite, muscovite/illite, gypsum
5a, 5b, 16, 18	SILT (5b) and SANDS	quartz, kaolinite, feldspars, muscovite/illite
19a	LIMESTONE	calcite, quartz, pyrite
19b, 20	SANDSTONES with calcite cement	quartz, kaolinite, feldspars, calcite
1a	SANDSTONE with marcasite cement	quartz, kaolinite, feldspars, muscovite/illite, marcasite
1b	SANDSTONE with siderite cement	quartz, kaolinite, feldspars, muscovite/illite, siderite
2b, 10a	SIDERITE CONCRETIONS	quartz, siderite

Table 4. Qualitative mineral composition of 23 samples determined by the XRD and lithologic names defined by macroscopic observation, granulometry and optical microscopy. At the sample numbers, abbreviation "Mic" means that the sample was also investigated microscopically, and "Gr" means that it was also analysed granulometrically. All samples were analysed geochemically.

Tabela 4. Kvalitativna mineralna sestava 23 vzorcev, določena z rentgensko praškovno difrakcijo ter litološka imena, določena makroskopsko ter na podlagi granulometrične analize in optične mikroskopije. Kratica »Mic« pomeni, da je bil vzorec preiskan tudi mikroskopsko, kratica »Gr« pa da tudi granulometrično. Vsi vzorci so bili preiskani geokemično.

Sample	Depth (m)	Lithologic name	MINERAL COMPOSITION DETERMINED BY XRD ANALYSIS								
			quartz (Qz)	feldspar (Fsp)	kaolinite (Kln)	gypsum (Gp)	siderite (Sd)	musco-vite/illite (Ms/Ilt)	marcasite (Mrc)	calcite (Cal)	pyrite (Py)
21	563.00 - 562.60	silt/siltstone	x	x	x	x		x			
20 (Mic)	563.50 - 563.15	slightly gravelly sandstone	x	x	x					x	
19b	564.00 - 563.60	slightly gravelly sandstone	x	x	x					x	
19a (Mic)	564.00 - 563.60	limestone	x							x	x
18 (Gr)	565.00 - 564.35	gravelly muddy sand	x	x	x			x			
17 (Gr)	565.30 - 565.10	slightly clayey silt	x		x	x		x			
16 (Gr)	565.50 - 565.30	very slightly clayey silty sand	x	x	x			x			
14b (Gr)	566.00 - 565.80	very slightly sandy slightly clayey silt	x		x			x			
13	567.35 - 566.00	xylite	x		x	x		x			
12	569.00 - 567.35	slightly sandy silt/siltstone	x		x	x		x			
11b	570.75 - 569.00	slightly sandy silt/siltstone	x		x			x			
10a (Mic)	571.75 - 570.75	siderite concretion	x				x				
9	573.95 - 571.95	silt/siltstone	x		x			x			
8b (Gr)	575.85 - 573.95	slightly clayey silt	x		x			x			
6 (Gr)	577.00 - 576.05	very slightly sandy slightly clayey silt	x		x			x			
5b (Gr)	577.95 - 577.00	very slightly sandy slightly clayey silt	x	x	x			x			
5a (Gr)	577.95 - 577.00	slightly clayey silty sand	x	x	x			x			
4b (Gr)	578.55 - 577.95	slightly clayey silt	x		x		x	x			
3a (Gr)	578.85 - 578.65	slightly clayey silt	x		x	x		x			
2b (Mic)	579.50 - 578.90	siderite concretion within sandstone	x				x				
1c (Gr)	580.00 - 579.50	very slightly sandy clayey silt	x		x			x			
1b (Mic)	580.00 - 579.50	slightly gravelly muddy sandstone	x	x	x		x				
1a (Mic)	580.00 - 579.50	slightly gravelly sandstone	x	x	x				x		

Twinned plagioclase and K-feldspar were determined, which are strongly sericitised. As in sample 1a, volcanic rock fragments (Pl. 3, fig. 4) prevail over plutonic ones also in sample 1b. Low-grade metamorphic rock fragments occur sparsely (Pl. 3, figs. 3a, 3b). Chert fragments are infrequent. Some grains of amphiboles (Pl. 3, figs. 2a, 2b) and biotite are replaced by chlorite as an alteration product. Very small amounts of calcite grains are also present. Brownish-coloured areas with high birefringence are mostly authigenic interstitial and also corrosive siderite cement, which is partly limonitised.

Calcite-rich sedimentary rocks (samples 19a and 20)

Calcite-rich rocks, reacting with a diluted HCl, appear only in the upper part of the observed profile (Fig. 4).

Sample 19a represents a limestone with fragments of carbonised plant remains. Pore spaces are filled with sparite cement. Subrounded monocrystalline quartz grains with mean grain size 0.06–0.1 mm dominate, while lithic grains of igneous origin are sparser (Pl. 4, fig.6).

Sample 20 was determined as a slightly pebbly to rubbly lithic feldspar quartz sandstone. It has a clastic texture (Pl. 5, figs. 1a, 1b) and consists of about 50 % terrigenous grains of various sizes (0.02–3 mm). The most common are monocrystalline quartz grains of 0.02–0.2 mm in size, grains of polycrystalline quartz also occur (Pl. 5, fig. 3). Feldspars belong to plagioclase and K-feldspar. Most of them are generally sericitised or/and kaolinised and 0.035–1.4 mm in size. Lithic grains are the least abundant; fragments of igneous rocks dominate among them. The Altered volcanic lithic grains with phenocrysts of plagioclase laths in microcrystalline matrix are the most common (Pl. 5, figs. 4, 7). Felsic plutonic rock fragments with holocrystalline texture (Pl. 5, fig. 5) and aplite with granophyric texture also occur (Pl. 5, fig.6). In addition to igneous lithic grains the sandstone also contains rock fragments of metamorphic and sedimentary origin. Grains of cherts and quartz sandstones (Pl. 5, fig. 2) 0.4–1.3 mm were determined. Flakes of muscovite and grains of framboidal pyrite are very rare. The cement is sparry calcite, which occurs mainly as interstitial and in some places as corrosive and radiaxial fibrous cement. Some grains contain micro-cracks filled with sparry calcite cement.

Siderite-rich concretions (samples 2b, 4a, 10a)

Siderite also occurs in the investigated samples in the form of siderite-rich concretions. Its origin is well known as authigenic, formed in low oxidative environments, but still somewhat higher in oxygen supply than in the case of pyrite formation. A slightly higher (oxygen providing) energy level of the environment is mostly interpreted when siderite occurs in the sediment instead of pyrite/marcasite, for example. Organic matter can also be well preserved in the Eh conditions of the siderite formation. In our case concentrations of siderite still contain small amounts of quartz (samples 2b and 4a) or they are almost clean siderite (sample 10a).

The most pure siderite sample 10a contains only very few quartz and lithic grains. It is covered by geloxylite (Fig. 5/5). A microscopic view of the siderite-geloxylite contact is shown in Pl. 4, fig.5.

A thin section of sample 2b was made from a siderite concretion within a slightly pebbly to rubbly sandstone. Quartz grains of two size classes (0.06–0.1 mm and 0.14–0.2 mm) predominate over lithic grains among terrigenous components (Pl. 4, figs. 1a, 1b). Lithic grains (mean grain size 2–3 mm) of volcanic and plutonic igneous rocks prevail over chert and metamorphic lithic grains (Pl. 4, fig. 2). Flakes of muscovite are very rare and their sizes reach up to 0.1 mm.

Sample 4a contains 10 % terrigenous component, 85 % siderite and 5 % pores. The terrigenous component in the siderite concretion is mainly composed of monocrystalline quartz grains (Pl. 4, figs. 4a, 4b) in addition to minor amounts of lithic grains. Rock fragments of volcanic origin with porphyritic texture predominate, while grains of cherts (Pl. 4, fig. 3) are very rare. Lithic grains are commonly altered and partly replaced by siderite and Fe-hydroxides, which also occur as interstitial minerals. Rare small grains of framboidal pyrite were also recognised.

Conclusions

Granulometrical, geochemical and mineralogical characterisation of sediments that underlie the Velenje lignite seam in the locality of the P-9k/92 borehole (central part of the Velenje Basin) has been carried out on a suite of 32 samples from 21 depth intervals. In spite of a relatively restricted extent of the investigated strata (only 20 m) we suppose that the study answered several questions and represents a good guide for eventual further investigations. Our work can be summarised in conclusions as follows:

The Velenje lignite underlying strata of the Pliocene age are heterogeneous by their granulometrical, chemical and mineral composition. Clastic grains vary from well-rounded to angular. The sedimentary material as a whole varies from almost non-lithified (easy to be disintegrated) material, termed "sediment" (e.g. silt), to well-lithified (cemented) material termed with the ending "-stone" – e.g. "siltstone". Non-lithified sediments were easily disintegrated and sieved for the grain size analysis, whereas lithified "stones" were suitable for preparation of thin sections. Clayey silts and siltstones predominate in the investigated profile. They indicate a prevailingly low energy level of the depositional environment. Sands and sandstones with admixtures of the gravelly fraction occur subordinately. They indicate sporadic water influxes of a higher energy level. Low roundness and angularity of terrigenous lithic grains, low sorting and asymmetric grain-size distributions show that the transport distances of deposited materials were short.

Both the XRD analysis and the optical microscopy have shown that the mineral composition of fine-grained clastics is different from the mineral composition of coarse-grained clastics. It is also different in the lower part of the profile in comparison to the upper part. Fine-grained clastics are mainly composed of quartz grains bound by kaolinite matrix, whereas coarse-grained clastics also contain lithic grains, which are mostly angular. The later indicate a relatively short distance from the erosion site to the depositional basin.

Cementitious minerals in well-lithified lithologic varieties are calcite, siderite and marcasite.

The composition of the lower investigated strata with abundant lithic grains of andesitic volcanic rocks indicates an inflow of eroded sedimentary material mainly from the south. At the same time lithic grains of magmatic and metamorphic rocks indicate inflow of eroded material from the Železna Kapla (Eisen Kappel) – the Karavanke magmatic zone, i.e. from the north.

The increased Ca-content in the upper part of the sedimentary succession indicates the influence of carbonate-rich waters inflowing from the northern terrains composed of Triassic limestones and dolostones. Carbonate waters from the north therefore became geochemically decisive toward the end of the pre-peat forming clastic infilling of the Velenje intermontane basin.

$Ca-HCO_3$ type of water and consequential alkalinity governed the diagenetic processes throughout the development of the peat-lignite formation.

Well-lithified clastic samples are sandstones, whereas poorly lithified clastics are mostly clayey silts with a negligible sandy fraction. This indicates that cementation was stronger in the case of coarse clastics than in the case of fine-grained clastics.

Siderite forms cement and concretions. Pyrite/marcasite occurs more rarely than siderite. Siderite indicates somewhat more oxidative conditions than pyrite. Both siderite and pyrite indicate low Eh environments caused by the presence of a considerable amount of decaying organic matter. The observed incrustations of geloxylite (coalified wood) over siderite and xylitic remnants in siderite concretions support this statement.

Gypsum was detected in some samples. It is most possibly a result of the oxidation of pyrite/marcasite in the presence of Ca and organic matter.

A detailed provenance of the sedimentary material that filled up the Velenje Basin prior to the establishment of the peat-forming environment still remains quite an open question and challenge for further research. A profound knowledge of geology and petrology of the wider area (the Savinja Alps, Smrekovec, Karavanke and Pohorje Mts) is necessary to solve such questions. Considerable knowledge already exists from the past and recent times. Our will is that it will be continued with further investigations. Referring to our study, the questions that remain especially interesting touch upon temporal dynamics and influx directions of the sedimentary material, as well as the roles of tectonics and climate as initial and controlling factors of sedimentary processes in the broader realm of the Velenje Basin.

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PLATE 1 - TABLA 1

All thin sections viewed under plane polarised light.
Vsi zbruski opazovani v presevni polarizirani svetlobi.

Sample 1a (Feldspar quartz lithic sandstone with marcasite cement)
Vzorec 1a (glinenčevo-kremenov litični peščenjak z markazitnim cementom)

Fig. 1. Lithic grain of low-grade metamorphic rock with mica flakes and quartz grains. The opaque mineral, filling the space between grains, is authigenic marcasite cement. Crossed polars, scale bar 500 µm.

Sl. 1. Litično zrno nizko metamorfne kamnine z zrni sljude in kremena. Nepreseven mineral, ki zapolnjuje medzrnski prostor, je avtigeno izločen markazitni cement. Navzkrižni nikoli, merilo 500 µm.

Fig. 2. Lithic grain of altered volcanic rock. Small laths of plagioclase in microcrystalline matrix on the right part of the lithic grain show intersertal texture. The left side of the black line separates the quartz vein which is visible within the lithic grain. Crossed polars, scale bar 100 µm.

Sl. 2. Spremenjeno litično zrno predornine. Podolgovati preseki plagioklazov v drobno kristaljeni do steklasti kažejo značilno intersertalno strukturo. Leva stran črne črte loči kremenovo žilico znotraj litičnega zrna. Navzkrižni nikoli, merilo 100 µm.

Fig. 3a. Polycrystalline quartz grain (Qz) and altered orthoclase grain (Or). Parallel polars, scale bar 500 µm.

Sl. 3a. Zrno polikristalnega kremena (Qz) in spremenjeno zrno ortoklaza (Or). Vzporedni nikoli, merilo 500 µm.

Fig. 3b. The same as fig. 3a. Polycrystalline quartz grain. Crossed polars, scale bar 500 µm.

Sl. 3b. Isto kot sl. 3a. Zrno polikristalnega kremena. Navzkrižni nikoli, merilo 500 µm.

Fig. 4. Weathered lithic grain of quartz sandstone. Crossed polars, scale bar 500 µm.

Sl. 4. Preperelo litično zrno kremenovega peščenjaka. Navzkrižni nikoli, merilo 500 µm.

Fig. 5. Lithic grains (Lg1 and Lg2). Lg1 belongs to the chert. Crossed polars, scale bar 500 µm.

Sl. 5. Litični zrni (Lg1 in Lg2). Litično zrno Lg1 pripada rožencu. Navzkrižni nikoli, merilo 500 µm.

Fig 6a. Altered volcanic rock fragment. Matrix is partly replaced by corrosive marcasite cement. Parallel polars, scale bar 100 µm.

Sl. 6a. Spremenjeno litično zrno predornine. Korozivni markazitni cement mestoma nadomešča osnovo litičnega zrna. Vzporedni nikoli, merilo 100 µm.

Fig. 6b. Hyalophitic texture is visible on the left part of the lithic grain and oriented plagioclase laths on the right show trachytic texture in altered volcanic (intermediate-mafic) rock. Crossed polars, scale bar 100 µm.

Sl. 6b. Na levi strani litičnega zrna je vidna hialofitska struktura, ki prehaja v trahitsko z usmerjenimi paličastimi plagioklazi v spremenjeni predornini (srednje do bazični sestave). Navzkrižni nikoli, merilo 100 µm.

PLATE 1 - TABLA 1

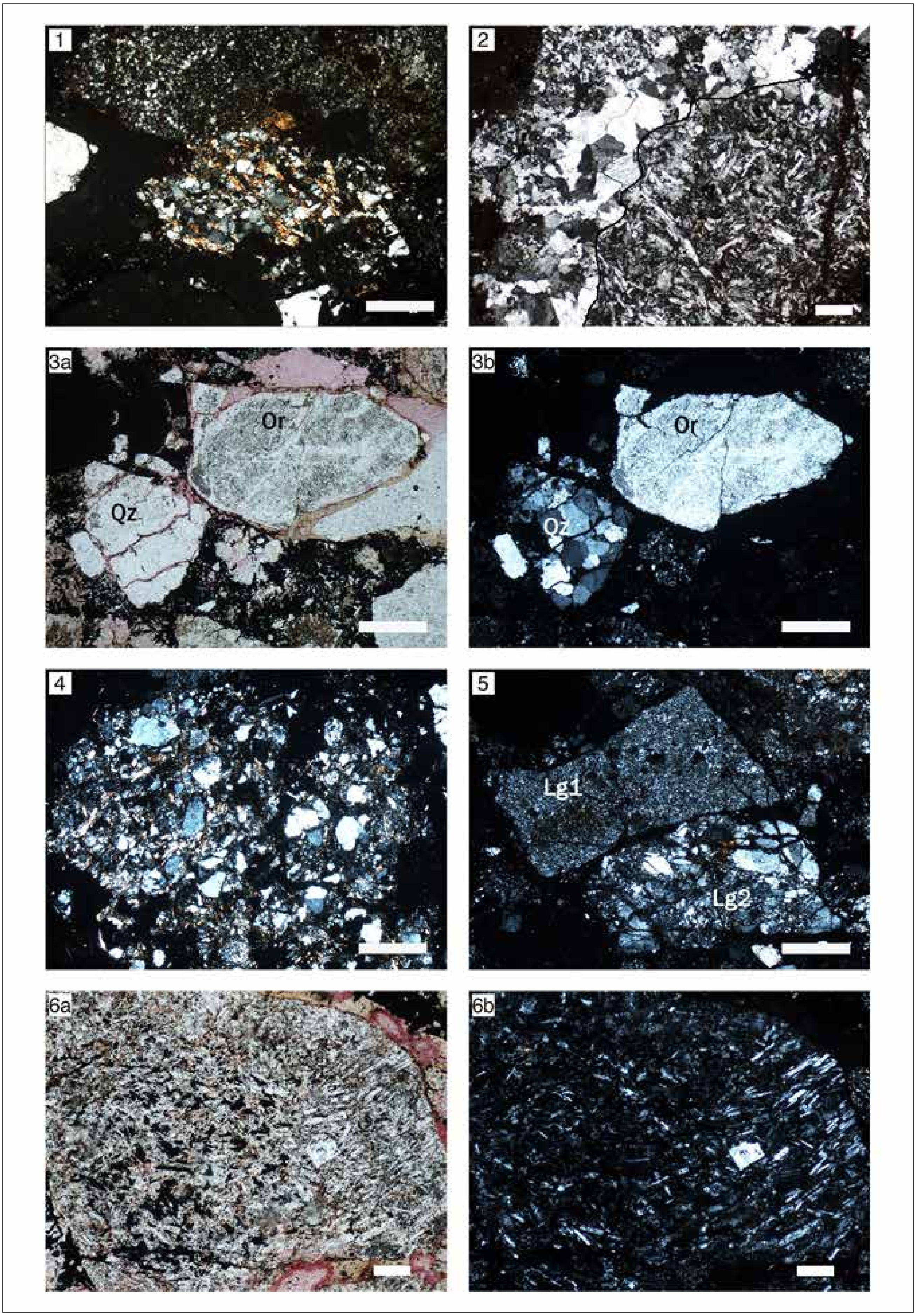


PLATE 2 - TABLA 2

Fig. 1a. Pores filled by marcasite (Mrc) and chlorite group mineral, and brown-colored Fe-oxy-hydroxides (Fe-hy). Parallel polars, scale bar 100 µm.

Sl. 1a. Z markazitom (Mrc) in mineralom iz kloritne skupine zapolnjene pore ter rjavo obarvani minerali Fe-oksidov in hidroksidov (Fe-hy). Vzporedni nikoli, merilo 100 µm.

Fig. 1b. The same motif as in Fig. 1a. Interference colours of chlorite group mineral (Chl), which occur together with marcasite as interstitial cement. Crossed polars, scale bar 100 µm.

Sl. 1b. Isti motiv kot na sl. 1a. Interferenčne barve minerala kloritove skupine (Chl), ki skupaj z markazitom nastopa kot porna cementna zapolnitev med zrni. Navzkrižni nikoli, merilo 100 µm.

Fig. 2. Lithic grain of volcanic rock with visible contact (white line) between the different granularities plagioclase phenocrysts. The bigger twinned grain may belongs to sanidine (Sa?). Crossed polars, scale bar 500 µm.

Sl. 2. Litično zrno z vidnim prehodom (bela linija) različne velikosti vtrošnikov plagioklazov. Večje dvojčično zrno lahko pripada sanidinu (Sa?). Navzkrižni nikoli, merilo 500 µm.

Fig. 3. Lithic grain of probably felsic volcanic rock with plagioclase phenocrysts in microcrystalline-cryptocrystalline matrix. Crossed polars, scale bar 1mm.

Sl. 3. Litično zrno najverjetneje kisle predornine z vtrošniki plagioklazov v mikrokristalni-kriptokristalni osnovi. Navzkrižni nikoli, merilo 1mm.

Fig. 4. Nests of opaque mineral marcasite. Parallel polars, scale bar 100 µm.

Sl. 4. Gnezda markazita. Vzporedni nikoli, merilo 100 µm.

Fig. 5. Chalcedony with radially oriented quartz fibers. Crossed polars, scale bar 100 µm.

Sl. 5. Kalcedon z radialno žarkovito strukturo. Navzkrižni nikoli, merilo 100 µm.

Fig. 6a. Lithic grain (Lg) of low-grade metamorphic rock. Marcasite cement forms the interstitial and also the corrosive cement (visible in the frame). Grain of plagioclase (Pl) occurs at the lower margin. Parallel polars, scale bar 500 µm.

Sl. 6a. Litično zrno nizko metamorfne kamnine. Markazitni cement se pojavlja v dveh oblikah, kot porni in korozivni cement (viden v označenem kvadratu). Manjše zrno plagioklaza na spodnjem robu slike (Pl). Vzporedni nikoli, merilo 500 µm.

Fig. 6b. The same as Fig. 6a. Sericite, chlorite and a plagioclase grain (Pl) can be seen. Crossed polars, scale bar 500 µm.

Sl. 6b. Isto kot sl. 6a. Vidni so listki sljude, klorit in zrno plagioklaza (Pl). Navzkrižni nikoli, merilo 500 µm.

PLATE 2 - TABLA 2

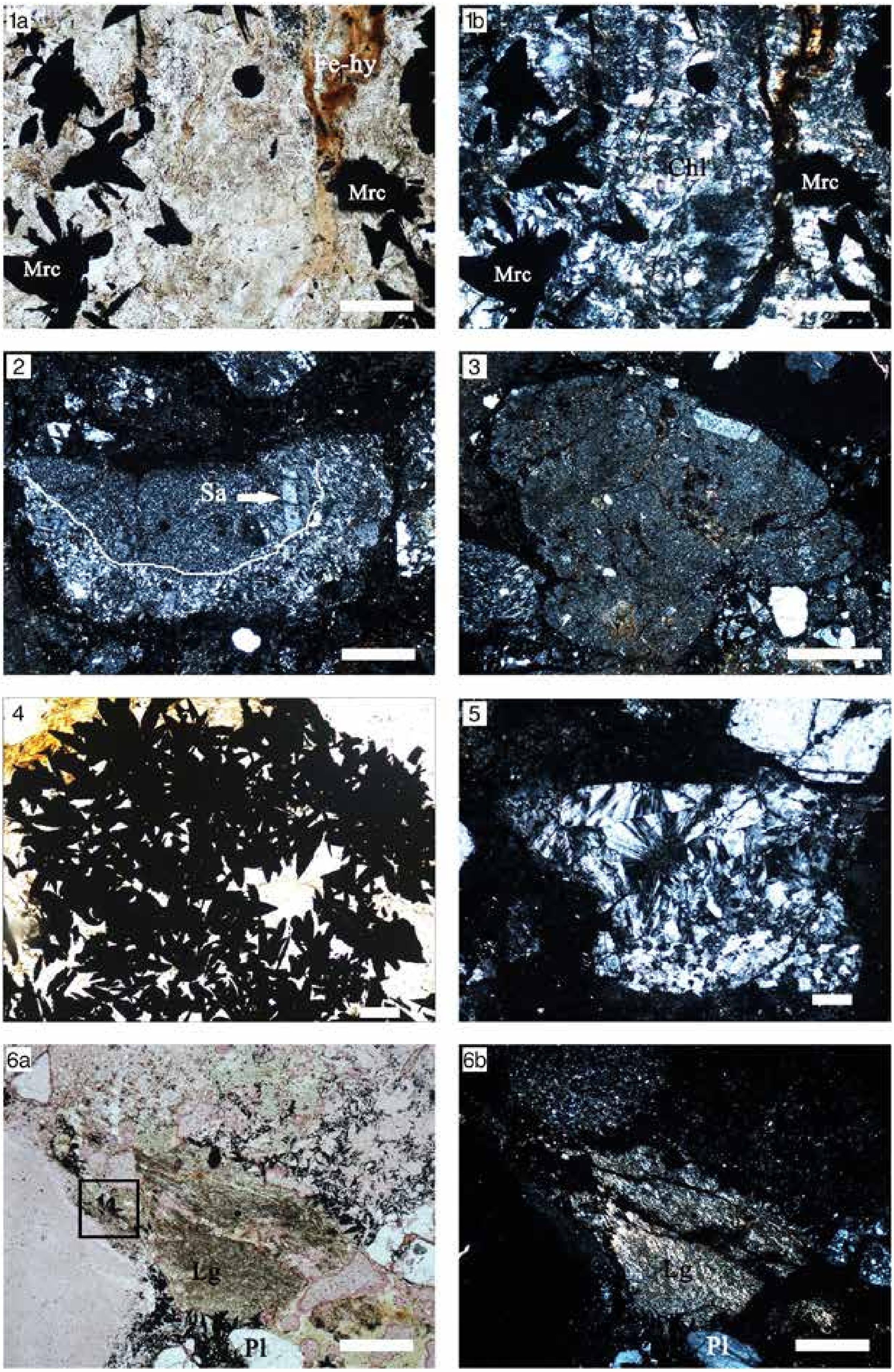


PLATE 3 - TABLA 3

Sample 1b (Quartz lithic sandstone with siderite cement)
Vzorec 1b (kremenovo-litični peščenjak s sideritnim cementom)

Fig. 1a. Grains of subangular quartz (Qz), rounded lithic grains (Lg) and fragments of carbonised plant residues in sandstone. Parallel polars, scale bar 1 mm.

Sl. 1a. Peščenjak z zrni kremena (Qz) in drobci različnih kamnin (Lg) ter fragmenti pooglenelih rastlinskih ostankov. Zrna kremena so pologlata, medtem ko so drobci kamnin zaobljeni. Vzporedni nikoli, merilo 1mm.

Fig. 1b. Most of the lithic grains in sandstone with authigenic siderite cement belongs to both, volcanic and plutonic rocks. Crossed polars, scale bar 1 mm.

Sl. 1b. Večina litičnih zrn v peščenjaku z avtigenim sideritnim cementom pripada magmatskim kamninam, tako predorninam kot globočninam. Navzkrižni nikoli, merilo 1mm.

Fig. 2a. Grain of some altered (chloritized) mafic mineral, most probably belonging to the amphibole group (Chl-Amp) and a smaller grain of quartz (Qz). Parallel polars, scale bar 100 µm.

Sl. 2a. Zrno spremenjenega (kloritiziranega) mafičnega minerala, ki verjetno pripada skupini amfibolov (Chl-Amp) in manjše zrno kremena (Qz). Vzporedni nikoli, merilo 100 µm.

Fig. 2b. The same as Fig.3. Crossed polars, scale bar 100 µm.

Sl. 2b. Isto kot sl. 3. Navzkrižni nikoli, merilo 100 µm.

Fig. 3a. Lithic grain of metamorphic rock (Lg1), quartz grains (Qz) and rock fragments (Lg2) in limonitised siderite cemented sanstone. Parallel polars, scale bar 500 µm.

Sl. 3a. Litično zrno metamorfne kamnine (Lg1), zrna kremena (Qz) in ostali drobci kamnin (Lg2) v sideritnem cementu peščenjaka. Vzporedni nikoli, merilo 500 µm.

Fig. 3b. The same as Fig. 3a. Lithic grain of metamorphic origin consists of quartz and muscovite (Lg1). Lithic grain of volcanic origin (Lg2) is visible on the left edge of the photo. Small quartz grains (Qz) occur over the entire surface of the thin section. Crossed polars, scale bar 500 µm.

Sl. 3b. Isto kot sl. 3a. Kremen in muskovit v sestavi litičnega zrna metamorfne kamnine (Lg1). Na levem robu slike je vidno zrno predornine (Lg2) in posamična manjša kremenova zrna (Qz), ki se pojavljajo po celotni površini zbruska. Navzkrižni nikoli, merilo 500 µm.

Fig. 4. Lithic grain of volcanic rock with phenocrysts of plagioclase in microcrystalline matrix. Crossed polars, scale bar 500 µm.

Sl. 4. Litično zrno predornine z vtrošniki plagioklazov v mikrokristalni osnovi. Navzkrižni nikoli, merilo 500 µm.

PLATE 3 - TABLA 3

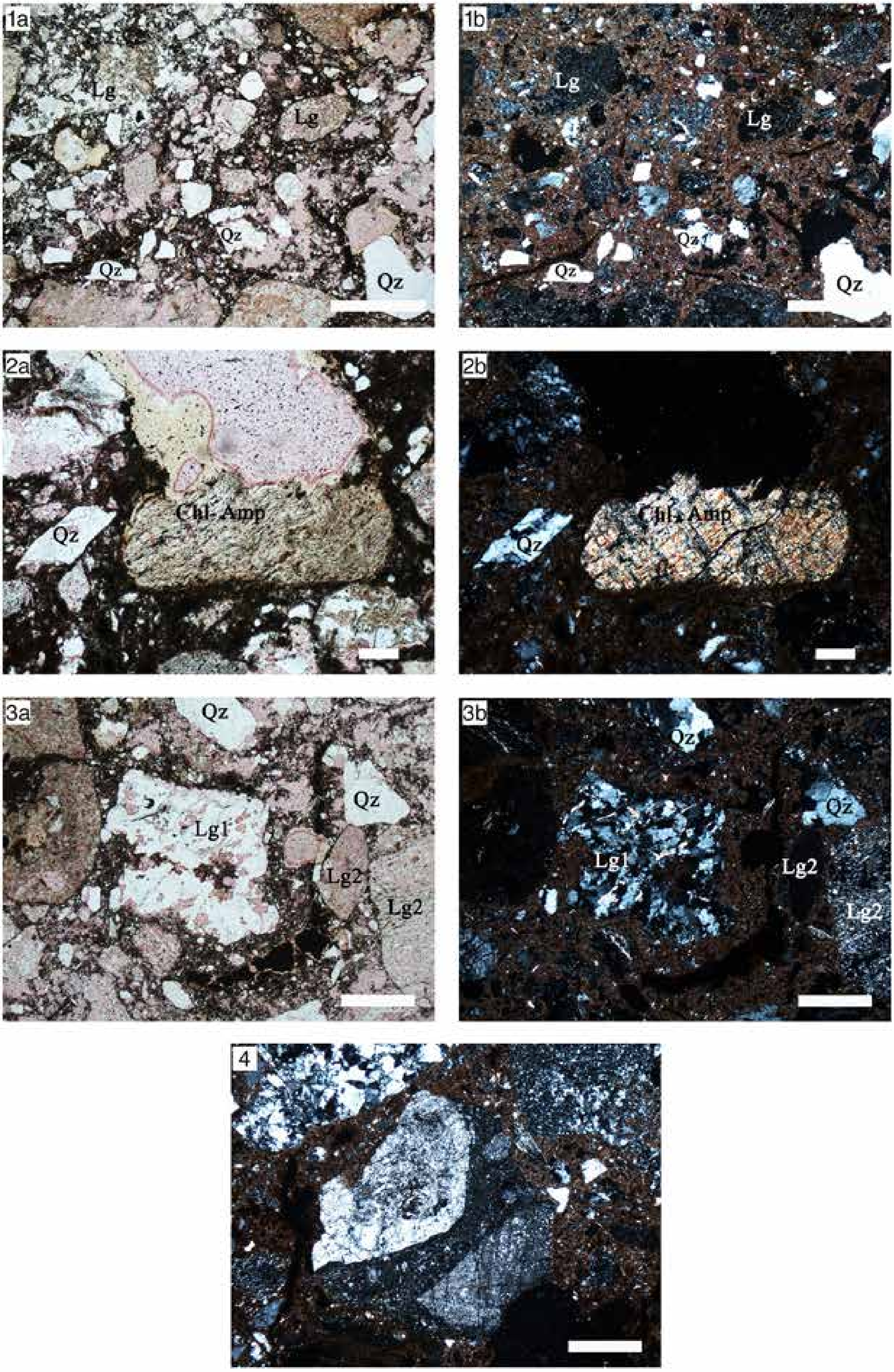


PLATE 4 - TABLA 4

Sample 2b (Siderite concretion within sandstone)
Vzorec 2b (sideritna konkrecija znotraj peščenjaka)

Fig. 1a. Small terrigenous quartz grains (Qz) and bigger lithic grains (Lg) in limonitised siderite cemented sandstone. Parallel polars, scale bar 1 mm.

Sl. 1a. Manjša terigena kremenova zrna (Qz) in večja zrna različnih drobcev kamnin (Lg) v peščenjaku z limonitiziranim sideritnim cementom. Vzporedni nikoli, merilo 1mm.

Fig. 1b. The same as Fig. 1a. Sandstone consists of crystals of quartz (Qz), lithic grains (Lg) and fragments of carbonised plant residues (black). Crossed polars, scale bar 1 mm.

Sl. 1b. Isto kot sl. 1a: Peščenjak z zrni kremena (Qz), drobci kamnin (Lg) in fragmenti pooglenelih rastlinskih ostankov (črni). Navzkrižni nikoli, merilo 1mm.

Fig. 2. Two lithic grains of igneous origin with holocrystalline texture (Lg1). Two grains of chert (Lg2) and volcanic rock fragment (Lg3) are visible. Crossed polars, scale bar 1 mm.

Sl. 2. Dve litični zrni kisle globočnine s holokristalno strukturo (Lg1), dve zrni roženca (Lg2) in zrno predornine (Lg3). Navzkrižni nikoli, merilo 1mm.

Sample 4a (Siderite concretion with quartz and lithic grains)
Vzorec 4a (sideritna konkrecija s kremenovimi in litičnimi zrni)

Fig. 3. Lithic grain of chert is visible in the middle of the microphotograph (Lg). Small grains of quartz and fragments of carbonised plant residues (black) occur within siderite concretion. Crossed polars, scale bar 500 µm.

Sl. 3. Na sredini slike je večje zrno najverjetneje roženca. Po celotni površini so manjša zrna kremena ter premoški fragmenti rastlinskih ostankov (črni). Navzkrižni nikoli, merilo 500 µm.

Fig. 4a. Small grains of quartz in siderite cement. Parallel polars, scale bar 500 µm.

Sl. 4a. Majhna zrna kremena v sideritnem cementu. Vzporedni nikoli, merilo 500 µm.

Fig. 4b. The same as Fig. 4a. Crossed polars, scale bar 500 µm.

Sl. 4b. Isto kot sl. 4a. Navzkrižni nikoli, merilo 500 µm.

Sample 10a (Siderite concretion)
Vzorec 10a (sideritna konkrecija)

Fig. 5. Limonitised siderite concretion with several grains of quartz (white) and fragments of carbonised plant residues. Parallel polars, scale bar 1mm.

Sl. 5. Limonitizirana sideritna konkrecija s posameznimi zrni kremena (bela) in fragmenti pooglenelih rastlinskih ostankov. Vzporedni nikoli, merilo 1mm.

Sample 19a (Limestone)
Vzorec 19a (apnenec)

Fig. 6. Rare small quartz grains (white and gray) and fragments of carbonised plant residues (black) in calcite cement. Crossed polars, scale bar 500 µm.

Sl. 6. Posamezna majhna zrna kremena (bela in siva) in premoški fragmenti rastlinskih ostankov (črni) v kalcitnem cementu. Navzkrižni nikoli, merilo 500 µm.

PLATE 4 - TABLA 4

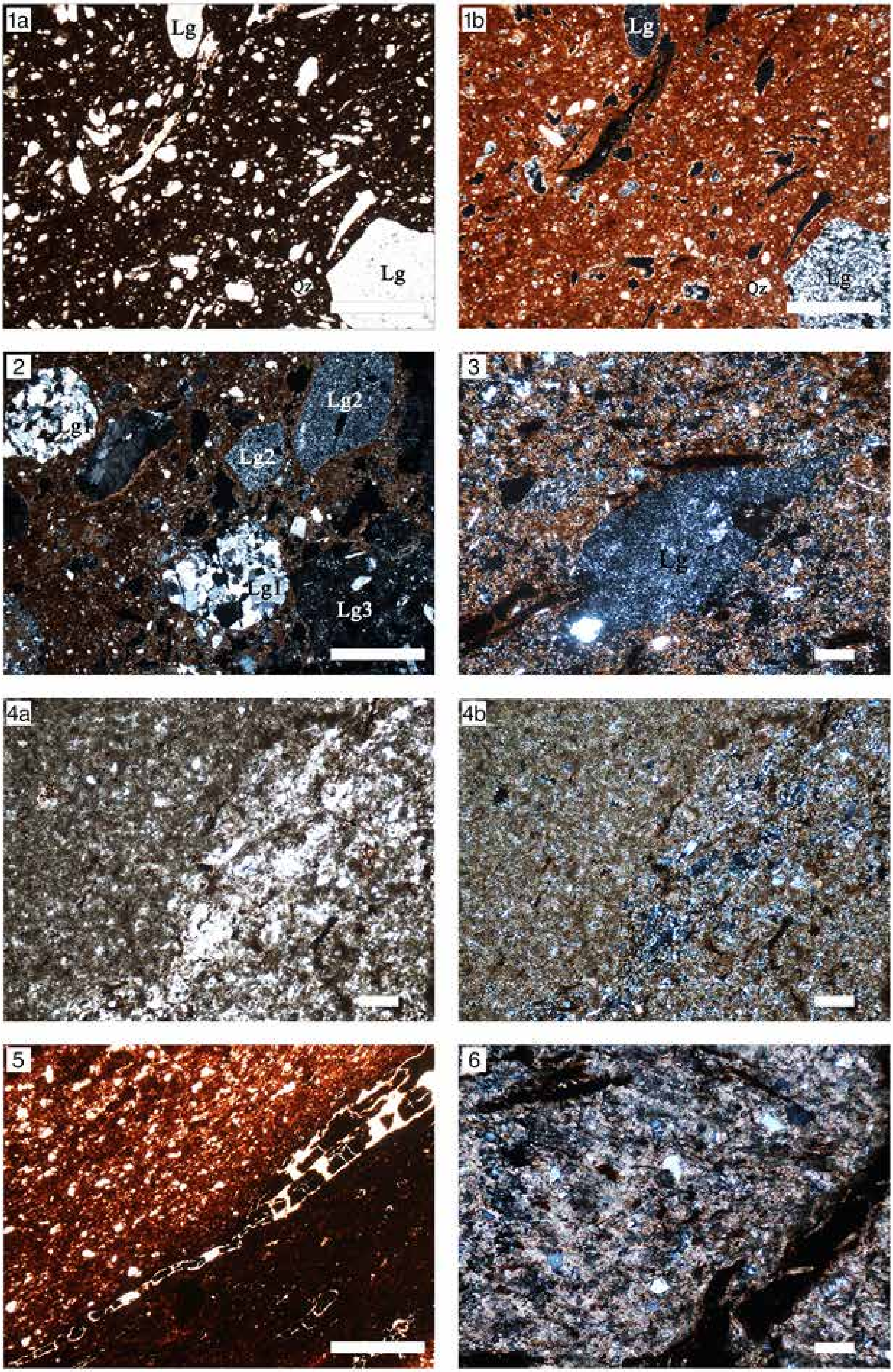


TABLA 5 - PLATE 5

Sample 20 (Lithic feldspar quartz sandstone with sparry calcite cement)
Vzorec 20 (litično-glinenčev kremenov peščenjak s sparitnim kalcitnim cementom)

Fig. 1a. Several monocrystalline quartz grains (Qz) and lithic grains (Lg) in sandstone with sparry calcite cement (stained red). Parallel polars, scale bar 1 mm.

Zrna monokristalnega kremena (Qz) in litičnih zrn (Lg) v peščenjaku s kalcitnim cementom (rdeče obarvan). Vzporedni nikoli, merilo 1 mm.

Fig. 1b. The same as Fig. 1. Crossed polars, scale bar 1 mm.

Sl. 1. Isto kot sl. 1. Navzkrižni nikoli, merilo 1 mm.

Fig. 2. Quartz sandstone lithic grain at the centre of photo and grains of quartz (Qz). Crossed polars, scale bar 100 µm.

Sl. 2. Litično zrno kremenovega peščenjaka na sredini slike in zrna kremena (Qz). Navzkrižni nikoli, merilo 100 µm.

Fig. 3. Grain of recrystallized polycrystalline quartz with undulose extinction. Crossed polars, scale bar 500 µm.

Sl. 3. Zrno rekristaliziranega polikristalnega kremena z valovito potemnitvijo. Navzkrižni nikoli, merilo 500 µm.

Fig. 4. Strongly altered volcanic rock fragment. Crossed polars, scale bar 500 µm.

Sl. 4. Zelo spremenjeno litično zrno predornine. Navzkrižni nikoli, povečava 500 µm.

Fig. 5. Lithic grain of felsic plutonic rock. Micro-cracks within the feldspar grain are filled with sparry calcite. Crossed polars, scale bar 100 µm.

Sl. 5. Litično zrno kisle globočnine. Razpoke v zrnu glinenca so zapolnjene s sparitnim kalcitom. Navzkrižni nikoli, merilo 100 µm.

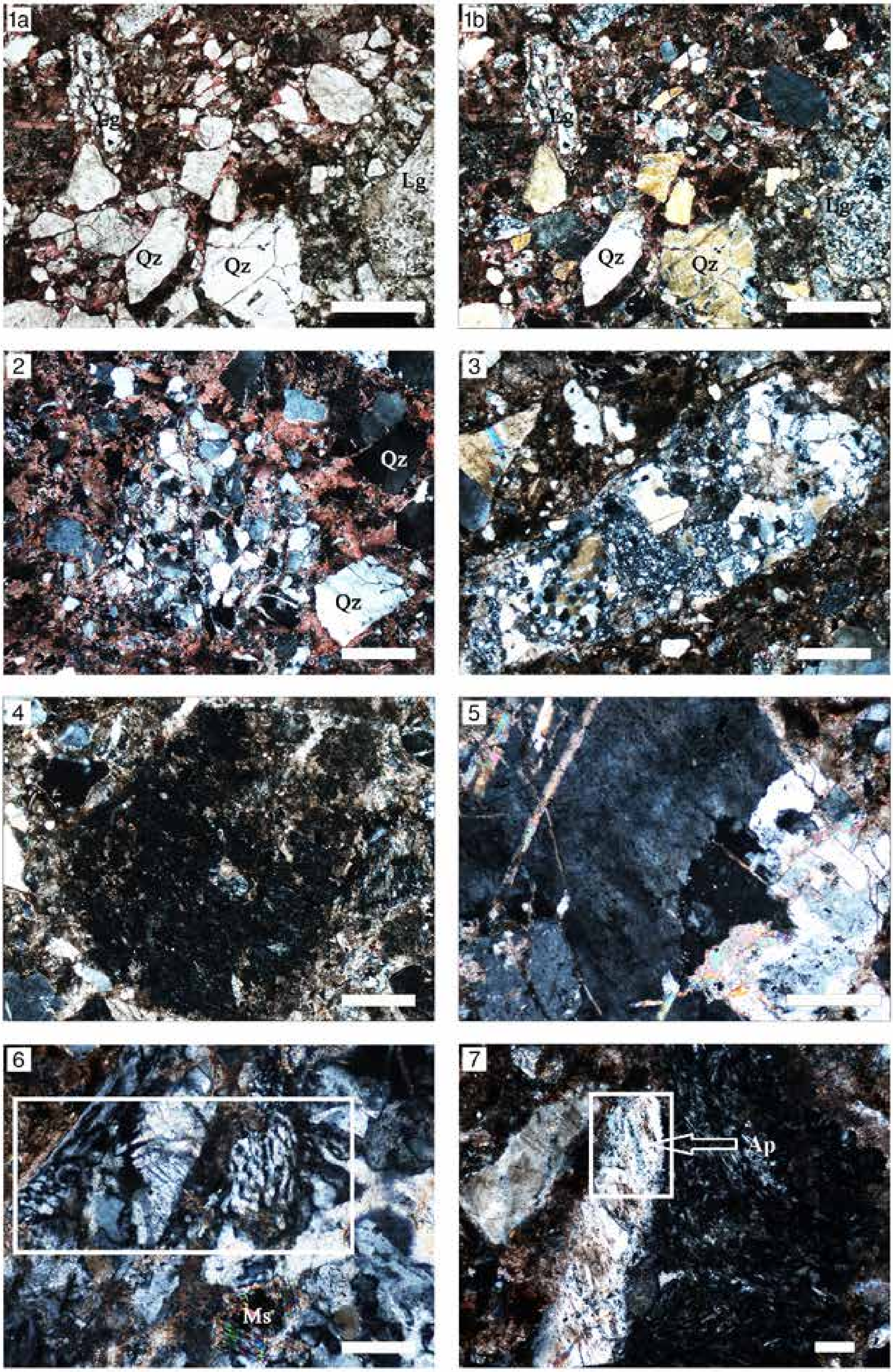
Fig. 6. Lithic grain of some igneous rock, most probably belonging to aplite with granophyric texture. Detail in rectangle shows an intergrowth of quartz and K-feldspar. Muscovite flake (Ms) is visible at the lower margin. Crossed polars, scale bar 100 µm.

Sl. 6. Litično zrno magmatske žilnine z granofirsko strukturo, najverjetneje aplita. V okvirju je vidno preraščanje kalijevih glinencev in kremena. Na spodnjem robu se pojavlja muskovit (Ms). Navzkrižni nikoli, merilo 100 µm.

Fig. 7. Volcanic rock fragment with phenocrysts of plagioclase. Grains of elongated apatite mineral (Ap) are visible in the frame. Crossed polars, scale bar 100 µm.

Sl. 7. Litično zrno predornine z vtrošniki plagioklazov. V okvirju so vidna podolgovata zrna apatita (Ap). Navzkrižni nikoli, 100 µm.

PLATE 5 - TABLA 5



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Isotopic composition of carbon in atmospheric air; use of a diffusion model at the water/atmosphere interface in Velenje Basin

Izotopska sestava ogljika v atmosferskem zraku in difuzijski model na fazni meji voda/atmosfera v Velenjskem bazenu

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Abstract

CO_2 concentrations (partial pressure of CO_2, pCO_2), and isotope compositions of carbon dioxide in air ($\delta^{13}C_{CO2}$), temperature (T) and relative humidity (H) have been measured in the atmosphere in the Velenje Basin. Samples were collected monthly in the calendar year 2011 from 9 locations in the area where the largest thermal power plant in Slovenia with the greatest emission of CO_2 to the atmosphere (around 4M t/year) is located. Values of pCO_2 ranged from 239 to 460 ppm with an average value of 294 ppm, which is below the average atmospheric CO_2 pressure (360 ppm). $\delta^{13}C_{CO2}$ ranged from -18.0 to -6.4 ‰, with an average value of -11.7 ‰. These values are similar to those measured in Wroclaw, Poland. We performed the comparison of $\delta^{13}C_{CO2}$ values in atmospheric air with Wroclaw since researchers used similar approach to trace $\delta^{13}C_{CO2}$ around anthropogenic sources. The isotopic composition of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) in rivers and lakes from the Velenje basin changes seasonally from -13.5 to -7.1‰. The values of $\delta^{13}C_{DIC}$ indicate the occurrence of biogeochemical processes in the surface waters, with dissolution of carbonates and degradation of organic matter being the most important. A concentration and diffusion model was used to calculate the time of equilibration between dissolved inorganic carbon in natural sources (rivers) and atmospheric CO_2.

Izvleček

Ta študija opisuje rezultate analize koncentracij CO_2 v zraku (parcialni tlak CO_2 , pCO_2) in izotopske sestave ogljika v atmosferskem zraku ($\delta^{13}C_{CO2}$), temperature (T) in relativne vlažnosti (H) v atmosferi iz Velenjskega bazena. Vzorce smo vzorčili mesečno na 9 lokacijah v koledarskem letu 2011 na območju Velenjskega bazena, kjer je locirana največja termoelektrarna v Sloveniji, ki predstavlja največjega proizvajalca emisij CO_2 v atmosfero (okoli 4 Mt/leto). Koncentracije pCO_2 v zraku se v času te študije spreminjajo od 239 do 460 ppm. Merjene povprečne koncentracije pCO_2 v naši študiji znašajo 294 ppm in so pod povprečnim atmosferskim tlakom CO_2, ki znaša 360 ppm. Merjena $\delta^{13}C_{CO2}$ se spreminja od -18,0 do -6,4 ‰ s povprečno vrednostjo $\delta^{13}C_{CO2}$ -11,7 ‰. Vrednosti atmosferskega CO_2 in $\delta^{13}C_{CO2}$ so v času te raziskave podobne vrednostim objavljenim za Wroclaw, Poljska. Naredili smo primerjavo z $\delta^{13}C_{CO2}$ vrednostmi v atmosferskem zraku z Wroclawom, ker so raziskovalci uporabili podoben pristop sledenja $\delta^{13}C_{CO2}$ vrednosti okrog antropogenih virov. Izotopska sestava raztopljenega anorganskega ogljika ($\delta^{13}C_{DIC}$) v rekah in jezerih Velenjskega bazena se je v letu 2011 sezonsko spreminjala od -13,5 do -7,1 ‰. Vrednosti $\delta^{13}C_{DIC}$ odražajo biogeokemijske procese v površinskih vodah, med katerimi sta najpomembnejša raztapljanje karbonatov in razgradnja organske snovi. Izdelali smo tudi koncentracijski in izotopski difuzijski model za izračun časa uravnoteženja med atmosferskim CO_2 in raztopljenim CO_2 na rečnih točkah.

Introduction

Investigation of the fate of atmospheric CO_2 is central to efforts to measure and predict global anthropogenic changes and to assess the impact of fossil fuel usage on environmental quality (EEA, 1998, 2003). Analyses of the concentration and anisotropic composition of atmospheric CO_2 have been carried out to assess their anthropogenic impact (Kuc et al., 2003; Longinelli & Selmo, 2005; Pataki et al., 2005; Zimnoch et al., 2004). In the atmospheric boundary layer, the concentration and carbon isotope composition of atmospheric CO_2 ($\delta^{13}C_{CO2}$) is determined by the mixing of tropospheric air with locally derived air that is affected by anthropogenic and/or biogenic CO_2 sources and sinks (Zimnoch et al., 2004). Biogenic CO_2 originates from plant respiration and from heterogenic soil microbes which convert soil organic matter to CO_2. Because ^{12}C is taken up preferentially by plants during photosynthesis, soils are lower in ^{13}C than the atmosphere (Bowling et al., 2008). Where C3 vegetation (e.g. Filipendulion (with dominant and characteristic species *Filipendula ulmaria* (L.) Maxim.) and Bidention (species from genera *Bidens* L., *Rorippa* Scop., *Chenopodium* L., *Polygonum* L.,…), *Fagus sylvatica* L., *Picea abies* (L.) Karst., *Abies alba* P. Mill.) dominates, as is the case for the studied area, soil organic matter and CO_2 respired by vegetation exhibit $\delta^{13}C$ values between -28 and -20 ‰ (Szaran, 2002). Values of $\delta^{13}C_{CO2}$ derived from burning fossil fuels (anthropogenic sources) range from -40.5 (natural gas burning fumes) to -24.6 ‰ (coal burning fumes) (Widory & Javoy, 2003). Combustion of coal produces almost twice as much carbon dioxide per unit of energy as does the combustion of natural gas, while the amount from the combustion of crude oil falls in between (Energy Information administration, Emissions of Greenhouse Gases in the United States 1985-1990 (DOE/EIA-0573)). In the vegetative season the anthropogenic input is minimized and the biological input is dominant (Longinelli & Semo, 2005). Values of $\delta^{13}C_{CO2}$ and pCO_2 in the atmosphere have also been used to determine pollution levels in the atmosphere (Zwoździak et al., 2010).

Concentrations of dissolved inorganic carbon, DIC, and its isotopic composition ($\delta^{13}C_{DIC}$) in freshwater environments have been widely investigated (Amiotte-Suchet et al., 1999; Atekwana & Krishnamurthy, 1998; Marfia et al., 2004; Kanduč et al., 2007) and groundwater/surface water interactions, with evaluation of biogeochemical processes, have been reported for Velenje Basin (Kanduč et al., 2010, Kanduč et al., 2014).

Here we report measurements of pCO_2 (partial pressure) and $\delta^{13}C_{CO2}$ in the vicinity of the Šoštanj thermal plant which is the biggest emitter of CO_2 to the atmosphere in Slovenia. Thus, around 4 Mt of CO_2 are emitted (EMEP/EEA, 2013) into the atmosphere per year. The aim of this study was 1) to measure monthly air concentrations of pCO_2 and to measure $\delta^{13}C_{CO2}$ in air to determine the influence of the combustion of lignite on pCO_2 concentrations and to define the origin of the CO_2 in the air masses in Velenje Basin, 2) to compare pCO_2 concentrations and $\delta^{13}C$ in air with published data (Wroclaw between 1st January and 31st December 2008) and 3) using the concentration and isotope diffusion model to calculate the time of equilibration of CO_2 needed to equilibrate concentrations of pCO_2 and $\delta^{13}C_{DIC}$ values between air/water interface.

Materials and methods

Partial pressure of CO_2 (pCO_2) in the atmosphere was measured above surface water at 9 locations (Figure 1) in Velenje Basin, using an IAQ-CALC Indoor Air Quality Meter, Model 7545, Thrust Science Innovation (TSI) with an accuracy of ±3 % of reading or ±50 ppm. Air samples for measurement of the carbon isotope composition in carbon dioxide in air ($\delta^{13}C_{CO2}$) were sampled as follows: a Labco ampoule (4 ampoules per location) was opened in the windward direction to let it fill with air. After filling (about 2 minutes), the ampoule was immediately closed and transported to the laboratory for prompt analysis of carbon isotope composition ($\delta^{13}C_{CO2}$). Air for $\delta^{13}C_{CO2}$ analysis was sampled 2 m above surface water. At the same locations, relative humidity (H), and

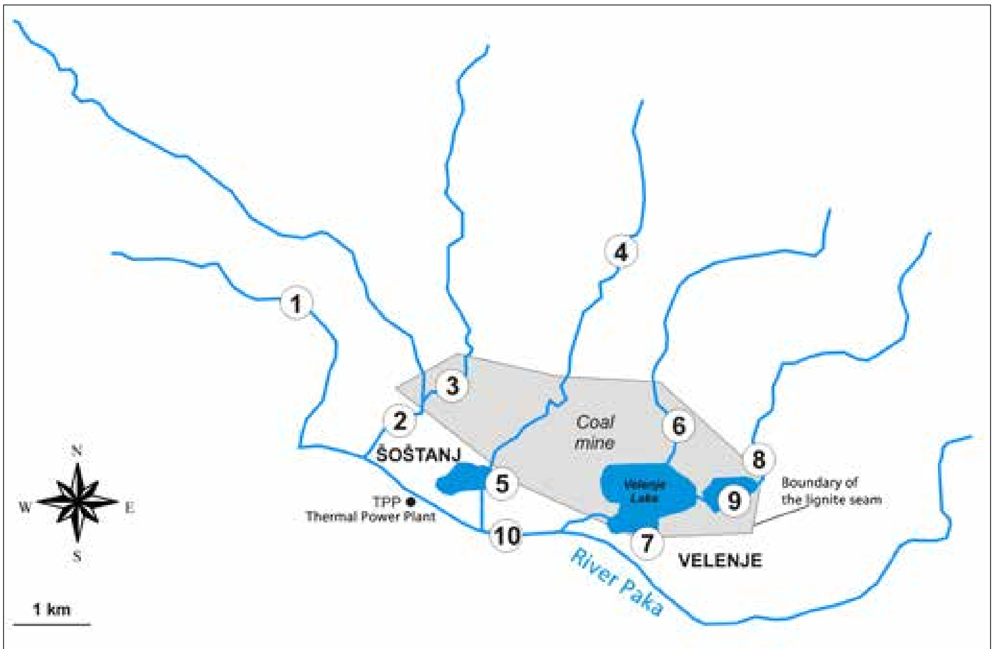

Figure 1. Sampling locations (10 locations) from Velenje Basin area (river locations: 1, 2, 3, 4, 6 and 8, lake locations: 5, 7, 9).

temperature (T), in the air were measured monthly during the year 2011. $\delta^{13}C_{CO2}$ in air was measured with a Europa Scientific 20-20 continuous flow IRMS ANCA-TG preparation module with an estimated precision of ±0.3 ‰. Working standards calibrated to VPDB (Vienna Pee Dee Belemnite) were used during measurements with a defined value of -3.2 ‰ for CO_2. Since CO_2 concentrations in air are very low, working standards were diluted to air CO_2 concentrations to optimize peak area. At the same locations surface water samples (additionally at location 3, which was not sampled for $\delta^{13}C_{CO2}$ air measurements) were collected seasonally for $\delta^{13}C_{DIC}$ measurements (Table 1, Figure 1).

Surface waters (lakes and rivers) were measured at 10 locations for alkalinity and $\delta^{13}C_{DIC}$ (Figure 1). Discharge data were obtained from the Slovenian Environment Agency for the gauging stations: Paka at Šoštanj, Gaberke at Velunja and Lepena at Škale (Internet). Total alkalinity of surface waters was measured according to Gran (Gieskes, 1974). The stable isotope content of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) in surface waters (lakes and rivers) was determined on an IsoPrime GV isotope ratio mass spectrometer coupled with a MultiflowBio preparation module. Phosphoric acid (100%) was added (100-200 µl) to a septum tube and then purged with pure He. A water sample (1 ml) was then injected into the tube and CO_2 measured directly from the headspace. Two standard solutions of Na_2CO_3 (Carlo Erba and Scientific Fisher), with known $\delta^{13}C_{DIC}$ values of –10.8 ± 0.2 ‰ and -4.8 ± 0.2 ‰, were used to calibrate $\delta^{13}C_{DIC}$ measurements (Spötl 2005; Kanduč et al., 2007). When sampling surface waters, pCO_2 immediately above the surface water was measured in an open system and in a closed system. pCO_2 was measured in a closed system above water as follows. A cardboard box with a surface area of 36 cm^2 and a probe for pCO_2 measurements (IAQ-CALC Indoor Air Quality Meter, Model 7545, Thrust Science Innovation (TSI)) was placed through a hole in a cardboard box and, after 10 minutes (Górka et al., 2011) of equilibration between water and air phase, pCO_2 (partial pressure of CO_2) was read.

Results and discussion

Atmospheric data: relative humidity (H), temperature (T), $\delta^{13}C_{CO2}$ and pCO_2 in calendar year 2011 with notes on weather conditions are presented in Table 1. Locations from 1-10 are labeled in Figure 1.

Table 1. Sampling locations with sampling dates, air temperature (T), relative humidity (H), and values of pCO_2, $\delta^{13}C_{CO2}$ together with notes on weather conditions.

No.	Location	Date	T (° C)	H (%)	pCO_2 (ppm)	$\delta^{13}C_{CO2}$ (‰)	NOTES
1	Toplica, 8h20	28.1.2011	10.5	52.8	350	-14.0	sunny
1	Toplica, 8h30	30.3.2011	21.0	26.6	305	-11.9	sunny
1	Toplica, 8h25	19.4.2011	20.8	22.7	290	-11.2	sunny
1	Toplica, 8h22	19.5.2011	26.4	36.1	272	-12.3	sunny
1	Toplica, 8h23	16.6.2011	31.1	41.0	250	-10.6	sunny
1	Toplica, 8h26	18.7.2011	21.2	78.0	285	-13.9	showers
1	Toplica, 8h27	26.8.2011	29.1	46.3	297	-12.7	sunny
1	Toplica, 8h28	15.9.2011	26.3	33.9	266	-12.0	sunny
1	Toplica, 8h35	29.9.2011	18.2	56.3	294	-12.4	sunny
1	Toplica, 8h38	10.10.2011	14.5	45.4	295	-8.1	sunny, after snow
2	Pečovnica, 8h40	28.1.2011	6.5	59.8	360	-10.9	sunny
2	Pečovnica, 8h50	30.3.2011	22.0	30.7	316	-12.5	sunny
2	Pečovnica, 8h45	19.4.2011	20.9	36.3	306	-9.3	sunny
2	Pečovnica, 8h42	19.5.2011	25.6	39.0	272	-12.9	sunny
2	Pečovnica, 8h43	16.6.2011	31.4	38.2	270	-11.0	sunny
2	Pečovnica, 8h46	18.7.2011	21.0	75.9	296	-13.1	showers
2	Pečovnica, 8h47	26.8.2011	31.0	38.5	303	-11.6	sunny
2	Pečovnica, 8h48	15.9.2011	22.4	37.6	255	-10.9	sunny
2	Pečovnica, 8h40	29.9.2011	17.5	55.1	303	-11.3	sunny
2	Pečovnica, 8h55	10.10.2011	12.6	45.3	297	-9.9	sunny, after snow
2	Pečovnica, 8h58	11.11.2011	9.0	53.0	309	-13.0	sunny
4	Velunja, 9h00	28.1.2011	8.8	55.4	333	-12.1	sunny
4	Velunja, 9h10	10.3.2011	17.4	32.4	316	-12.5	sunny
4	Velunja, 9h05	30.3.2011	21.6	31.3	294	-12.1	sunny
4	Velunja, 9h02	19.4.2011	21.4	21.5	300	-10.1	sunny
4	Velunja, 9h03	19.5.2011	25.7	36.6	272	-11.9	sunny

4	Velunja, 9h03	19.5.2011	25.7	36.6	272	-11.9	sunny
4	Velunja, 9h06	16.6.2011	35.0	37.4	239	-13.0	sunny
4	Velunja, 9h07	18.7.2011	21.1	76.0	294	-13.5	showers
4	Velunja, 9h08	26.8.2011	29.1	45.0	275	-11.3	sunny
4	Velunja, 9h10	15.9.2011	25.9	28.3	247	-11.5	sunny
4	Velunja, 9h15	29.9.2011	18.9	46.0	280	-9.5	sunny
4	Velunja, 9h20	11.11.2011	8.0	55.0	270	-11.1	sunny
5	Šoštanjsko jezero, 9h20	28.1.2011	9.1	54.0	330	-10.4	sunny
5	Šoštanjsko jezero, 9h30	10.3.2011	13.6	27.2	330	-11.5	sunny
5	šoštanjsko jezero, 9h25	30.3.2011	21.5	31.2	312	-11.9	sunny
5	šoštanjsko jezero, 9h22	19.4.2011	19.6	23.0	292	-11.3	sunny
5	Šoštanjsko jezero, 9h23	19.5.2011	28.5	27.0	270	-10.5	sunny
5	Šoštanjsko jezero, 9h26	16.6.2011	29.0	47.8	255	-11.0	sunny
5	Šoštanjsko jezero,9h27	18.7.2011	21.3	77.1	303	-12.0	showers
5	Šoštanjsko jezero, 9h28	26.8.2011	28.4	38.0	280	-11.3	sunny
5	Šoštanjsko jezero, 9h30	15.9.2011	30.8	27.9	269	-10.2	sunny
5	šoštanjsko jezero, 9h35	29.9.2011	19.9	51.7	320	-10.8	sunny
5	Šoštanjsko jezero, 9h40	10.10.2011	8.3	65.9	290	-15.6	sunny, after snow
5	Šoštanjsko jezero, 9h45	11.11.2011	7.7	53.9	311	-12.3	sunny
6	Ljubela, 9h40	28.1.2011	8.6	51.8	320	-11.9	sunny
6	Ljubela , 9h50	10.3.2011	16.5	21.0	314	-12.0	sunny
6	Ljubela, 9h45	30.3.2011	20.0	30.0	299	-13.0	sunny
6	Ljubela, 9h42	19.4.2011	19.2	30.3	289	-9.5	sunny
6	Ljubela, 9h 43	19.5.2011	23.5	38.2	270	-10.5	sunny
6	Ljubela, 9h46	16.6.2011	29.4	31.4	242	-10.5	sunny
6	Ljubela, 9h47	18.7.2011	20.7	72.4	290	-11.8	showers
6	Ljubela, 9h48	26.8.2011				-12.0	sunny
6	Ljubela, 9h 50	15.9.2011	27.6	34.5	252	-12.0	sunny
6	Ljubela, 9h 55	29.9.2011	21.3	47.3	283	-12.3	sunny
6	Ljubela, 10h00	10.10.2011	8.2	66.3	280	-7.7	sunny, after snow
6	Ljubela, 10h05	11.11.2011	9.9	54.0	250	-11.1	sunny
7	Velenjsko jezero, 10h00	28.1.2011	9.2	54.5	328	-9.4	sunny
7	Velenjsko jezero,10h10	10.3.2011	15.3	20.2	316	-11.1	sunny
7	Velenjsko jezero, 10h05	30.3.2011	22.3	31.5	299	-12.8	sunny
7	Velenjsko jezero, 10h12	19.4.2011	19.2	31.9	295	-11.7	sunny
7	Velenjsko jezero, 10h13	19.5.2011	26.6	36.5	271	-10.5	sunny
7	Velenjsko jezero, 10h16	16.6.2011	35.0	37.4	239	-10.7	sunny
7	Velenjsko jezero,10h08	18.7.2011	22.1	71.8	289	-12.0	showers
7	Velenjsko jezero, 10h20	15.9.2011	27.3	31.5	249	-12.5	sunny
7	Velenjsko jezero, 10h40	29.9.2011	10.2	54.1	300	-10.7	sunny
7	Velenjsko jezero, 11h00	10.10.2011	10.2	54.1	300	-9.5	sunny, after snow
7	Velenjsko jezero,11h20	11.11.2011	9.5	55.2	260	-18.0	sunny
8	Lepena,10h20	28.1.2011	12.9	44.2	335	-12.4	sunny
8	Lepena,10h30	10.3.2011	16.2	18.0	316	-11.5	sunny
8	Lepena,10h25	30.3.2011	24.8	28.8	309	-13.5	sunny
8	Lepena,10h32	19.4.2011	20.0	21.6	290	-10.7	sunny
8	Lepena,10h33	19.5.2011	25.6	36.8	262	-10.3	sunny
8	Lepena,10h36	16.6.2011	31.4	35.2	244	-12.5	sunny
8	Lepena, 10h28	18.7.2011	21.0	77.2	285	-12.4	showers
8	Lepena, 11h00	26.8.2011	31.1	31.0	271	-12.0	sunny
8	Lepena, 11h20	15.9.2011	27.3	28.7	246	-11.9	sunny
8	Lepena,11h40	29.9.2011	20.6	50.5	282	-11.6	sunny
8	Lepena,12h00	10.10.2011	11.3	50.4	298	-9.0	sunny, after snow
8	Lepena, 12h20	11.11.2011	9.2	52.2	316	-12.2	sunny

9	Škalsko jezero, 10h40	28.1.2011	6.3	66.2	328	-15.0	sunny
9	Škalsko jezero, 10h50	10.3.2011	17.8	23.2	326	-11.7	sunny
9	Škalsko jezero, 10h45	30.3.2011	22.6	27.7	298	-12.7	sunny
9	Škalsko jezero,11h05	19.4.2011	19.0	29.8	291	-14.5	sunny
9	Škalsko jezero,11h25	19.5.2011	26.5	37.6	262	-10.1	sunny
9	Škalsko jezero, 11h45	16.6.2011	31.6	35.8	251	-10.5	sunny
9	Škalsko jezero,12h05	18.7.2011	21.3	74.5	283	-11.9	showers
9	Škalsko jezero, 12h25	26.8.2011	30.2	45.6	270	-11.5	sunny
9	Škalsko jezero,12h45	15.9.2011	29.7	27.7	272	-12.7	sunny
9	Škalsko jezero, 13h05	29.9.2011	22.0	47.1	285	-11.6	sunny
9	Škalsko jezero, 13h25	10.10.2011	7.4	63.3	293	-8.9	sunny, after snow
9	Škalsko jezero,13h45	11.11.2011	8.9	53.6	317	-17.9	sunny
10	Paka, at 8h10	28.1.2011	5.6	70.0	330	-12.1	sunny
10	Paka, at 8h20	10.3.2011	11.6	31.0	360	-11.4	sunny
10	Paka, at 8h10	30.3.2011	20.1	29.8	323	-13.8	sunny
10	Paka, at 8h05	19.4.2011	19.7	25.6	305	-9.5	sunny
10	Paka, at 8h02	19.5.2011	24.2	42.3	293	-11.9	sunny
10	Paka, at 8h03	16.6.2011	28.8	40.1	266	-10.5	sunny
10	Paka, at 8h06	18.7.2011	20.0	63.5	333	-13.5	showers
10	Paka, at 8h07	26.8.2011	28.1	53.0	460	-14.9	sunny
10	Paka, at 8h08	15.9.2011	25.7	39.0	267	-13.0	sunny
10	Paka, at 8h15	29.9.2011	17.2	65.9	333	-12.0	sunny
10	Paka, at 8h18	10.10.2011	12.6	37.6	318	-6.4	sunny, after snow
10	Paka, at 8h19	11.11.2011	10.0	53.4	314	-12.3	sunny

Air temperature ranged from 5.6 to 35.0 °C during 2011 (Figure 2A). Relative humidity ranged from 18.0 to 78.0 % with an average value of 43.6 % (Figure 2B).

CO_2 concentration in the atmosphere, expressed in [ppm] as pCO_2 and carbon isotope signatures of carbon dioxide in the atmosphere ($\delta^{13}C_{CO2}$) from the Velenje Basin indicate seasonal variation (Figures 3A and B). Partial pressures (pCO_2) in the atmosphere from 9 different locations range from 239 to 460 ppm – average 294 ppm. The lowest pCO_2 value was recorded at Velunja location and the maximum value at Paka River (Figure 3A). The values of $\delta^{13}C_{CO2}$ range from -18 to -6.4 ‰, depending on the source (Figure 3 B). The $\delta^{13}C_{CO2}$ values that approach -6.4 ‰ (location Paka, South Preloge mine) could reflect bacterial CO_2 and/or endogenic CO_2 from underground coalmine activity (Lazar et al., 2014), while values approaching -18 ‰ (Škalsko and Velenjsko jezero in November 2011) could be attributed to anthropogenic

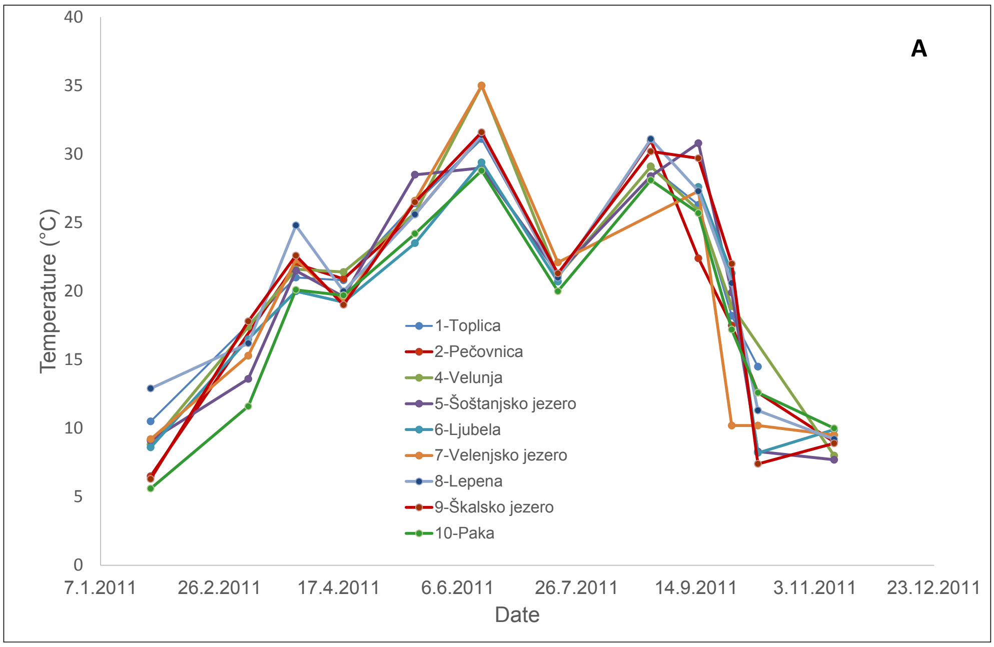

Figure 2A. Air temperature in the calendar year 2011.

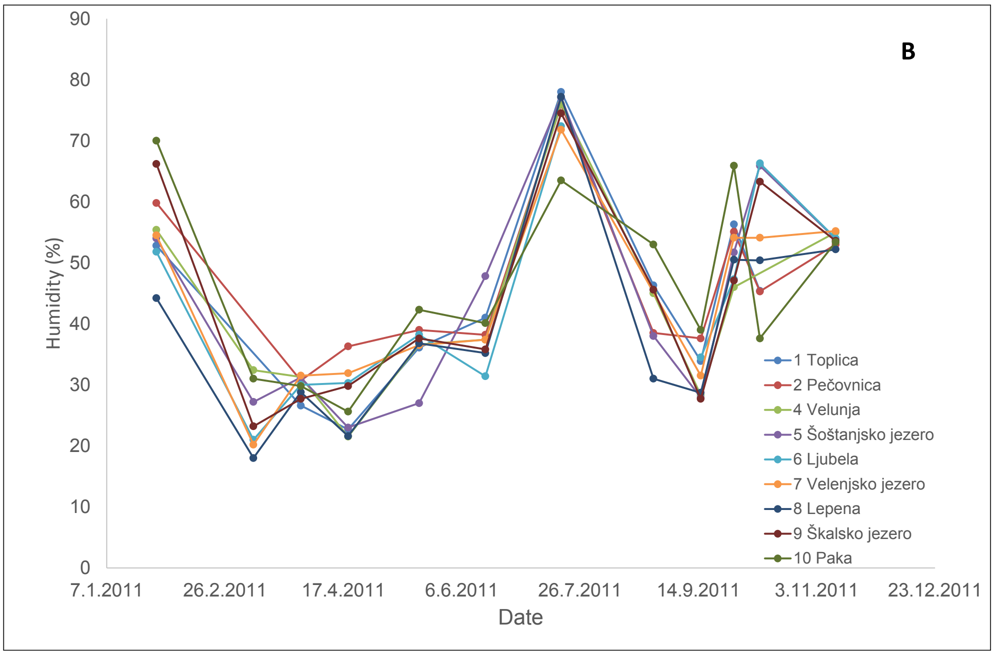

Figure 2B. Humidity in the calendar year 2011. Numbers from 1–10 refer to sampling locations. At location 3 only surface water was sampled.

pollution and natural sources (Figure 3 B). For comparison, the concentration of atmospheric CO_2 at the pristine river Kamniška Bistrica source was 355 ppm and $\delta^{13}C_{CO2}$ value -9 ‰ in different sampling seasons in 2011 (Kanduč, unpublished data). The concentrations of pCO_2 and $\delta^{13}C_{CO2}$ values reported in this study for Velenje basin are similar to those reported for southern Poland (Kuc et al., 2003; Zimnnoch et al, 2004) (Figure 4). Comparison with Wraclaw, Poland was performed since their study was focused on investigation of isotopic composition of carbon in air ($\delta^{13}C_{CO2}$) around anthropogenic sources in relation with other air parameters. The unpolluted $\delta^{13}C_{CO2}$ value (around -8 ‰) is taken from Baltic Sea values (White & Vaughn, 2009) and the $\delta^{13}C_{CO2}$ values of respiration of C3 plants from Pataki et al., 2003. In a coal burning chimney, $\delta^{13}C_{CO2}$ values are -24.1 ‰, exhaust from a gasoline propelled car has values of $\delta^{13}C_{CO2}$ of -31.7 ‰, from a diesel car -31.9 ‰ and from a liquid petroleum gas car -33.5 ‰ (Górka et al., 2011). The characteristic value of $\delta^{13}C_{CO2}$ for a coal-burning chimney is -24.1 ‰ and is much lower in comparison to $\delta^{13}C_{CO2}$ values in our study, where $\delta^{13}C_{CO2}$ ranges from -18.0 to -6.4 ‰ (Table 1).

No correlation was obtained between the following parameters measured in the atmosphere for different locations and in different seasons in Velenje Basin: pCO_2 vs. $\delta^{13}C_{CO2}$ (R^2=0.0292), H vs. pCO_2 (R^2=0.0324), pCO_2 vs $\delta^{13}C_{CO2}$ (R^2=0.0292), T vs. pCO_2 (R^2=0.2644), T vs. $\delta^{13}C_{CO2}$ (R^2=0.0008). Similarly no significant regression was obtained between measured quantities in air (daily temperature vs. humidity, CO concentration, CO_2 concentration, $\delta^{13}C_{CO2}$) for Wroclaw (Górka et al., 2011).

Seasonal variations of total alkalinity, $\delta^{13}C_{DIC}$ and pCO_2 (ppm) in surface waters, with pCO_2 (closed system, measurements with cardboard box) measured and pCO_2 measured just above surface water during year 2011 are presented in Table 2. Discharge data (Q) were obtained from the Slovenian Environmental Agency gauging stations for the year 2011 for locations Velunja, Lepena and Paka.

Alkalinity in surface waters changes seasonally from 2.2 to 5.7 mM in January 2011, from 2.6 to 5.5 mM in May 2011, from 2.5 to 6.1 mM in August 2011 and from 2.5 to 5.7 mM in October 2011. $\delta^{13}C_{DIC}$ changes seasonally from -11.0 to -8.8 ‰ in January 2011, from -11.8 to -7.7 ‰ in May 2011, from -13.5 to -7.1 ‰ in August 2011 and from -12.8 to -9.1 ‰ in October 2011 (Table 2). Higher $\delta^{13}C_{DIC}$ values would be expected in lake water (standing water) since it equilibrates more quickly than surface water (running water), but it is only the case in lake Velenje ($\delta^{13}C_{DIC}$ = -7.7 ‰ in spring season). The opposite trend is observed between $\delta^{13}C_{DIC}$ and alkalinities (Figure 5A), with the lowest $\delta^{13}C_{DIC}$ value and the highest alkalinity being observed at location Pečovnica (location 2) in January 2011.

Since surface water is an open system, its equilibration with the atmosphere is important. Equilibration lines (Figure 5A) were calculated according to possible biogeochemical processes influencing $\delta^{13}C_{DIC}$ value as follows:

Line 1. Given the isotopic composition of atmospheric CO_2 of -7.8 ‰ (Levin et al., 1987) and the equilibration fractionation with DIC of +9 ‰, DIC in equilibrium with the atmosphere should have a $\delta^{13}C_{DIC}$ of about +1 ‰.

Line 2. Considering the average isotopic composition of carbonates ($\delta^{13}C_{CaCO3}$) with a value of -2 ‰ (Kanduč & Pezdič, 2005) and isotopic fractionation (and enrichment in ^{12}C) due to dissolution of carbonates, which is 1.0±0.2 ‰ (Romanek et al., 1992), $\delta^{13}C_{DIC}$ would be -3.0±0.2 ‰.

Table 2. Carbon species in surface waters (alkalinity, $\delta^{13}C_{DIC}$, pCO_2 air-opened system, pCO_2 water/air closed system), discharge data (m^3/s) and surface water temperature (°C) in the year 2011.

Numbers	Locations	Date of sampling	Q (m^3/s)	T [°C]	Alkalinity (mM)	$\delta^{13}C_{DIC}$ (‰)	pCO_2 air, opened system (ppm)	pCO_2 water/air, closed system (ppm)
1	Toplica	January, 2011		8.6	3.6	-10.4	355	357
2	Pečovnica	January, 2011		2.1	2.2	-10.2	360	356
3	Klančnica	January, 2011						
4	Velunja	January, 2011	0.633	2.0	3.0	-8.8	357	357
5	Šoštanjsko jezero	January, 2011		1.2	2.7	-11.0		
6	Ljubela	January, 2011		3.0	5.4	-10.1	361	
7	Velenjsko jezero	January, 2011		2.2	3.2	-9.8	363	
8	Lepena	January, 2011	0.063	3.0	5.7	-10.4	364	355
9	Škalsko jezero	January, 2011		0.7	5.4	-11.0	363	
10	Paka	January, 2011	2.79	2.6	4.4	-10.1	360	363
Numbers	**Locations**	**Date of sampling**	**Q (m^3/s)**	**T [°C]**	**Alkalinity (mM)**	**$\delta^{13}C_{DIC}$ (‰)**	**pCO_2 air, opened system (ppm)**	**pCO_2 water/air, closed system (ppm)**
1	Toplica	May, 2011		16.5	3.6	-9.9	362	365
2	Pečovnica	May, 2011		14.0	3.0	-10.4	404	425
3	Klančnica	May, 2011		16.5	2.9	-11.8	370	388
4	Velunja	May, 2011	0.431	15.8	2.9	-8.9	362	362
5	Šoštanjsko jezero	May, 2011		20.2	2.6	-9.1	368	368
6	Ljubela	May, 2011		16.0	5.1	-10.3	358	370
7	Velenjsko jezero	May, 2011		19.6	3.4	-7.7	361	351
8	Lepena	May, 2011	0.052	17.1	5.5	-10.3	387	353
9	Škalsko jezero	May, 2011		20.9	4.9	-8.4	350	356
10	Paka	May, 2011	2.05	14.1	4.1	-9.9	402	389
Numbers	**Locations**	**Date of sampling**	**Q (m^3/s)**	**T [°C]**	**Alkalinity (mM)**	**$\delta^{13}C_{DIC}$ (‰)**	**pCO_2 air opened system (ppm)**	**pCO_2 water/air, closed system (ppm)**
1	Toplica	August, 2011		16.2	4.8	-10.4	360	362
2	Pečovnica	August, 2011		16.7	6.1	-13.1	358	360
3	Klančnica	August, 2011		23.3	2.5	-7.0	355	367
4	Velunja	August, 2011	0.37	16.7	3.4	-7.8	400	408
5	Šoštanjsko jezero	August, 2011		16.7	4.6	-12.6	395	396
6	Ljubela	August, 2011		23.3	4.2	-7.7	350	353
7	Velenjsko jezero	August, 2011		16.4	3.1	-11.0	365	370
8	Lepena	August, 2011	0.04	16.4	3.6	-13.5	375	378
9	Škalsko jezero	August, 2011		17.5	3.8	-11.3	360	364
10	Paka	August, 2011	1.86	24.0	2.5	-7.1	350	355
Numbers	**Locations**	**Date of sampling**	**Q (m^3/s)**	**T [°C]**	**Alkalinity (mM)**	**$\delta^{13}C_{DIC}$ (‰)**	**pCO_2 air opened system (ppm)**	**pCO_2 water/air, closed system (ppm)**
1	Toplica	October, 2011		9.3	4.0	-12.5	408	420
2	Pečovnica	October, 2011		6.3	2.5	-12.1	421	450
3	Klančnica	October, 2011			3.2			
4	Velunja	October, 2011	0.37	7.8	3.1	-11.3	388	390
5	Šoštanjsko jezero	October, 2011		9.1	3.3	-10.3	386	395
6	Ljubela	October, 2011		7.5	5.1	-12.3	386	400
7	Velenjsko jezero	October, 2011		11.6	2.9	-9.1	386	400
8	Lepena	October, 2011	0.03	7.5	5.7	-12.8	396	402
9	Škalsko jezero	October, 2011		10.4	5.2	-12.1	386	400
10	Paka	October, 2011	1.55	6.7	4.5	-11.0	460	480

Line 3. An average $\delta^{13}C$ value of -26.6 ‰ for particulate organic carbon (POC) was assumed to represent the isotopic composition of POC that was transferred to DIC by in-stream respiration. Open system equilibration of DIC with CO_2 enriches DIC in ^{13}C by about 9 ‰ (Mook et al., 1974), which corresponds to a value of -17.6 ‰.

Line 4 represents open system equilibration of DIC, with soil CO_2 originating from degradation of organic matter with $\delta^{13}C_{CO2}$ of -26.6 ‰.

From Figure 5A it is observed that most of the samples fall between lines 2 and 3: dissolution of carbonates with an average $\delta^{13}C_{CaCO3}$ = -2 ‰ and non-equilibrium carbonate dissolution with carbonic acid produced from soil zone with $\delta^{13}C_{CO2}$ of -26.6 ‰. The highest pCO_2 is observed at location Paka (location 10) with a value of 460 ppm (open system), pCO_2 measured value is 480 ppm (measured as a closed system) in October 2011 probably due to higher degradation of organic matter at the end of the summer season. Elevated pCO_2 concentrations are also recorded at

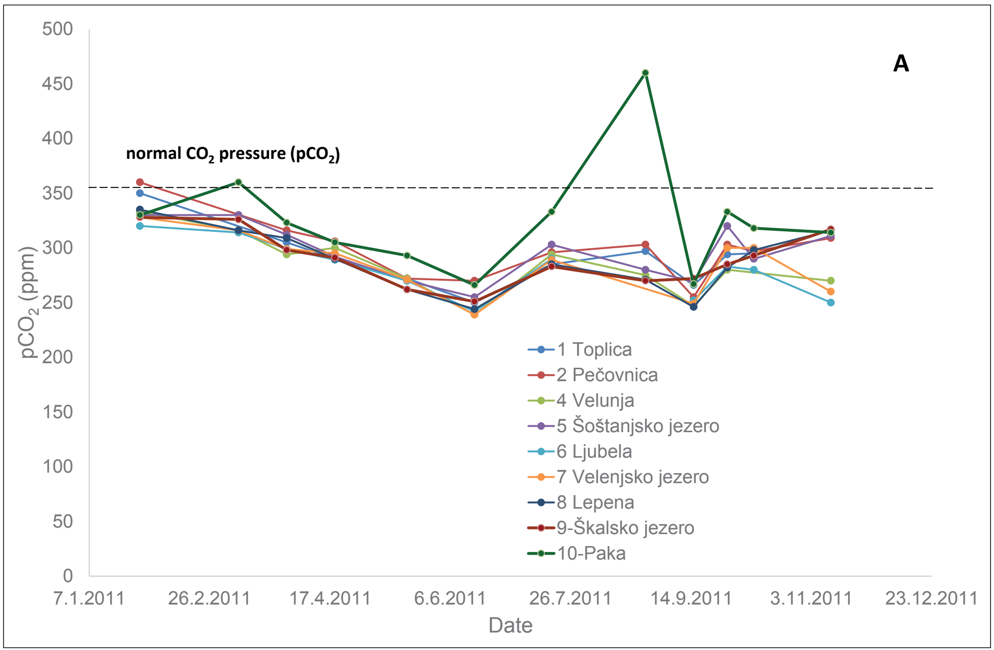

Figure 3A. pCO_2 (partial pressure in air) in the calendar year 2011.

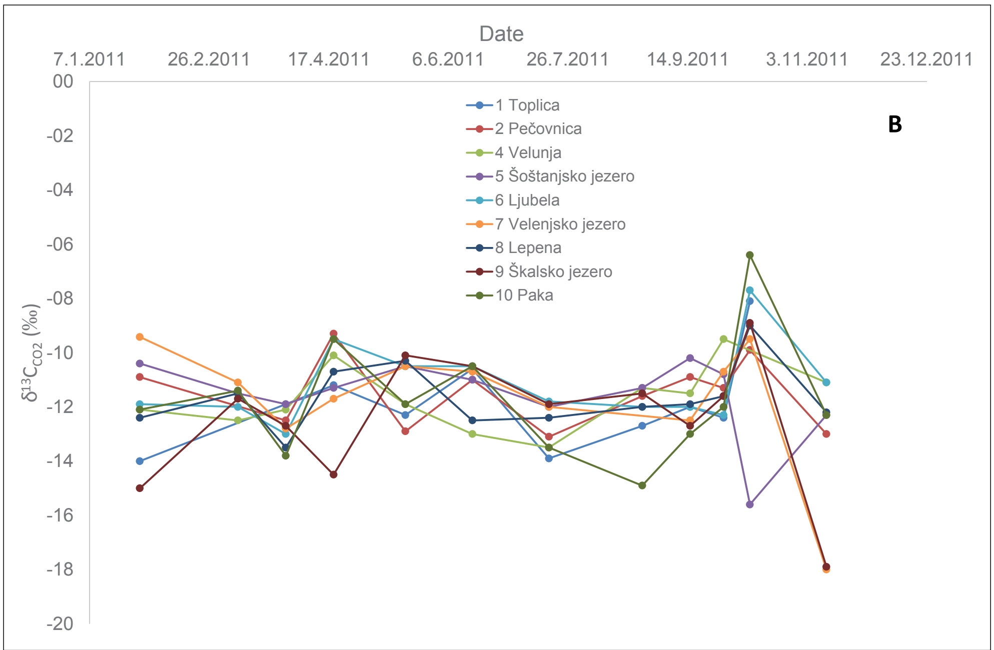

Figure 3B. $\delta^{13}C_{CO2}$ in the calendar year 2011. Numbers from 1–10 refer to sampling locations. At location 3 only surface water was sampled.

Pečovnica (location 2) with value of 404 ppm in surface water measured in opened system above water and 425 ppm as measured in closed system (in cardboard box) May 2011 (Figure 5B).

Calculation of fluxes

The CO_2 flux between surface water and the atmosphere $[DIC]_{ex}$ based on a diffusion model (two layer model in which the molecules are transported through a gas film and a liquid layer adjacent to the surface) can be calculated according to the following equation (Broecker, 1974):

$$[DIC]_{ex} = \frac{D}{z} \cdot ([CO_2]_{eq} - [CO_2]) \tag{1}$$

where D is the CO_2 diffusion coefficient in water with value of 1.26 x 10^{-5} cm^2/s at a temperature of 10 °C and 1.67 x 10^{-5} cm^2/s at a temperature of 20 °C (Jähne et al., 1987), z is the empirical thickness of the liquid layer [cm], $[CO_2]_{eq}$ and $[CO_2]$ are the concentrations of dissolved CO_2 at equilibrium with the atmosphere and with the studied water [$mol \cdot cm^{-3}$], respectively. The thickness of the boundary layer z, a thin film existing at the air-water interface, depends largely on wind velocity (Broecker et al., 1978) and water turbulence (Holley, 1977). D/z, therefore, is the gas exchange rate, which gives the height of the water column that will equilibrate with the atmosphere per unit time. Using a mean wind speed of 4 m/s in all sampling seasons (Jähne et al., 1987), D/z was estimated to be 8 cm/h under low turbulence conditions, 28 cm/h under moderate turbulence conditions and 115 cm/h under high turbulence conditions.

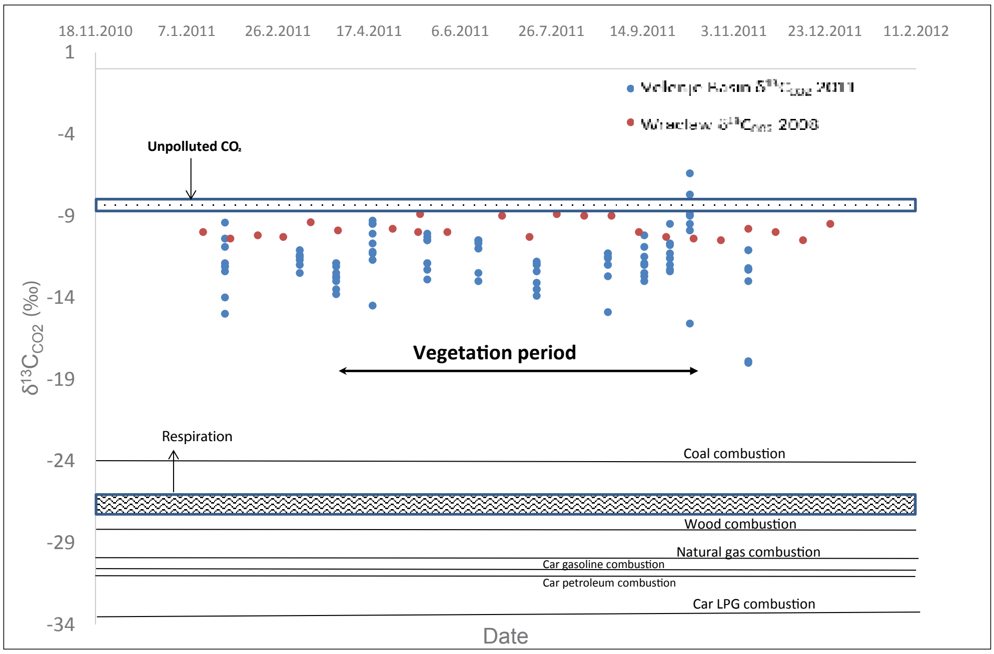

Figure 4. $\delta^{13}C_{CO2}$ levels in the calendar year 2011 compared with those at Wroclaw (Górka et al., 2011). Bold lines indicate the potential anthropogenic sources analyzed in Wroclaw (Górka et al., 2011). The $\delta^{13}C_{CO2}$ value characteristic for the absence of pollution is taken from Baltic Sea values (White & Vaughn, 2009) and $\delta^{13}C_{CO2}$ values characteristic for C3 plants respiration from Pataki et al., 2003.

Calculation of the CO_2 flux between the river water surface and the atmosphere at the Paka River gauging station, according to equation (1), gives values ranging from 2.6 x 10^{-8} to 9.0 x 10^{-8} mol/cm^{2}h in spring 2011, from 6.0 x 10^{-8} to 20 x 10^{-8} mol/cm^{2}h in late summer 2011 and from 2.7 x 10^{-8} to 9.4 x 10^{-8} mol/cm^{2}h in winter 2011. Taking into consideration the river surface area of 0.40 km^2 (mean width of 10 m and length of 40 km), the total loss of inorganic carbon through its surface in the spring ranges from 6.0 x 10^4 mol/day during periods of low wind speeds to 2.0 x 10^5 mol/day during high turbulence storm events. The predicted total loss of inorganic carbon to the atmosphere in the late summer ranges from 1.0 x 10^5 to 5.0 x 10^5 mol/day and from 6.0 x 10^4 to 2.1 x 10^5 mol/day in winter.

Concentration diffusion model

In addition, values of the time evolution of stream pCO_2 and $\delta^{13}C_{DIC}$ were calculated using available diffusion models (e.g. Broecker 1974; Richey et al. 1990; Aucour et al., 1999). These calculations yield the amount of time needed for CO_2 evasion and for stream – atmosphere isotopic exchange relative to the transit time of stream waters. Such calculations were performed only for two main tributaries: Velunja River (location 4) and Paka River (location 10) for all sampling seasons (Figure 1, Table 2). The estimated rate of change of DIC concentration due to CO_2 evasion are calculated by:

$$\frac{d[DIC]}{dt} = \frac{D}{zh} \cdot ([CO_2]_{eq} - [CO_2]) \qquad (2)$$

and the DIC concentration in water is expressed as a function of time by:

$$[DIC] = [CO_2]_{eq} - ([CO_2]_{eq} - [CO_2]_0) \cdot e^{-\frac{D}{zh}t} \qquad (3)$$

where h is the mean depth of the river [cm] and t is the time needed for equilibration [min], all other parameters having been determined by equation (1). The calculations assume a value of 8 cm/h for D/z (low turbulent conditions due to low discharge) for both locations (4 and 10) (Mook, 1970) and h values of 10 cm. The computed results, according to equation (3), show that between 0.6 and 2.6 hours (January, 2011), 8.8 and 9.2 hours (May, 2011), 5.7 and 6.4 hours (August, 2011), and from 5.7 to 6.4 hours (October, 2011) would be required for equilibrium between atmospheric CO_2 and dissolved riverine CO_2 to be approached.

Isotopic diffusion model

Additionally, the rate of change of $\delta^{13}C_{DIC}$ resulting from CO_2 exchange between the river and the atmosphere was also estimated by the equation (Aucour et al., 1999):

$$\frac{d\delta^{13}C_{DIC}}{dt} = \frac{D[CO_2]_{eq}}{zh\,[DIC]} \cdot (\delta^{13}C_a - \delta^{13}C_{DIC} + \varepsilon) \qquad (4)$$

Again, the DIC concentration ([DIC]) is expressed as a function of time (t) by:

$$\delta^{13}C_{DIC} = (\delta^{13}C_a - \varepsilon) - (\delta^{13}C_a - \varepsilon - \delta^{13}C_{DIC,0}) \cdot e^{-\frac{D[CO_2]_{eq}}{zh[DIC]}t} \qquad (5)$$

In equations (4) and (5), $\delta^{13}C_a$ and $\delta^{13}C_{DIC}$ are the $\delta^{13}C$ values of atmospheric CO_2 (-7.8 ‰; Levin et al., 1987) and DIC, $\delta^{13}C_0$ is the initial value of DIC and ε is the equilibrium fractionation factor between CO_2 and HCO_3^- (Zhang et al., 1995).

Starting with the $\delta^{13}C_{DIC}$ value of –12.5 ‰ (Aucour et al., 1999) and h value of of 10 cm, calculated time of equilibration ranged from 26.2 to 132.6 hours, which would be needed to equilibrate $\delta^{13}C_{DIC}$ and $\delta^{13}C_{CO2}$ values. This time interval was calculated for Velunja River

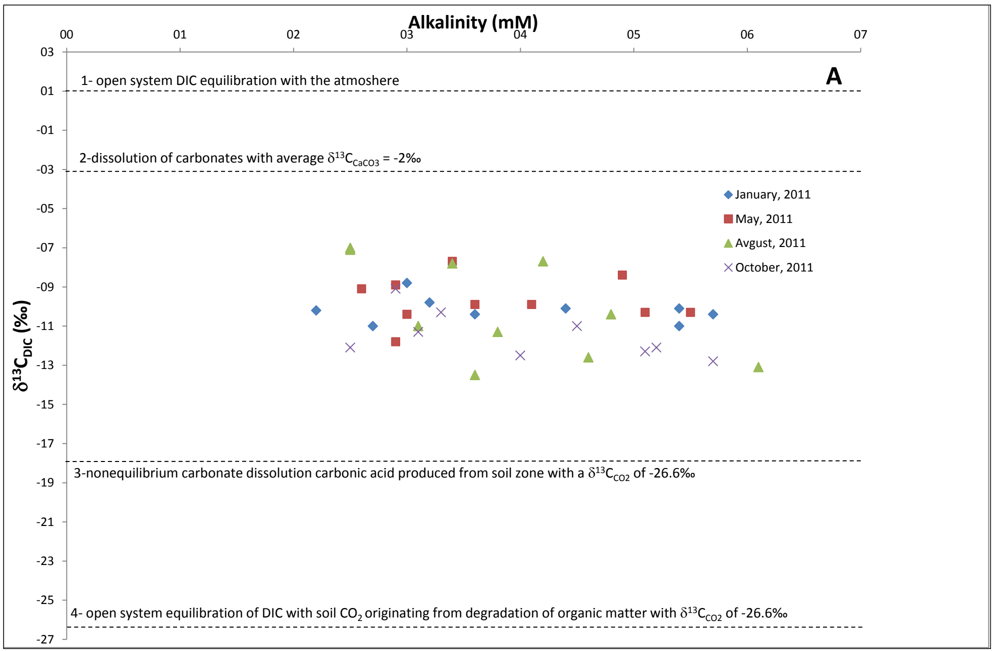

Figure 5A. $\delta^{13}C_{DIC}$ values of surface water samples as a function of alkalinity, with lines indicating processes occurring in surface waters in Velenje Basin. Arrows show expected trends for a variety of biogeochemical processes (Coetsiers & Walraevens, 2009).

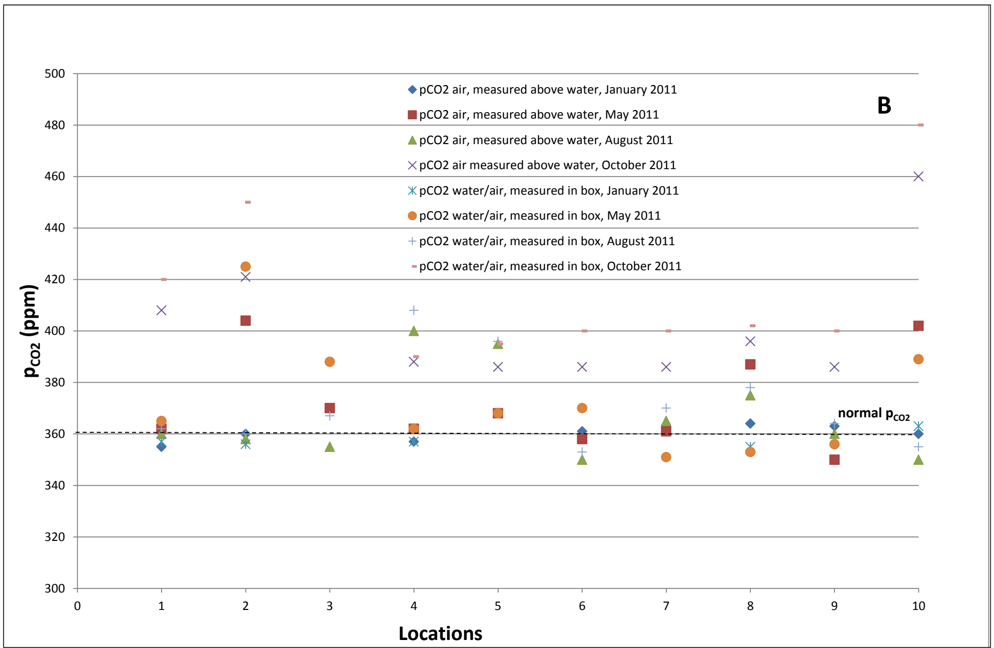

Figure 5B. Seasonal variation of pCO_2; comparison between pCO_2 air (open system) and pCO_2 water/air (closed system) at 9 locations from Velenje Basin. Normal pCO_2 in air is considered to be 360 ppm.

(location 4) and Paka River (location 10) and suggests that stream – atmosphere isotopic exchange alone cannot explain the ^{13}C enrichment of DIC in this carbonate/clastics catchment. Stream – atmosphere isotopic exchange alone cannot explain the ^{13}C enrichment of DIC since longer time is needed for equilibration than expected. Both models (concentration and isotopic) should provide same values of time of equilibration, but in our case they do not. However, it has been shown that equilibration of CO_2 between water/air boundaries is more significant in impermeable silicate drainages (Kanduč et al., 2007). Therefore equilibration of atmospheric CO_2 does not influence the value of $\delta^{13}C_{DIC}$ in surface waters significantly, which is a consequence of low discharge conditions in the catchment area.

Conclusions

Values of the carbon isotope composition of atmospheric CO_2 ($\delta^{13}C_{CO2}$), at locations in the vicinity of the thermal power plant in Velenje Basin, have been measured in the calendar year 2011. Based on measurements of alkalinity and $\delta^{13}C_{DIC}$ for surface water, values of $\delta^{13}C_{CO2}$ of air samples taken just above water (opened system) and from a closed cardboard box (closed system) it is concluded that combustion of lignite in thermal power plant has little influence on the $\delta^{13}C_{CO2}$ value in the atmosphere. Measured CO_2 concentrations (average pCO_2 value of 294 ppm) and $\delta^{13}C_{CO2}$ in the atmosphere in the vicinity (few kilometers) of the thermal power plant are in the normal range in the atmosphere (360 ppm) and the influence of lignite combustion is negligible at the locations investigated in this study. The values of $\delta^{13}C_{CO2}$ in air range from -18 to -6.4 ‰, with an average value of -11.7 ‰, indicating the absence of influence of coal combustion, since the characteristic value of coal combustion is -24.1 ‰. $\delta^{13}C_{CO2}$ values in our study (observations during year 2011) are similar as obtained for Wroclaw, Poland (observation during year 2008).

The total alkalinity in surface waters ranged from 2.2 to 6.1 mM. Dissolution of carbonates and degradation of organic matter are the most important biogeochemical processes affecting $\delta^{13}C_{DIC}$. They range seasonally from -13.5 to -7.1 ‰ in the surface waters (lakes, rivers) investigated in this study. pCO_2 in the air immediately above water (open system) and in the air above the water, measured in the cardboard box (closed system), is similar at all measured locations. The highest pCO_2 in an open system – immediately above water– and in a closed system (measured in a box) were measured at Paka (location 10) and Pečovnica (location 2) in May 2011 and in October 2011, respectively. Both locations are located in the vicinity of the thermal power plant. Based on thermodynamic modelling and on previous studies reported for Slovenian watersheds (rivers and lakes), surface waters acted like sources of CO_2 (oversaturated more than 10 times) released to the atmosphere. However, the measurements of pCO_2 reported here were made just above the surface water, where normal values of pCO_2 (around 360 ppm) are present.

Two diffusion models (concentration and isotopic) were applied to obtain the time of equilibration at two locations. Between 0.6 and 6.4 hours were required to equilibrate atmospheric CO_2 and dissolved riverine DIC (concentration diffusion model), and 26.2 to 132.6 hours to equilibrate $\delta^{13}C_{DIC}$ and $\delta^{13}C_{CO2}$ values (isotopic diffusion model) if equilibration with atmospheric CO_2 was the only factor influencing DIC values of surface waters.

Even though Velenje Basin is a natural analogue with very large amounts of endogenic and bacterial CO_2 (with the characteristic value of $\delta^{13}C_{CO2} \sim 2$ ‰) and with large amounts of CO_2 emitted (around 4 Mt/year) from lignite combustion from the thermal power plant, we conclude from this study that pCO_2 concentrations in air around the thermal power plant are not elevated.

Acknowledgements

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Spatio-temporal distribution of discharges in the Radovna River valley at low water conditions

Prostorsko-časovna porazdelitev pretokov v dolini reke Radovne v obdobju nizkih vod

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Ključne besede: vodonosnik, podzemna voda, meritve pretokov, elektroprevodnost, reka Radovna

Abstract

The Radovna River is a 19.4 km long river located in the north-western part of Slovenia, which runs almost entirely over the area of Triglav National Park. The bottom of the valley is filled with fluvioglacial sediments, which represent an unconfined aquifer with karst aquifers in the recharge area consisting of carbonate rocks of the Triassic age. The Radovna River has only few short stream tributaries, which are recharged from the karstic springs. Therefore, the Radovna River is groundwater dominated river. Within this study, simultaneous measurements of discharge were performed. Discharge and electrical conductivity (EC) were shown to increase downstream. In low water conditions, the average increase in discharge was from 88 l/s km^{-1} to 287 l/s km^{-1}.

Izvleček

Reka Radovna je 19,4 km dolga reka v severozahodni Sloveniji, ki skoraj v celoti teče po območju Triglavskega narodnega parka. Njeno dolino tvorijo fluvioglacialni sedimenti, ki predstavljajo odprt vodonosnik, zaledje pa tvorijo kraški vodonosniki v triasnih karbonatnih kamninah. Reka ima le nekaj kratkih pritokov, ki jih napajajo kraški izviri, zaradi tega je pretežno pod vplivom podzemne vode. V okviru raziskav so bile izvedene večkratne simultane meritve pretokov, s katerimi je bilo ugotovljeno, da pretok in elektroprevodnost naraščata vzdolž toka. V obdobju nizkih vod znaša povprečni prirastek pretoka od 88 l/s km^{-1} do 287 l/s km^{-1}.

Introduction

In Slovenia, most of the drinking water comes from groundwater resources. Although the Radovna River is not a large river, groundwater from its alluvium already supplies three large communities in NW Slovenia: Bled, Gorje and Radovljica. It is important to understand the hydrogeological conditions in the Radovna River valley and its recharge area. Firstly, because potential water reserves are much greater than used today (Marinko, 1978; Internet 2), and secondly, because the valley is positioned in the Triglav National Park, representing an important natural treasure.

The purpose of the present study is to describe hydrogeological phenomena and conditions in the Radovna River. In parallel, the spatial distribution of discharges in low water conditions along the river course. It is hypothesised that, in low water conditions, only groundwater outflow is presented in the Radovna riverbed, and with the methods applied, possible spatial relations between various contributions to the river flow can be interpreted. During 2006, 2008 and 2009, discharge and electrical conductivity (EC) were measured at several locations along the river.

General settings

The Radovna River is, in large part, an Alpine river positioned in a narrow glacial valley with steep slopes. The bottom of the valley is filled with alluvial and glacial material. The river flows between the karstified mountainous plateaus of Pokljuka in the south and Mežakla in the north, both of which are covered by forests (Fig. 1). Pokljuka is a 20 km long plateau with an altitude of between 1000 and 1400 m a.s.l., with the highest point at 1630 m a.s.l. The Mežakla plateau is surrounded by two rivers: the Sava Dolinka River in the north and the Radovna River in the south. The altitude of the plateau is approximately 1200 m a.s.l., with the highest point at 1593 metres. The total width of the Radovna River valley is between 300 and 350 metres. The narrowest part is the Vintgar gorge, which is located in the lower part of the valley and is surrounded by two hills: Hom (834 m) and Boršt (931 m). The river's terminal springs are positioned in Zgornja Radovna. In the village of Moste, near Žirovnica, the river, after 19.4 km, converges with the Sava Dolinka River. In the valley, only a few stream tributaries are present; all of which are short, and nearly all are supplied by karstic springs. From south of village Zgornje Gorje, small stream Buden is coming from the dolomite aquifer and in the watershed of Rečica part of water is coming from the Obranca area where also dolomite aquifer is present. North of Rečica is the Poljane valley, which does not have significant surface water flow. All water sinks into the sediments on the valley floor; even after a heavy rain, water does not reach Rečica. Between Spodnja Radovna and the Grabče gorge, Ribščica is also present, where water only flows after heavy rain. It has been estimated that the balance contribution of these creeks during periods of low water is negligible.

Along the valley, several factors indicate that the Radovna River is a groundwater dominated river; in all cases, the groundwater level on the banks is higher than the water level in the river. In the upper part of the valley, Kreda, an artificial lake representing a former chalk pit, is present. During exploitation, two separate layers of gravel were open from where groundwater flowed into the pit: the water level in the lake was higher than in Radovna. In Srednja Radovna, in two artesian boreholes (downstream from RMP-4), the hydraulic head is higher than the water level in the Radovna River. The last indicator is the drainage gallery in Ovčja jama, in which the water level is again higher than in the Radovna. Streams dominated by groundwater can be indicated by other factors, including a stable flow regime and stable water temperature (Sear et al, 1999).

The upper part of the Radovna River valley continues further to two Alpine glacial valleys, Kot and Krma, with occasional streams Kotarica and Krmarica. Both valleys are filled with highly permeable gravel. Precipitation in this area infiltrates and recharges groundwater; therefore, no surface springs and streams are present. Springs and torrential water in the streambeds occur only after prolonged periods of rain.

In various parts of the valley, several geological and hydrogeological investigations were conducted. However, almost no results were published, but all data are available in the archive of the Geological Survey of Slovenia. In 1961, the first geological mapping was conducted for chalk exploitation in Srednja Radovna (Jamšek, 1969). In 1977 and 1987, geological mapping was performed in the same region for the preparation

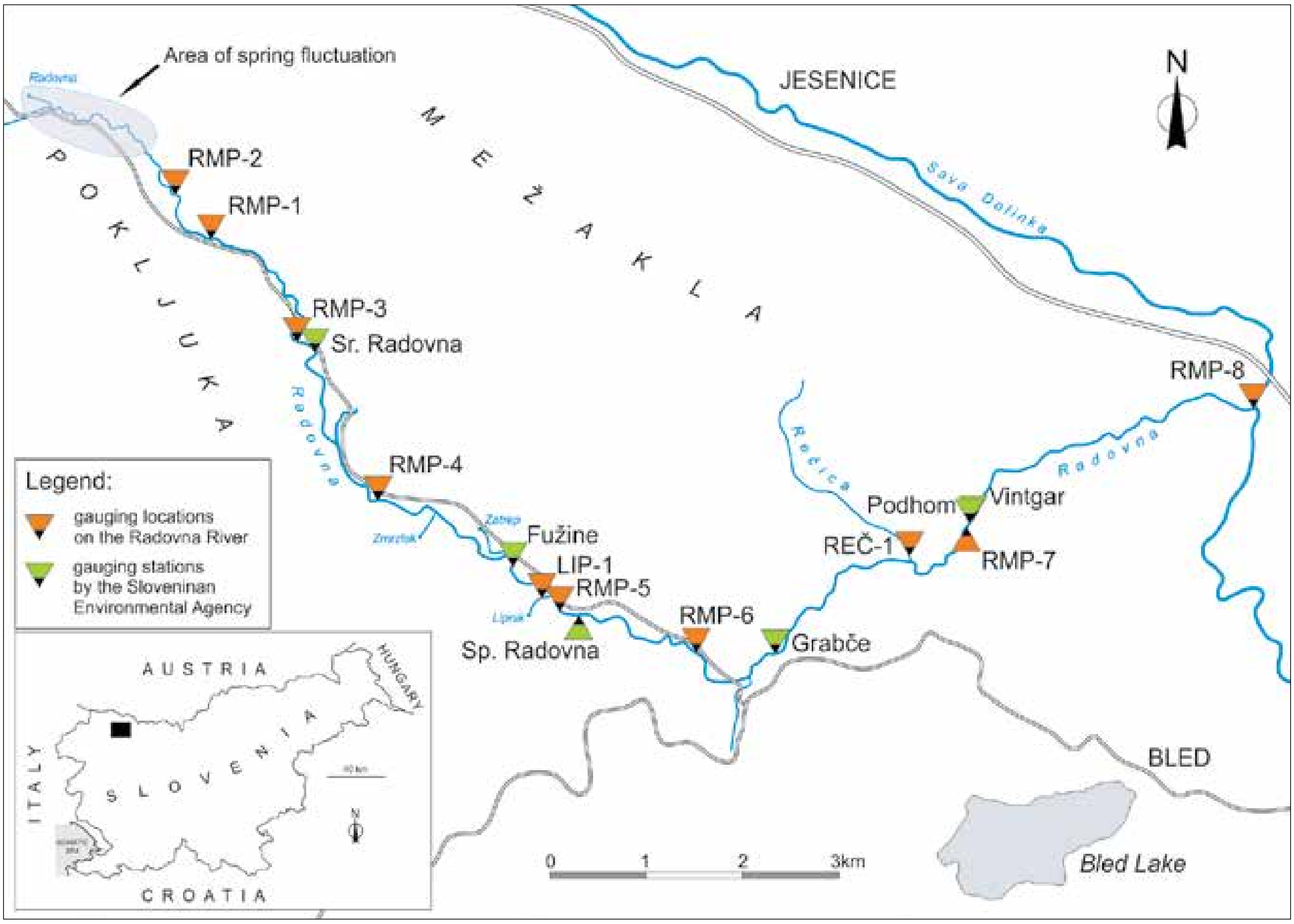

Fig. 1. Geographical map of the area with gauging locations.
Sl. 1. Geografska karta območja z lokacijami merskih točk.

of state geological maps: sheets Celovec and Beljak - Ponteba (Buser, 1980; Jurkovšek, 1987). In 1975, hydrogeological and geomechanical investigations were carried out in the region between Zgornja Radovna and Gabrje for a high-dam construction waterstorage reservoir (Drobne, 1975); however, construction never began. In 1978, hydrogeological investigations were performed south-east of Srednja Radovna (Ovčja jama) for planning and designing a deep-drainage for water supply (Marinko, 1978). In parallel, engineering geology was performed along the pipeline route (Marinko & Andrič, 1978). After the capture zone, the Ovčja jama was constructed and in 1984, detailed hydrogeological mapping was done for the design of groundwater protection zones (Rogelj, 1984). Recent studies in the Radovna River valley refer to the stable isotope composition of three karstic springs (Kanduč et al, 2012) and to the impact of iron ore processing activity in Srednja Radovna (Ferjan Stanič et al, 2013). In addition, the hydrogeology of spring Zmrzlek was investigated (Serianz, 2013).

Geological settings

Wider area of the Radovna River valley is comprised of Triassic, Tertiary and Quaternary rocks and sediments. Lower Triassic marl, marlstone, oolite, grained limestone, mica dolomite and silt are positioned in the eastern part of the Mežakla plateau. Anisian strata located in the north-eastern part of the Mežakla plateau are represented as light grey and thick stratified massive reef limestone, which is deposited on stratified dolomite. There exists an Anisian-Ladinian rock outcrop on the southern slope of Mežakla near the village of Srednja Radovna, in which dolomite prevails; the rocks are different colours and vary from dark and olive grey to brown and slightly pink. Ladinian rocks are positioned in the eastern part of Pokljuka and Mežakla, represented as light and brownish grey platy and stratified micritic limestone with chert. Numerous patches of volcanic rock are present on the Pokljuka plateau; however, their frequency is higher in the east than in the west. A large portion of the Carnian rock in both plateaus is represented as granular massive dolomites; among them, stratification is subordinate. Locally, dolomite, limestone and dolomitised limestone can also occur. Middle Oligocene layers are present south of the Žirovnica village, at the confluence of the Radovna and Sava Dolinka rivers. Beds are comprised of dark grey mica sandy silt, which transitions into clay.

Quaternary sediments occur in the bottom of the valley. In Srednja Radovna village, chalk deposited in the fluvioglacial lake is present and, in the past, it has been exploited. Chalk also outcrops in the north-western part of the valley, but it is mixed with sand. Unconsolidated fluvioglacial sediments are represented as gravel and sand and are only partly conglomerated. Moraines are separated according to the location where they occur: in the valley, on the slope and in the Pokljuka plateau. Moraines in the valley are homogeneous and are the result of accumulation due to glacial activity. Slope moraines occur on slopes of the Pokljuka plateau and are comprised of unsorted material, which is dominated by finer fractions with rare, round rocks of limestone. The youngest moraines are on the Pokljuka plateau and are represented as unconsolidated and unsorted grains: predominantly limestone. Flat heterogeneous alluvial deposits of the Holocene age are located along both banks of the stream in the central part of the valley. These deposits are covered with dark grey to black alluvial, containing a number of sharp-edged pieces of white and light grey Triassic limestone and dolomite (Buser, 1980; Jurkovšek, 1987).

The overall thickness of the Quaternary deposits is unknown, but only a few boreholes were made in the past along the valley, which can indicate the approximate thickness of the sediments. During the planning of a tourist centre in 1965, three boreholes were drilled in Krma valley, showing that the thickness of the glacial and alluvial deposits is at least 60 m (Žlebnik, 1966). Later between Srednja Radovna and Gabrje, in 1974, three boreholes were drilled for high-dam construction. The deepest borehole was 103 metres and did not reach the bottom of the valley (Drobne, 1975). Based on these data, we can conclude that, in the upper part of the Krma valley, the thickness of the sediment is at least 60 m and, in the central part of the valley, the thickness is greater than 100 m.

Hydrogeological settings

In the Radovna River valley and its recharge area, a combination of intergranular and karst aquifers is present. Intergranular aquifers are positioned at the bottom of the valley, while karst aquifers form valley slopes and a wider recharge area. In the valley, numerous springs are present. They can be classified into karstic springs, gravity (descending) springs, contact springs on the edge of moraines, seepage springs and diffuse springs from unconsolidated sediments (Kresic, 2010); some of which are present only during high water conditions.

The terminal spring of the river is positioned in Zgornja Radovna, in the area where the large and steep alluvial fan comes from the west and is in contact with the relatively flat fluvioglacial deposits of the river bottom in Gogala in the settlement of Zgornja Radovna. There are several diffuse springs with non-permanent positions. Because the alluvial fan is an unconfined aquifer, the groundwater table in the aquifer substantially fluctuates depending on precipitation and snowmelt infiltration. Consequently, the location of the springs moves up and down along the upper part of the valley.

In addition to the main terminal of the Radovna River spring, numerous springs are present in the valley; however, only two (Lipnik and Rečica) were investigated (Fig. 1). Springs appear throughout the valley, while short tributaries appear mainly in the central part of the valley. The recharge areas of all springs are in the karstic aquifers and are developed due to the contact between alluvial sediments in the central part of the valley and carbonate rocks on valley slopes. Due to the karstic nature of springs, their discharge fluctuates profoundly depending on the amount of precipitation and snowmelt infiltration. The following springs are positioned downstream from the terminal of the Radovna River springs on the north-west side. South of Mlinarjev rovt, the right-bank tributary is recharged by the karstic spring, Zmrzlek, where discharge substantially fluctuates and, thus, the position of the spring changes depending on hydrological conditions. Further downstream, on the left bank of the karstic spring, Zatrep is positioned. It is recharging in the area of Perniki. The next tributary is Lipnik, which is on the right bank, and is recharged from the karstic spring of the same name. Its recharge area is on Pokljuka plateau. The last tributary is the Rečica creek on the left bank, between Zgornje Laze and Poljane villages, flowing out from the south-eastern part of Mežakla plateau. The Rečica creek is supplied with several karstic springs.

Water intake structures

Several water intake structures for the capture and abstraction of water appear along the Radovna River. The structure that is furthest upstream is a small hydroelectric power plant (HPP), Klemenak, which has been in operation since 1993: it provides 40kW of power. This HPP diverts water from the riverbed. The Zmrzlek spodnji spring, which is positioned approximately 250 m downstream from the main Zmrzlek spring, is captured for water supply. Presently, water from this source is not used (Internet 2). Bellow Srednja Radovna is the Gorje HPP, which has been in operation since 1906 and is one of the oldest in Slovenia (Papler, 2004). The water is taken from the river at a nearby small dam and diverted to the HPP; during low water conditions between the intake structure and the outflow from the HPP (at a distance of 1000 m), the riverbed is occasionally completely dry, which profoundly influences the river's hydrologic regime. Further down the river at Ovčja jama on the left bank, a deep drainage reservoir for drinking water (with a capacity of 400 l/s) is positioned (Internet 2). In NW Slovenia, this is one of the most important water resources, as it supplies 14,500 inhabitants. In the village of Grabče, an intake structure on the right bank is positioned. The intake is intended to supply Bled Lake via tunnel transfer with fresh, aerated water. The tunnel was constructed between 1962 and 1964, and water transfer began in 1972. The tunnel has a transfer capacity of up to 2000 l/s (Podlipnik & Lukan, 1999). Until 1994, 200 l/s were transferred to the Bled Lake; later, the intake increased to 400 l/s (Remec-Rekar, 2004). In the village of Grabče, a small HPP (Mihova kovačnica, operating since 1990) is also positioned. The last water structure on the river is Vintgar HPP, which has been in operation since 1903; this is also one of the oldest HPPs in Slovenia (Remec-Rekar, 2004). Upstream from Vintgar HPP, a dam used for water capture is constructed. Beside the dam, there is a canal for water abstraction. Vintgar HPP abstracts most of the water from the river and transfers it downstream directly into the Sava Dolinka River at Zasip village. Consequently, the lower part Radovna River flows into the Sava Dolinka River only during high water conditions.

Methods and materials

Measuring sites and events

Discharge and EC of the river and spring water were measured at eight locations along the river and at tributaries. The locations on the river were named RMP-1 to RMP-8 (Fig. 1). At tributaries, measurements were made on Lipnik (LIP-1) and Rečica (REČ-1). Water coming out of the Gorje HPP in Srednja Radovna was also measured. For further interpretation, the discharges at locations RMP-5 and Gorje HPP were combined and used as one discharge. RMP-2 is the first location downstream from the main terminal spring (GKY 421837, GKX 142602). As the position of the main spring fluctuates substantially, the location was selected where the discharge is always present. RMP-1 is the next downstream location, which is situated where the otherwise braided riverbed becomes uniform. RMP-3 is situated after Kreda Lake. RMP-4 and RMP-5 are located before and after the lake, where most of the karstic springs discharge into the Radovna River. RMP-6 is located after Ovčja jama and before the Rečica flows into the Radovna River. RMP-7 is positioned before Vintgar gorge, where the maximum discharge in low flow conditions is measured. The last location, RMP-8, is located before the Radovna River discharges into the Sava Dolinka River.

Additional discharge data were provided by the Slovenian Environmental Agency. Measurements were performed daily at Podhom, which is positioned in front of the Vintgar gorge (GKY 430055, GKX 139215). The data gathered was from 1933–2013. For further interpretation, the average annual discharge of water flow was calculated.

Discharge measurements

The chemical integration method was used for discharge measurements in the Radovna valley. The method is based on the instantaneous injection of the tracer into the stream. The method is usually used for watercourses that have high velocities and uneven river bottoms (Boiten, 2008). As a tracer, kitchen salt was used. It is the most

Table 1. Discharge and electrical conductivity at gauging points.

Tabela 1. Pretok in elektroprevodnost na merskih točkah.

LOCATION	DATE	GKY	GKX	DISCHARGE (l/s)	ELECTRICAL CONDUCTIVITY (µS/cm)
RMP-2	3.2.2006	421837	142602	148	225
0 km	15.2.2008			408	225
	2.9.2008			1840	215
	16.3.2009			1100	209
RMP-1	1.2.2006	422188	142150	824	213
0,65 km	15.2.2008			1040	221
	2.9.2008			1580	218
	17.3.2009			1270	229
RMP-3	3.2.2006	423082	141082	554	224
2,40 km	15.2.2008			740	221
	2.9.2008			1720	222
	16.3.2009			1545	233
RMP-4	3.2.2006	423923	139420	857	228
6,96 km	14.2.2008			1440	229
	2.9.2008			2990	229
	16.3.2009			2010	240
RMP-5	3.2.2006	425832	138291	1221	286
7,04 km	14.2.2008			2052	283
	1.9.2008			3792	276
	17.3.2009			3596	287
RMP-6	2.2.2006	427249	137822	1010	246
8,77 km	14.2.2008			1815	242
	1.9.2008			2375	248
	17.3.2009			2240	259
RMP-7	2.2.2006	429975	138975	1510	256
12,68 km	14.2.2008			2760	252
	1.9.2008			4435	252
	17.3.2009			4600	271
RMP-8	2.2.2006	432988	140308	206	283
16,56 km	15.2.2008			40	283
	1.9.2008			32	276
LIP-1	1.2.2006	425635	138412	134	/
	15.2.2008			186	277
	1.9.2008			526	294
	16.3.2009			483	294
REČ-1	2.2.2006	429446	138863	64	374
	14.2.2008			146	289
	1.9.2008			108	352
	17.3.2009			443	330

commonly used tracer for this method because it is easily available, inexpensive, has good solubility and does little or no harm to animal life and flora in the water. Salt concentration was determined by the EC of, in our experiment, the Flo-Tracer of Flow-Tronic. Before each field campaign, the instrument was calibrated in the laboratory. A certain quantity of salt is injected at a point in the watercourse; then, downstream at a certain point, where the tracer has been sufficiently dispersed, the instrument is gauging the tracer cloud. The recommended quantity of salt is 2 to 12 g per 1 l/s (Internet 1). The salt quantity was chosen based on previous recommendations, the distance between the injection and gauging points, and according to the knowledge of the experienced technician who performed the measurements. The longer the distance, the bigger the tracer dilution and, as a result, the smaller the increase in salinity in the gauging area. Discharge calculations were based on the following expression (Boiten, 2008, Internet 1).

$$Q = \frac{m}{\int_{t_1}^{t_2} c(t)dt}$$

where Q is the flow to be determined, m is the mass of the tracer, t is the time, t_1 is the time at the beginning of the tracer's passage, t_2 is the time at the end of tracer's passage and c(t) is the time dependent tracer concentration.

Electrical conductivity

EC is a simple method for indirectly estimating the total dissolved solids in water. It is very often employed during filed hydrogeological mapping and is defined as the EC of one cubic centimetre of water at a constant water temperature of 25 °C. When the temperature increases by 1 °C, EC rises approximately 2 %. The international unit of EC is Si/cm (Todd & Mays, 2005), where Si is the Siemens unit. Measurements together with water temperature were performed with a WTW Multiline P3 instrument.

Results and discussion

Measurement campaigns were performed in February 2006, in February 2008, in September 2008 and in March 2009. Coordinates and distances of the measuring points from the terminal spring in the NW part of the valley are presented in Table 1. On all measurement campaigns, discharge was gauged at 11 locations, except in March 2009, when RMP-8 was not accessible due to weather conditions. EC was measured concomitantly at the same locations as the discharge. The spatial distributions of discharges and EC are plotted as curved lines (Figs. 2 and 4). To provide the representative discharge measurements at every location, discharges were measured twice, or, at some locations, three times. The average relative error was below 10 %; only at two locations was the error between 15 and 20 % (RMP-3 in February 2008 and RMP-5 in 2009). Representative discharge was calculated as an average. During the evaluation of measured values, the shape of the salt dilution breakthrough curve was verified.

In the past, at particular time intervals, discharges of the Radovna River were more closely monitored with several gauging stations. Overall, six gauging stations were in operation; however, their observation periods were different; Fužine (1953–1982), Grabče (1960–1982), Podhom (1933–current), Spodnja Radovna (1957–1966), Srednja

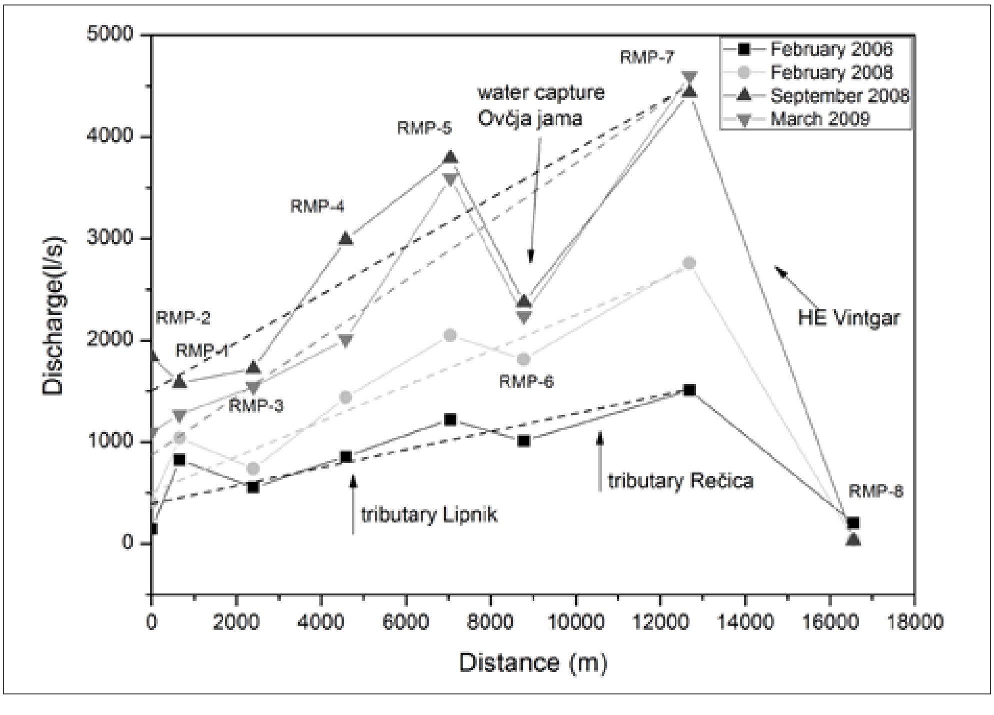

Fig. 2. Plot of discharge versus distance from the spring with trend lines.

Sl. 2. Diagram pretoka v odvisnosti od razdalje od izvira s trendnimi črtami.

Radovna (1952–1982) and Vintgar (1954–1966) (Fig. 1). Currently, the Podhom gauging station is the only station in operation, and we have applied only these data; others were statistically analysed elsewhere (Torkar, 2010). The average annual discharges for the Podhom gauging station were calculated and illustrated in Figure 3. The annual average discharge is between 5.1 m^3/s and 13.2 m^3/s, with one exception (in 1934, when the average annual discharge was 18.3 m^3/s) (Fig. 3). Lower annual average discharges are present after 1970, and are rarely above 10 m^3/s. A decrease in discharge could be attributed to the upstream construction of tunnels, which conduct fresh water to Lake Bled. Data in Figure 3 illustrate that measuring campaigns were performed during conditions that were lower than average.

Discharge measured in 2006 was between 148 l/s and 1510 l/s. In February 2008, discharge was between 40 l/s and 2760 l/s, and in September 2008, it was between 32 l/s and 3792 l/s. In the last campaign performed in March 2009, discharge was between 1100 l/s and 4600 l/s. During measuring campaigns, maximum discharges were not observed inside only one campaign. In September 2008, maximum discharges were measured at all points, except at RMP-7 and at RMP-8, which are positioned in the most distant part of the river valley (before the confluence with the Sava Dolinka River) (Table 1). In March 2009, maximum discharges were measured at points RMP-7 and RMP-8 (Table 1). Despite the difference between measuring campaigns, the relation

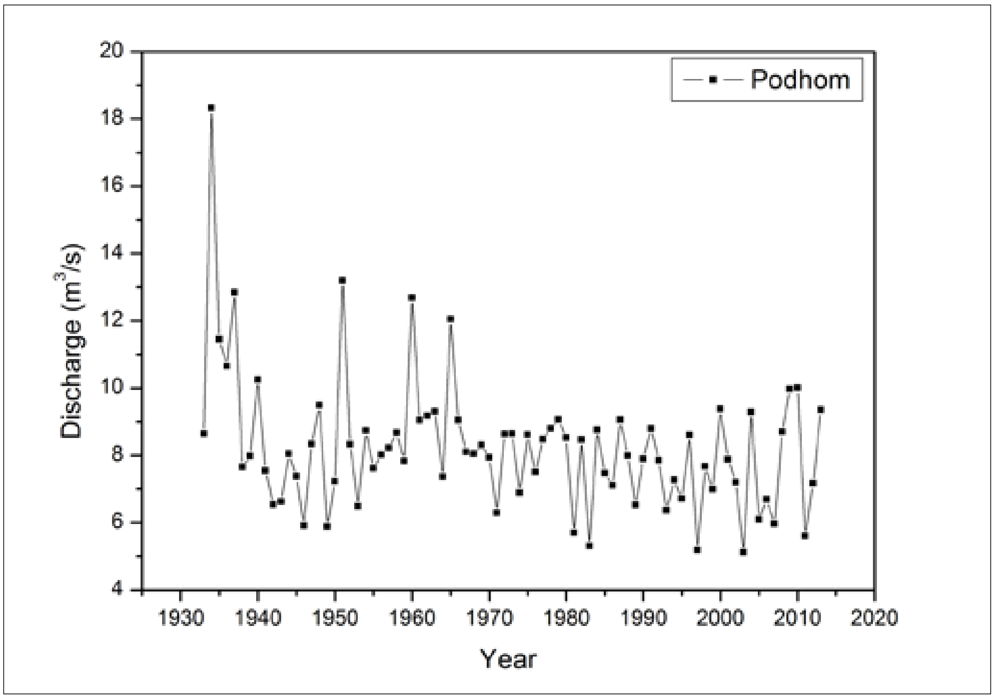

Fig. 3. Average yearly discharge at the location Podhom between 1933 and 2013.

Sl. 3. Povprečni letni pretoki za mersko mesto Podhom v letih od 1933 do 2013.

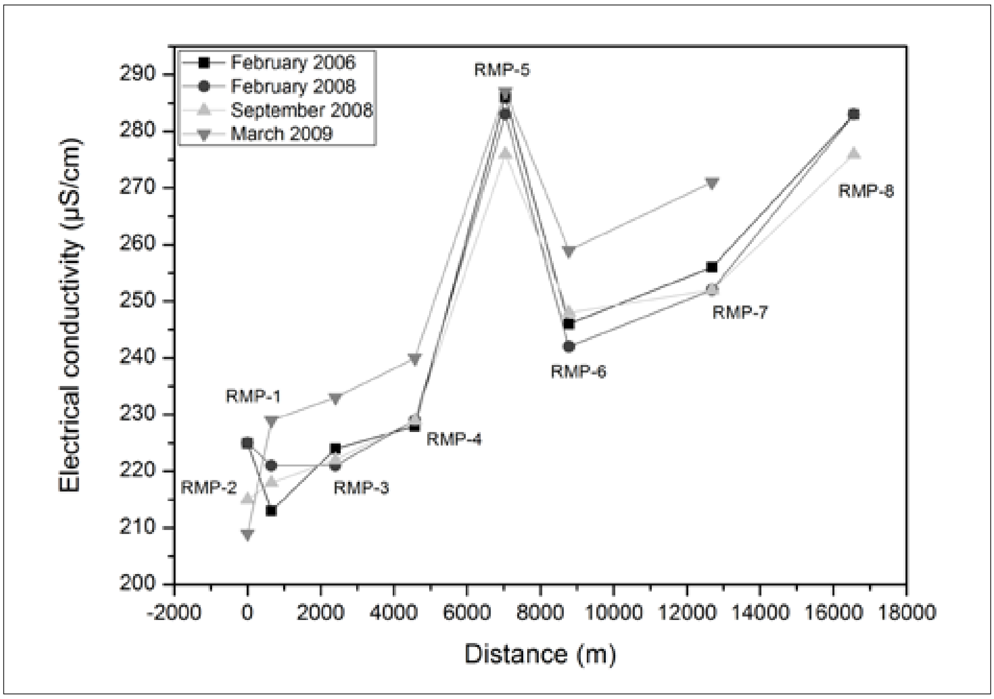

Fig. 4. Plot of electrical conductivity versus the distance from the spring.

Sl. 4. Diagram elektroprevodnosti v odvisnosti od razdalje od izvira.

between discharges measured at particular points and their spatial positions along the riverbed show similar behaviour (Fig. 2). The relative distances between measuring points are similar, but the differences between measurements at the particular measuring point for different sampling campaigns are more profound when high water conditions are present.

Along the river, an increase in discharges was expected and observed. Trend lines neglecting measuring points RMP-6 and RMP-8, representing a strong deviation from the trend, are calculated and illustrated in Figure 2. These trends indicate an average increase of discharge along the riverbed. In February 2006, the average discharge increase was 88 l/s km^{-1}; in February 2008, the discharge increase was 174 l/s km^{1}; in September 2008, the discharge increase was 237 l/s km^{-1}; and in March 2009, the discharge increase was 287 l/s km^{-1}. The diagram in Figure 2 indicates that the average discharge increase also specifies hydrological conditions along the river. In low water conditions is lower than at the higher conditions.

An increase in discharge is a consequence of direct inflows to the riverbed as well as of recharge from karstic springs from both sides of the valley. Discharges from the Lipnik tributary (LIP-1) were between 134 l/s and 526 l/s, and were between 64 l/s and 443 l/s from Rečica (REČ-1) (Table 1). Slight irregularities were observed at RMP-1, RMP-2 and RMP-3. In this part of the valley, a hyporheic flow is present. These differences can also be attributed to the changes in the riverbed due to the high spatial fluctuations of the terminal spring position and relatively braided riverbed where certain changes in riverbed morphology can occur over time.

During all four campaigns, a significant drop in discharges can be seen at RMP-6 and RMP-8. RMP-6 is positioned after Ovčja jama, where a large drinking water resource is positioned. It is expected that a certain amount of water is diverted from the riverbed by water abstraction from the drainage; consequently, a drop in the river discharge is expected. However, the drop in discharge in relatively high water conditions in September 2008 and March 2009 is too big to be attributed only to water abstraction. At this point, it is possible that certain discharge is flowing in the alluvial sediments parallel to the river course. Because the RMP-6 gauging profile river water flow is relatively idle, possible discharge differences can also be attributed to the applied discharge measuring method. The chemical integration method is most suitable for turbulent flows. At RMP-6, the water current slows, which does not favour the mixing of diluted salt. The large drop between RMP-7 and RMP-8 is due to water intake for the Vintgar HPP. From the diagram, it can be clearly seen that nearly all the water is taken from the riverbed, and water reaching the Sava Dolinka River via natural river flow is negligible compared to the discharge before the Vintgar HPP intake structure. Such conditions have substantial hydromorphological and ecological consequences, which, for the river flowing in the Triglav National Park, are unacceptable.

EC is an indicator of total dissolved solids and indirectly points to lithology in the recharge area, groundwater residence time in the aquifer and possible pollution. Higher EC occurs where water is in contact with more soluble minerals for longer periods. Measured EC is between 213 µS/cm and 287 µS/cm. EC values are not high due to carbonate lithology in the recharge area and indicate a very permeable aquifer with a low residence time. In general, EC increases along the river course. There is only one significant deviation from this trend: RMP-5. This is the observation point where the Lipnik tributary flows into the Radovna River and where discharge in the riverbed is relatively depleted due to water removed by the Gorje HPP. An increase in the EC of the Radovna River is due to the inflowing waters with higher ECs (e.g., Rečica); however, there could also be processes in the river water responsible for this trend, which remains to be investigated.

Conclusions

Discharge measurements at all four measuring campaigns on the Radovna River indicated their gradual increase along the riverbed. The average discharge increase was from 88 l/s km^{-1} to 287 l/s km^{-1} depending strongly on hydrological conditions. Due to the presence of several water intake structures along the valley, the increase was not regular, and significant drops in the discharge are present. An analysis of the EC indicated a monotone increase in the downstream direction and, consequently, low residence times in permeable intergranular and karstic aquifers recharging the river. In the upper part of the river, changes in the discharge trend were also consequences of the stream's hyporheic flow. With the lack of significant tributaries, it was evident that the flow of Radovna is mainly supplied by groundwater directly flowing into the riverbed.

With the results represented, we have illustrated the fact already known from the direct hydrogeological observations that Radovna River is groundwater dominated river. However, in the hydrology of the Radovna River, several questions remain. In the future, more precise discharge measurements along the river are needed for better understanding of groundwater and surface water exchange. The chemical integration method is suitable for use with the torrential flow in the upper part of the Radovna River, but is not precise enough for the lower part, where the water flow is slower and the riverbed is wider. There are also many questions related to the water balance of the river basin as a whole, as well as particular tributaries and karstic springs on the rim of the Radovna Valley.

Acknowledgments

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INTERNET 2: http://www.infrastruktura-bled.si/sl/Dejavnosti/Vodovod/Vodovodni-sistemi (25.3.2015)

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Zob paleozojskega morskega psa rodu *Glikmanius* (Chondrichthyes, Ctenacanthidae) iz Karavank (Slovenija)

Upper Paleozoic shark tooth of genus *Glikmanius* (Chondrichthyes, Ctenacanthidae) from Karavanke Mts. (NW Slovenia)

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Key words: Paleozoic shark, cladodont shark, *Glikmanius*, Lower Permian, Karavanke Mts., Slovenia

Izvleček

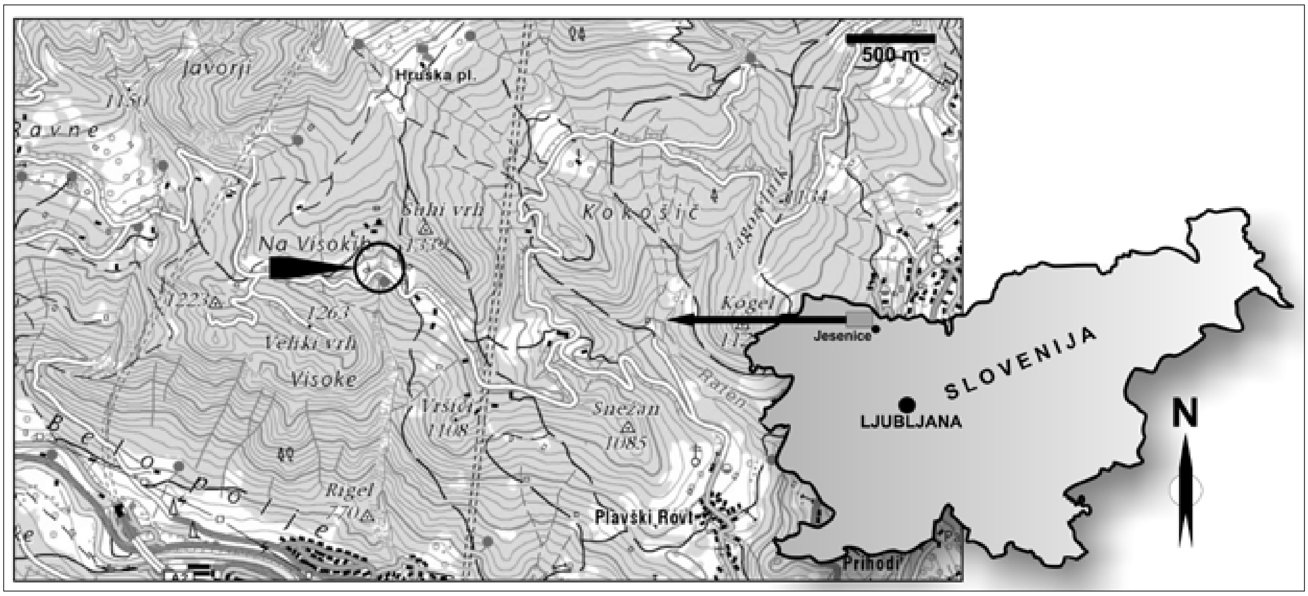
Zgornjepaleozojske (karbonske in permske) plasti v Karavankah so znane po pestri favni nevretenčarjev in posameznih najdbah karbonskih rastlin. Zelo redki so ostanki vretenčarjev. Nova in presenetljiva je najdba večjega zoba ktenakantidnega morskega psa vrste *Glikmanius* cf. *occidentalis* (Leidy) iz spodnjepermskih plasti med Dovjim in Plavškim Rovtom, severno od Hrušice. Gre za prvo najdbo te vrste v južni Evropi.

Abstract

Upper Paleozoic beds of Karavanke Mountains are rich in invertebrate and plant fossils, while the remains of vertebrates are extremely rare. A new cladodont shark tooth was found in Lower Permian beds near Hrušica, at the locality named Na Visokih. We have identified the tooth as belonging to species *Glikmanius* cf. *occidentalis* (Leidy). This is the first find of this species in the southern Europe.

Uvod

Na ozemlju med Jesenicami in Dovjim poznamo vrsto zanimivih najdišč fosilov, ki stratigrafsko ustrezajo zgornjemu karbonu (Auerniška in Schulterkofelska formacija) in spodnjemu permu (Ramovš, 1978). V zgornjekarbonskih plasteh so našli predvsem trilobite (Hahn et al., 1977) in različne ramenonožce (Ramovš, 1969; Novak & Skaberne, 2009). Spodnjepermske plasti vsebujejo poleg bogate favne ramenonožcev (Schellwien, 1900) in trilobitov (Hahn et al., 1990)



Sl. 1. Karta z najdiščem Na Visokih v Karavankah; najdišče je obkroženo. Vir zemljevida: geopedia.si.
Fig. 1. Map of locality Na Visokih in Karavanke Mountains, Slovenia; locality in circle. Source of map: geopedia.si.

tudi biostratigrafsko pomembne fuzulinidne foraminifere (NOVAK, 2007).

Nasprotno so najdbe vretenčarjev izjemno redke. O najdbi zob rodu *Petalodus* v Sloveniji sta prva poročala RAMOVŠ in BEDIČ (1993). RAMOVŠ (1997) je pozneje najdbe tudi opisal in določil kot vrsto *Petalodus ohioensis* Safford. PETERNEL (1995) poroča o omenjenih najdbah in še o dveh novih primerkih iz Karavank. PAVŠIČ (1995) prikazuje enega izmed bolje ohranjenih primerkov zob iz najdišča v Javorniškem Rovtu. RAMOVŠ (1998) je določil še en primerek zoba kot *Petalodus ohioensis* Safford in opisal nedoločeni petalodontni zob, ki ju omenja in prikazuje že PETERNEL (1995) in izhajata iz nahajališča pri Planini pod Golico. NOVAK (2006) poroča o najdbi zoba družine Petalodontidae v spodnjepermskih (sakmarijskih) plasti v Dovžanovi soteski.

V pričujočem članku predstavljam novo najdbo zoba ktenakantidnega morskega psa iz spodnjepermskh plasti v okolici Hrušice.

Geološka zgradba okolice najdišča

Na osnovi geološke karte (BUSER, 1980) kamnine na najdišču pripadajo spodnjepermskim rotnoveškim in trogkofelskim plastem. V širšem smislu pripadajo kamnine klastično-karbonatni seriji spodnjepermskih plasti (RAMOVŠ, 1968; NOVAK & SKABERNE, 2009). Kosi kamnitih blokov iz najdišča in prikamnina na primerku vsebujejo množico izluženih pecljev morskih lilij, preseke ramenonožcev (cf. *Martinia* sp.) in fuzulinidne foraminifere s podolgovatimi hišicami (verjetno rodovi *Pseudofusulina* ali *Quasifusulina*). Kamnina je svetlo do temno sivi apnenec (biomikrit), ki ima na površini prevleke sljudnatega peščenjaka in meljevca. Natančnejša določitev fuzulinidnih foraminifer nam bo omogočila natančno opredelitev starosti kamnine s primerkom.

Paleontološki del

Sistematika sledi GINTER et al., 2010.

Classis Chondrichthyes Huxley, 1880
Subclassis Elasmobranchii Bonaparte, 1838
Ordo Ctenacanthiformes Glikman, 1964
Familia Ctenacanthidae Dean, 1909

Genus *Glikmanius* Ginter, Ivanov & Lebedev, 2005

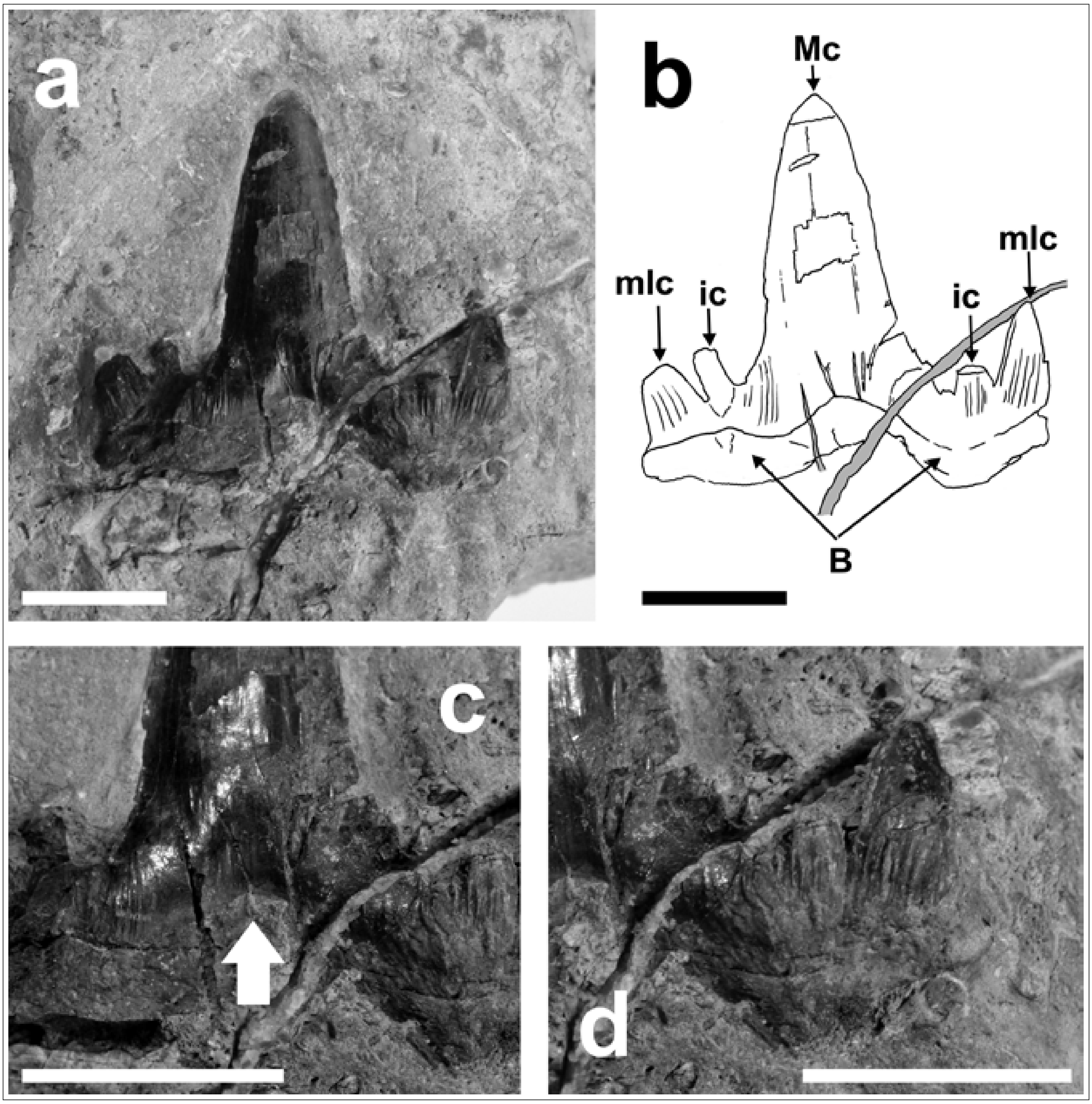
Rod *Glikmanius* so z revizijo zelo širokega rodu *Cladodus* revidirali GINTER s sodelavci (2005). Rod se pojavlja v karbonskih in permskih plasteh ZDA, Rusije in Japonske (GINTER et al., 2010; YAMAGISHI & FUJIMOTO, 2011). Glavne značilnosti zob rodu *Glikmanius* podajajo DUFFIN & GINTER (2006) in HODNETT s sodelavci (2012).

Glikmanius cf. occidentalis (Leidy, 1859)
(sl. / fig. 3, a-d)

1903 *Cladodus occidentalis* Leidy, 1859 – EASTMAN, Pl. 2, Figs. 3, 8, 9.
2002 »*Cladodus*« *occidentalis* Leidy, 1859 – GINTER, 549, Fig. 1, D-F.
2004 »*Cladodus*« *occidentalis* Leidy, 1859 – ELLIOTT et al., 274, Fig. 4, J-L.
2005 *Glikmanius occidentalis* (Leidy, 1859) – GINTER et al., 625, Fig. 1, C, Fig. 2, B.
2008 *Glikmanius occidentalis* (Leidy, 1859) – JOHNSON, 206, Figs. 1–2.
2011 *Glikmanius occidentalis* (Leidy, 1859) – YAMAGISHI & FUJIMOTO, 2, Figs. A-F.
2012 *Glikmanius occidentalis* (Leidy, 1859) – HODNETT et al., 5, Fig. 2, F-G.

Sl. 2. Natančnejši položaj najdišča primerka zoba ob cestnem vseku (a). Zob takoj po odkritju, še vedno v prikamnini (b). Foto: M. Križnar (a) in A. Novak (b).

Fig. 2. Picture of locality at road cut (a). Described tooth, photographed immediately after the discovery. Photo: M. Križnar (a) in A. Novak (b).



Sl. 3. *Glikmanius* cf. *occidentalis* (Leidy), inv. št. 2349. Najdišče: Na Visokih, severno od Hrušice, Karavanke. Merila 10 mm.
a. Primerek na kamnini. Labialni pogled.
b. Risba primerka z označenimi glavnimi morfološkimi znaki.
c. Globok žleb v bazolabialnem delu (puščica).
d. Stranske konice na desni strani zoba.

Okrajšave (morfološki znaki):
Mc – glavna konica zoba
mlc – zunanja stranska (sekundarna) konica zoba
ic – srednja stranska (notranja) konica zoba
B – korenina zoba (baza zoba)

Fig. 3. *Glikmanius* cf. *occidentalis* (Leidy), specimen no. SMNH 2349. Locality: Na Visokih, north of Hrušica, Karavanke Mts. Labial view. Scale bar 10 mm.
a. Specimen in matrix, labial view.
b. Drawing of specimen with some morphological terms.
c. Deep basolabial depression of specimen (arrow).
d. Lateral cusp on right side of specimens.

Abbreviations (morphological terms):
Mc – median cusp
mlc – main lateral cusp
ic – intermediate cusplet (cusp)
B – base

Material: Na kamnini ohranjen zob, lingvalna stran zoba še vedno v kamnini (inv. št. 2349). Shranjen v paleontološki zbirki Prirodoslovnega muzeja Slovenije (PMS). Primerek je našla Adrijana Novak (Šoštanj) sredi leta 2012.

Najdišče: Primerek je bil najden severno od Hrušice. Natančneje na območju imenovanem Na Visokih ob večjem cestnem useku, jugozahodno od vzpetine Suhi vrh (sl. 1). Kos kamnine z zobom je ležal na površini melišča in je verjetno prinesen iz nekoliko višje ležečega primarnega mesta (sl. 2). Koordinate najdišča: GKY: 424241, GKX: 147309.

Dimenzije zoba, inv. št. 2349 (Dimensions of tooth, specimen no. 2349)

Višina zoba *Tooth height*	26 mm
Širina zoba *Tooth lenght*	28 mm
Višina glavne konice *Height of main cusp*	20 mm
Višina največje lateralne (zunanje) konice *Height of main lateral cusp*	8 mm

Opis primerka: Opisani zob je močno razpokan. Razpoke kažejo na lomljenje in zapolnitve razpok, ko je bil zob že fosiliziran. Vidna je labialna stran zoba, preostali del je v kamnini (sl. 3a). Zob ima ohranjeno glavno konico in na vsaki strani po dve stranski (lateralni) konici (sl. 3b). Korenina zoba je slabo ohranjena. Površina korone ima v celotni dolžini baze grebene, ki potekajo proti vrhu krone. Srednji del zoba (bazolabialni del) je močno vdrt, tako da tvori žlebič, ki poteka do sredine glavne konice (sl. 3c). Glavna konica je trikotne oblike, kjer je vrh poškodovan oziroma odlomljen (sl. 3a). Obe srednji (notranji) lateralni konici sta poškodovani, toda njuna baza je še vedno dobro razvidna. Obe konici sta nekoliko izbočeni v labialno smer. Zunanji stranski (sekundarni) konici sta bolje ohranjeni in sta skoraj za polovico večji od srednjih lateralnih konic (sl. 2d). Zunanji lateralni konici sta rahlo konveksni, kjer je baza konic nekoliko zamaknjena v lingvalno smer. S tafonomskega pogleda so najdeni zobje rodu *Glikmanius* pogosto poškodovani oziroma kažejo sledi abrazije (Elliott et al., 2004; Hodnett et al., 2012).

Primerjava: Eastman (1903) omenja in prikazuje slabše ohranjen zob vrste *Cladodus occidentalis* Leidy. Kasneje so rod *Cladodus* pisali v narekovajih, kajti z novimi najdbami je postala taksonomija (na osnovi zob) paleozojskih morskih psov zapletena in nepregledna. Ginter (2002) razpravlja o problematiki vrste *Symmorium reniforme* Cope, kjer to vrsto opisuje kot sinonim vrste »*Cladodus*« *occidentalis* Leidy in hkrati predlaga naj se vrsto uvrsti v novi rod kladodontnih morskih psov ali obstoječi rod *Symmorium* (Ginter, 2002). Revizijo vrste »*Cladodus*« *occidentalis* Leidy so opravili Ginter s sodelavci (Ginter et al., 2005) in vrsto umestili v nov rod *Glikmanius*. Rodu *Glikmanius* pripisujejo še vrsto *Glikmanius myachkovensis* (Lebedev), ki pa je veliko manjša in ima običajno po tri lateralne konice na zobu (Ginter et al., 2005; Ginter et al., 2010).

Novi primerek *Glikmanius* cf. *occidentalis* iz Karavank (inv. št. 2349) se dobro ujema z zobmi, ki jih prikazujejo Ginter (2002), Elliott s sodelavci (2004), Ginter s sodelavci (2005), Johnson (2008) in Hodnett s sodelavci (2012). Zob se tudi dimenzijsko ujema s primerki iz ZDA in Rusije.

Stratigrafska in geografska razširjenost: Vrsta *Glikmanius occidentalis* (Leidy), kot tudi rod *Glikmanius*, se stratigrafsko pojavlja v plasteh od zgornjega karbona do spodnjega perma oziroma verjetno celo do srednjega perma (wordij) (Ginter et al., 2010). Po pregledu dosegljivih virov so ostanki zob *Glikmanius occidentalis* (Leidy) redki in pogosto poškodovani. Ostanki zob *Glikmanius occidentalis* (Leidy) so bili odkriti v Združenih državah Amerike (Zveznih državah New Mexico, Arizona, Kansas, Indiana, Illinois, Ohio, Colorado) in Rusiji (Ural) (Ginter et al., 2010). Vrsto omenjajo tudi iz srednjega perma Japonske (Yamagishi & Fujimoto, 2011).

Zaključki

Ostanki paleozojskih vretenčarjev so v Sloveniji izjemno redki. Vse dokumentirane in opisane najdbe zob petalodontnih morskih psov prihajajo iz Karavank (Ramovš & Bedič, 1993; Ramovš, 1997; Ramovš, 1998; Novak, 2006). Leta 2012 je bil odkrit nov ostanek paleozojskega vretenčarja, ki predstavlja tipični zob kladodontnega morskega psa. Zob je bil odkrit severno od Hrušice, na območju imenovanem Na Visokih. Po preparaciji smo ga lahko natančneje identificirali kot *Glikmanius* cf. *occidentalis* (Leidy). Zob ima trikotno glavno konico in značilni stranski (lateralni) bodici na vsaki strani zoba. Zunanja stranska bodica je tudi večja od srednje. Nov primerek *Glikmanius* cf. *occidentalis* (Leidy) iz Karavank tako predstavlja prvo najdbo te vrste v Južnih Alpah, oziroma južni Evropi.

Zahvala

Zahvaljujemo se zbiralcema Adrijani Novak in Davorinu Preisingerju za posredovanje in podaritev primerka zoba Prirodoslovnemu muzeju Slovenije.

Late Paleozoic shark tooth of genus *Glikmanius* (Chondrichthyes, Ctenacanthidae) from Karavanke Mts. (NW Slovenia)

Conclusion

Remains of Paleozoic vertebrates are very rare in Slovenia. All of documented remains were found in Karavanke Mountains and were identified as petalodont teeth (Ramovš & Bedič, 1993; Ramovš, 1997, 1998; Novak, 2006). In year 2012, a new and different, typical cladodont shark tooth was found in presumably Lower Permian beds, near the town of Hrušica on locality named Na Visokih. After preparation of specimen (no. 2349, collection Slovenian Museum of Natural History), we identified it as *Glikmanius* cf. *occidentalis* (Leidy). The tooth has triangular median cusp, deep basolabial depression and two cusplets on both side, with bigger main lateral cusp. New specimen of *Glikmanius* cf. *occidentalis* (Leidy) from Karavanke Mountains (Slovenia) is the first from Southern Alps or perhaps even from southern Europe.

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Nekaj novih najdb eocenskih rakovic iz najdišča Ćopi v Istri

Some new finds of Eocene crabs from Ćopi in Istria, Croatia

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Ključne besede: rakovice (Decapoda), srednji eocen, Ćopi, osrednja Istra, Hrvaška
Key words: crabs (Decapoda), Middle Eocene, Ćopi, Central Istria, Croatia

Izvleček

V prispevku so obravnavani ostanki rakovic iz srednjeeocenskih flišnih plasti okolice Ćopija v osrednji Istri na Hrvaškem. Dva primerka pripadata razmeroma pogostni vrsti *Lophoranina marestiana* (König, 1825), del oklepa in segment škarij pa vrsti *Lessinicarcinus euglyphos* (Bittner, 1875). Manjšega kamenega jedra zaradi njegove slabše ohranjenosti ni mogoče taksonomsko opredeliti.

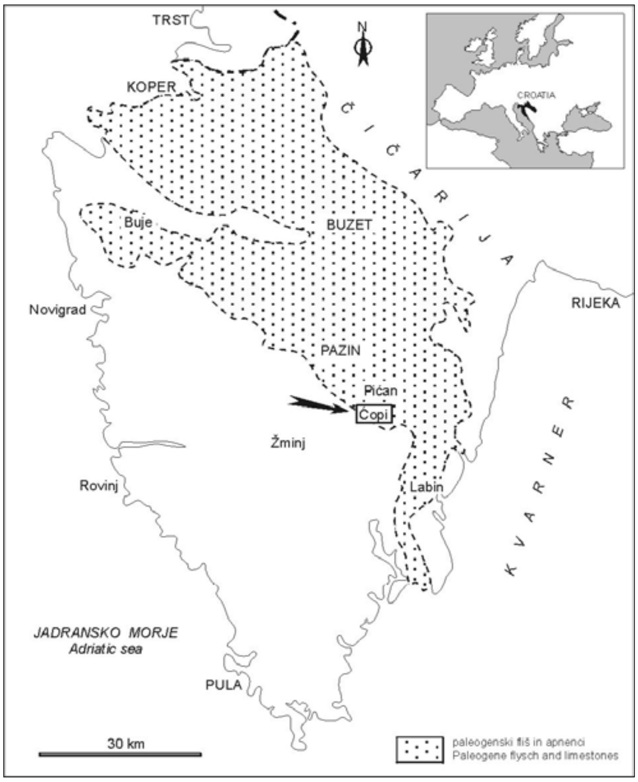
Abstract

The contribution deals with crab remains from Middle Eocene flysch beds of environs of Ćopi in central Istria, Croatia. Two specimens belong to the relatively abundant species *Lophoranina marestiana* (König, 1825). A part of carapace and a segment of chela belong to the species *Lessinicarcinus euglyphos* (Bittner, 1875). A smaller crab stone cast could not be taxonomically interpreted due to its poor state of preservation.

Uvod

V osrednji Istri je veliko eocenskih flišnih kamnin s številnimi fosilnimi ostanki najrazličnejših morskih organizmov. V določenih horizontih fliša najdemo tudi veliko makrofavne. Na širšem območju Ćopija, ki leži južnovzhodno od Pazina (sl. 1) je več najdišč eocenske makrofavne. Prevladujejo ostanki velikih foraminifer, mehkužcev in morskih ježkov, manj je ostankov rakovic. V letu 2012 je Vili Rakovc iz Kranja znova obiskal tamkajšnja najdišča in našel nekaj novih rakovičjih ostankov, ki jih prikazujemo v prispevku.

O najdbah in raziskavah rakovic iz Istre smo že poročali. Iz Gračišća pri Pazinu smo predstavili večjo rakovico vrste *Harpactoxanthopsis quadrilobata* (Desmarest) in skromen ostanek vrste *Lophoranina marestiana* (König) (Mikuž, 2002; 2004), iz Ćopija smo imeli v raziskavah več primerkov vrste *Lophoranina marestiana* (König), karapaks vrste *Lobonotus* ? *euglyphos* (Bittner), (Mikuž, 2010 a; 2011) in karapaks vrste *Cyrtorhina globosa* Beschin, De Angeli & Tessier, 1988 (Mikuž, 2010 b).



Sl. 1. Geografski položaj najdišča Ćopi v Istri
Fig. 1. Geographical position of site Ćopi in Istria

Paleontološki del

Sistematika po: MARTIN & DAVIS 2001, DE GRAVE et al. 2009 in DE ANGELI 2012

Subphylum Crustacea Brünnich, 1772
Classis Malacostraca Latreille, 1802
Subclassis Eumalacostraca Grobben, 1892
Superordo Eucarida Calman, 1904
Ordo Decapoda Latreille, 1802
Subordo Pleocyemata Burkenroad, 1963
Infraordo Brachyura Linnaeus, 1758
Sectio Raninoida De Haan, 1839
Familia Raninidae De Haan, 1839
Subfamilia Ranininae De Haan, 1839
Genus *Lophoranina* Fabiani, 1910

BESCHIN, DE ANGELI & ZORZIN (2011: 38) pišejo, da so primerki rodu *Lophoranina* izključno fosilni in razširjeni od zgornje krede do oligocena.

Lophoranina marestiana (König, 1825)
Tab. 1, sl. 1, 2a-2b

1825 *Ranina Maresiana.* n. – KÖNIG, 2, Fig. 14

1825 *Ranina Maretiana* – KÖNIG, I, Fig. 15

1859 *Ranina Marestiana* Kön. – REUSS, 21, 81, Taf. 5, Figs. 1-2

1872 *Ranina Maresiana* Koenig – MILNE EDWARDS, 8

1875 *Ranina Marestiana* König – BITTNER, 64, Taf. 1, Figs. 1, 2a-2c

1877 *R. Maresiana*, Koenig – BROCCHI, 7

1881 *Ranina Maresiana* (Koenig) – MILNE EDWARDS, 7

1910 *Lophoranina. R. marestiana* Koenig – FABIANI, 89

2005 *Lophoranina marestiana* (Kjunig, 1825) – ILYIN, 223, Tabl. 10, Figs. 4-7

2009 *Lophoranina marestiana* (König, 1825) – BESCHIN, DE ANGELI & ZORZIN, 69, Tav. 3, Figs. 2, 3

2010 a *Lophoranina marestiana* (König, 1825) – MIKUŽ, 48, Tab. 1, Sl. 1-11

2011 *Lophoranina marestiana* (König, 1825) – BESCHIN, DE ANGELI & ZORZIN, 38, Fig. 5, Tav. 1, Figs. 1-4

Material in najdišče: En delno ohranjen karapaks in del prve lovilne, grabilne ali obrambne okončine. Oboje je našel Vili Rakovc v letu 2012 blizu zaselka Ćopi, v kaotični breči s številnimi numulitinami različnih velikosti in drugimi foraminiferami, redkimi ostanki rakovic in polihetov, pogostnimi kamenimi jedri mehkužcev in razmeroma dobro ohranjenimi koronami iregularnih morskih ježkov.

Velikost karapaksa (Size of carapace):
Tab. 1, sl. 1

dolžina (Length) = 54 mm
širina (Width) = 45 mm
število prečnih grebenov
(Number of transverse ridges) = 14

Velikost lakta ali roke (Size of arm or merus):
Tab. 1, sl. 2a-2b

dolžina (Length) = 23 mm
širina (Width) = č13 mm
debelina (Thickness) = 10 mm
število prečnih grebenov
(Number of transverse ridges) = 7

Pripombe: Prva lovilna, grabilna ali obrambna okončina (chelipeda) sestoji iz več členov, trije večji segmenti so: škarje ali klešče, ki sestoje iz telesa ali propodusa, spodnjega nepremičnega prsta in zgornjega premičnega prsta, sledita zapestje (carpus) in laket ali roka (merus).

MUNIER-CHALMAS (1891: 48, 51, 53) iz več najdišč Veneta navaja vrsto *Ranina marestiana* König, vendar izključno iz srednjeeocenskih skladov. FABIANI (1915: 284-285) vrsto *Ranina marestiana* Koenig omenja iz Veneta v skladih od lutetija do priabonija, torej od srednjega do vključno zgornjega eocena. WANK (1986: 61-62) predstavlja primerka vrste *Ranina (Lophoranina)* cf. *marestiana* Koenig iz eocenskih skladov cementarne Wietersdorf, severno od Dobranberga na Koroškem.

Primerjava: Med nekaterimi vrstami loforanin je opaziti veliko podobnosti na njihovih karapaksih. Mislim, da pri fosilnih loforaninah še ne poznamo dovolj njihovih vrstnih raznolikosti, razen tega je pri družini Raninidae ugotovljen tudi spolni dimorfizem (FELDMANN & SCHWEITZER 2007), ki je najbolj izrazit v oblikovanosti in velikosti njihovega abdomna.

Stratigrafska in geografska razširjenost vrste *Lophoranina marestiana* (König, 1825) v Evropi in severni Afriki (tabela 1), primerke iste vrste so našli tudi v spodnjeeocenskih skladih severnega dela Evrazije (ILYIN 2005: 223, Tabl. 10, Figs. 4-7).

Sectio Eubrachyura de Saint Laurent, 1980
Subsectio Heterotremata Guinot, 1977
Superfamilia Pilumnoidea Samouelle, 1819
Familia Pilumnidae Samouelle, 1819
Subfamilia Pilumninae Samouelle, 1819
Genus *Lessinicarcinus* De Angeli, 2012

Lessinicarcinus euglyphos (Bittner, 1875)
Tab. 1, sl. 3a-3b, 5

1875 *Titanocarcinus euglyphos* nov. spec. – BITTNER, 35 (95), Taf. 2, Figs. 6a-6b

2007 *»Titanocarcinus« euglyphos* – SCHWEITZER et al., 282-283, Figs. 1A, B, D

Tabela 1. Stratigrafska in geografska razširjenost vrste *Lophoranina marestiana* (König, 1825) v Evropi in severni Afriki
Table 1. Stratigraphical and geographical distribution of *Lophoranina marestiana* (König, 1825) in Europe and north Africa

NAJDIŠČA / LOCALITIES	STAROST / AGE	EOCEN / EOCENE: SPODNJI / EARLY	EOCEN / EOCENE: SREDNJI / MIDDLE	EOCEN / EOCENE: ZGORNJI / LATE	AVTORJI / AUTHORS
ŠPANIJA / SPAIN	Provinca Alicante (Tángel, Garbinet, Callosa de Ensarriá, Agost, Orcheta)	-	---------		Vía 1959; 1970 Beschin et al. 1988; 1994; 1998; 2011
ITALIJA / ITALY	Okolica Verone, San Giovanni Ilarione, Veneto, Mt. Postale, Ciuppio, Mt. Vegroni, Purga di Bolca, Vallle di Chiampo, Cava »Rossi« di Monte di Malo, Vicenza, Pordenone, Friuli Venezia-Giulia, Palermo-Sicilija?	---	--------------	-----	Reuss 1859 Milne Edwards 1872 Bittner 1875; 1883 Munier-Chalmas 1891 Oppenheim 1896 Dainelli 1915 Fabiani 1910; 1915 Parona 1924 Ancona 1966 Glaessner 1969 Savazzi 1981 Beschin et al. 1988; 1994; 1998; 2009; 2011
HRVAŠKA / CROATIA	Okolica Splita, Istra (v okolici Labina in Raše, v okolici Pazina - Paz, Gračišče, Ćopi)	-	---------		Schubert 1905 Pavlovec 1958 Kochansky-Devidé 1964 Moosleitner 1996 Mikuž 2004; 2010a Beschin et al. 2011
AVSTRIJA / AUSTRIA	St. Pankraz (Salzburg), Wietersdorf	-	---------		Vogeltanz 1968 Vía 1970 Wank 1986 Hagn, Darga & Schmid 1992 Schultz 1998
ŠVICA / SWITZERL.	Severnovzhodni del Švice, blizu meje z Nemčijo?	-	----?-----		Vía 1970
NEMČIJA / GERMANY	Kressenberg (Bavarska)	---------			Milne Edwards 1872 Zittel 1895 Vía 1970 Hagn, Darga & Schmid 1992
EGIPT / EGYPT	Mokattam, Gebel Haridi		-----	-----	Nötling 1885 Vía 1970

2011 *Lobonotus? euglyphos* (Bittner, 1875) – Mikuž, 24, Tab. 1, Sl. 1a-1b

2012 *Lessinicarcinus euglyphos* (Bittner, 1875), comb. nov. – De Angeli, 79, Figs. 2a-2b, 3b

Material in najdišče: Razmeroma dobro ohranjen segment prve okončine, ki ga je našel Vili Rakovc in leva polovica oklepa ali karapaksa (Ćr-22), ki ga je pred leti našel avtor prispevka. Oba primerka sta najdena v kaotični breči pod zaselkom Ćopi.

Telo desnih škarij (Right chela):
Tab. 1, sl. 3a-3b

dolžina = 26 mm
širina = 18 mm
debelina = 11 mm

Leva polovica karapaksa (Left half of carapace):
Tab. 1, sl. 5

dolžina ostanka karapaksa
(Length of carapace remain) = 27 mm

Opis in primerjava: Oblika in vzorec ornamentiranosti škarij ustrezata primerku iz Italije, ki ga prikazuje De Angeli (2012: 81, Fig. 3. 2a-2b). Tudi del rakovičinega karapaksa iz Ć opija lahko primerjamo s primerki De Angeli-ja (2012: 81, Fig. 3. 1, 3b, 4b). Površina na karapaksu iz Ćopija je zelo reliefna in izrazita ter bolj bogato ornamentirana.

Stratigrafska in geografska razširjenost: Fabiani (1915: 285) vrsto rakovice *Titanocarcinus euglyphos* Bittn. omenja samo iz lutetijskih plasti Veneta. De Angeli (2012: 79) je postavil nov rod *Lessinicarcinus*, vrsta *L. euglyphos* pa je opisana iz srednjeeocenskih skladov najdišča Cava Main di Arzignano v dolini rečice Chiampo, v italijanski pokrajini Monti Lessini Veronesi.

Genus et species indet.
Tab. 1, Sl. 4a-4b

Material: En slabo ohranjen ostanek kamenega jedra (Ćr-20) iz najdišča pod zaselkom Ćopi. Našel sem ga pred nekaj leti.

Velikost problematičnega ostanka
(Size of problematic remain):
Tab. 1, sl. 4a-4b

dolžina (Length) = 25 mm
širina (Width) = 18 mm

Opis in primerjava: Zelo pomanjkljivo kameno jedro iz Ćopija (Ćr-20) oziroma odtis notranjosti treh členov cefalotoraksa ali pa abdominalnega dela dekapodnega raka je razmeroma majhno. Posamezni členi se deloma prekrivajo. Najdba je problematična in njena uvrstitev je vprašljiva.

Takšno nakazano trojno segmentacijo karapaksa in precejšno podobnost v velikosti ter izbočenosti najdemo tudi pri eocenskih dekapodnih vrstah *Dromia hilarionis* (Bittner 1883: 306, Taf. 1, Fig. 5) in *D. claudiopolitana* (Bittner 1893: 21, Tab. 2, Fig. 5). Rodovno ime druge oblike je bilo preimenovano v *Noetlingia,* torej *Noetlingia claudiopolitana* (Bittner, 1893) (Beschin et al. 1994: 166, Tav. 1, Fig. 4). Bittner (1893: 21) še piše, da je primerek iz panonske kotline (najdišča Kardosfalva) velik 26 x 18 mm, kar je zelo blizu velikosti primerka iz Ćopija. Bittner (1893: 22) in Beschin et al. (1994: 166) omenjajo še eno eocensko vrsto *Dromia veronensis* (Bittner, 1886).

Na podlagi navedenih podobnostih lahko sklenemo, da kameno jedro iz Ćopija najverjetneje pripada primerku rodu *Noetlingia* Beurlen 1928, ki je iz družine Dromiidae De Haan 1833, naddružine Dromioidea De Haan 1833 ter sekcije Dromiacea De Haan 1833.

Pripombe: Ostanek kamenega jedra (Ćr-20) je deloma podoben tudi trem segmentom manjšega navtilidnega fragmokona, vendar pri kamričnih šivih navtilidov običajno ne opazujemo takšnega prekrivanja. Pri navtilidih se kamrični segmenti proti ustju počasi širijo, podaljšujejo in hkrati povečujejo, pri primerku iz Ćopija (tab. 1, sl. 4a-4b), te navtilidne značilnosti širjenja kamric ni videti.

Diskusija in zaključki

V raziskavi smo imeli pet različnih, dobro do slabo ohranjenih fosilnih ostankov iz srednjeeocenskih kaotičnih breč najdišča Ćopi v osrednji Istri na Hrvaškem. Dva rakovičina ostanka (tab. 1, sl. 1, 2a-2b) pripadata vrsti *Lophoranina marestiana* (König, 1825), druga dva (tab. 1, sl. 3a-3b, 5) vrsti *Lessinicarcinus euglyphos* (Bittner, 1875), določitev petega ostanka kamenega jedra (tab. 1, sl. 4a-4b) ni bila mogoča.

Če upoštevamo podatke o stratigrafski razširjenosti vrste *Lophoranina marestiana* (tabela 1) in če so stratigrafski podatki korektni ugotavljamo, da je ta vrsta rakovice eocenska. Na območju današnje Evrope in severne Afrike je najdena v kamninah različne eocenske starosti. Kaže, da so se loforanine pojavile najprej v severnem delu takratnega sedimentacijskega bazena v spodnjem eocenu, v srednjem eocenu so se razširile proti jugu in v zgornjem eocenu pristale še južneje. V eocenskih kamninah Slovenije loforanin do sedaj še nismo našli.

Šele zdaj, ko nam je uspelo pridobiti in videti prvi König-ov opis iz leta 1825, imamo pri poimenovanju dekapodne vrste *Lophoranina marestiana* nekaj pripomb in predlogov. Nemški botanik in mineralog Carl (Charles) Dietrich Eberhard König (1774-1851) je leta 1825 prvi nakazal novo obliko fosilne raninidne rakovice, ki je bila drugačna od takrat že določene Ranzanijeve vrste *Ranina aldrovandi* (cf. Desmarest 1822: 121). Novo obliko naj bi König poimenoval v čast francoskemu zoologu Anselme-ju Gaëtan-u Desmarest-u (1784-1838). König-ov opis nove oblike oziroma vrste (1825: 2) je zelo pomanjkljiv, prikazan primerek holotipa in njegova risba (I, Fig. 15) pa izredno slaba. Zato predlagamo, da italijanski raziskovalci in specialisti eocenskih dekapodov, ki imajo najbolje ohranjene primerke tovrstnih eocenskih loforanin izberejo neotip omenjene oblike in preimenujejo König-ovo vrstno ime, ki je dejansko neustrezno oziroma po nomenklaturnih pravilih zelo vprašljivo.

König (1825: 2, I, Fig. 14) je novo vrsto poimenoval *Ranina Maresiana. n.*, njena podoba je na tabli I pod številko 15 in ne 14! V istem njegovem delu zasledimo še drugo ime *Ranina Maretiana* (I, Fig. 15). Torej dvakrat z različnima in napačnima vrstnima imenoma, noben od njiju pa ne ustreza imenu *Ranina marestiana*, ki ga zasledimo šele pri Reuss-u iz leta 1859. Takšno taksonomsko stanje z neustreznima vrstnima imenoma lahko uvrstimo med gola imena ali »nomina nuda«. Ker je priimek nekdanjega francoskega zoologa Desmarest in ker je bilo ime rakovice posvečeno njemu, predlagamo preimenovanje vrstnega imena *marestiana* v *desmaresti*, torej *Lophoranina desmaresti* ali v povsem novo vrstno ime po nemškem naravoslovcu, avtorju in predlagatelju nove vrste C. D. E. Königu - *Lophoranina koenigi.*

Some new remains of Eocene crabs from Ćopi in Istria, Croatia

Discussion and conclusion

Examined were five different well to poorly preserved fossil remains from the Middle Eocene chaotic breccias at the Ćopi locality in central Istria, Croatia. Two crab remains (pl. 1, figs. 1, 2a-2b) belong to species *Lophoranina marestiana* (König, 1825), the following two (pl. 1, figs. 3a-3b, 5) to species *Lessinicarcinus euglyphos* (Bittner, 1875), whereas the attribution of the fifth remain of a stone cast (pl. 1, fig. 4a-4b) could not be done.

If taking into consideration the data on stratigraphic distribution of species *Lophoranina marestiana* (tabela 1), and accepting the stratigraphic data as correct, we should conclude that this crab species is of Eocene age. In the realm of the present Europe and North Africa the species occurs in rocks of various Eocene ages. It looks like that lophoraninas appeared first in the northern part of the sedimentary basin that existed in the Early Eocene; in the Middle Eocene it expanded southwards, and in the Late Eocene even farther to the south. In Eocene rocks of Slovenia no lophoraninas were found so far.

Only now, after obtaining and inspecting the first König's description from 1825, we could forward several remarks and proposals concerning the naming of the decapod species *Lophoranina marestiana.* The German botanist and mineralogist Carl (Charles) Dietrich Eberhard König (1774-1851) in 1825 first denoted a new form of the fossil raninid crab, different of the then already determined Ranzani's species *Ranina aldrovandi* (Desmarest 1822: 121). The new form should have been named by König in honor of the French zoologist Anselme Gaëtan Desmarest (1784-1838). König's description of the new form respectively species (1825: 2) is, however, very deficient, and the presented specimen of the holotype and its drawing (I, Fig. 15) very poor. Therefore we are advancing the proposal that Italian researchers and specialists for Eocene decapoda, who have in posession the best preserved specimens of these Eocene lophoraninas, select the neotype of the mentioned form and rename the König's species name, which is actually unsuitable, and very questionable in view of the nomenclature rules.

König (1825: 2, I, Fig. 14) named the new *species Ranina Maresiana. n., and its drawing* appears on plate I under number 15, and not 14! In his same work we find an additional name, *Ranina Maretiana* (I, Fig. 15). So twice with distinct and erroneous species names, of which none corresponds to the name *Ranina marestiana* that can be found only with Reuss in 1859. Such taxonomic situation with improper species names can be attributed to »nomina nuda«. Since the family name of the mentioned French zoologist is Desmarest and since the name of the crab was dedicated to him, we propose to rename the species name *marestiana* to *desmaresti*, i.e. *Lophoranina desmaresti,* or, perhaps to a completely new species name after the German natural scientist, author and proposer of the new species. C. D. E. *König - Lophoranina koenigi.*

Zahvale

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TABLA 1 - PLATE 1

1 *Lophoranina marestiana* (König, 1825); karapaks, hrbtna ali dorzalna stran, Ćopi, južnovzhodno od Pazina (osrednja Istra), × 1,5
Lophoranina marestiana (König, 1825); carapace, dorsal view, Ćopi, southeast of Pazin (central Istria), x 1,5

2a *Lophoranina marestiana* (König, 1825); zapestni del ali karpus, s strani,Ćopi, × 2,5
Lophoranina marestiana (König, 1825); wrist or carpus, lateral view, Ćopi, × 2,5

2b Nasprotna bočna stran istega primerka, Ćopi, × 2,5
Same specimen, lateral-dorsal view, Ćopi, × 2,5

3a *Lessinicarcinus euglyphos* (Bittner, 1875); telo desnih škarij, zunanja površina, Ćopi, × 2,4
Lessinicarcinus euglyphos (Bittner, 1875); right chela, external surface, Ćopi, × 2,4

3b Notranja stran istega primerka, Ćopi, × 2,4
Same specimen, inner surface, Ćopi, × 2,4

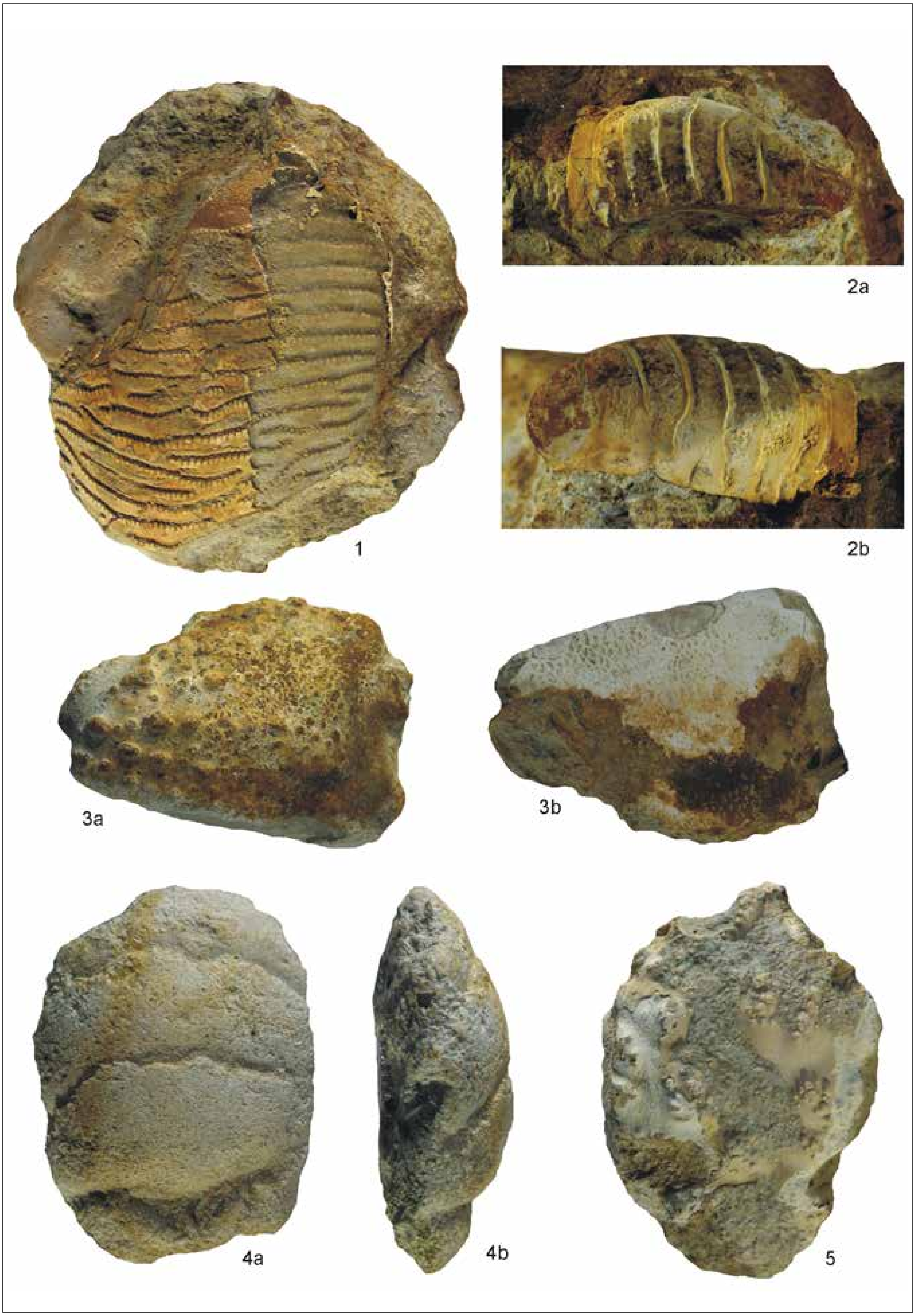
4a Kameno jedro, gen. et spec. indet.; zgornja stran, (Ćr-20), Ćopi, × 2,7
Stone cast, gen. et spec. indet.; dorsal view, (Ćr-20), Ćopi, × 2,7

4b Bočna stran istega primerka, Ćopi, × 2,7
Same specimen, lateral view, Ćopi, × 2,7

5 *Lessinicarcinus euglyphos* (Bittner, 1875); levi del karapaksa, hrbtna stran, (Ćr-22), Ćopi, × 2,5
Lessinicarcinus euglyphos (Bittner, 1875); the left part of carapace, dorsal view, (Ćr-22), Ćopi, × 2,5

Foto (Photo): Marijan Grm

TABLA 1 - PLATE 1



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Panonijski mehkužci iz najdišča Osek-2 v Slovenskih goricah

Pannonian moluscs from site Osek-2 in Slovenske gorice, Slovenia

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Ključne besede: mehkužci, zgornji miocen, spodnji panonij, Zgornji Osek, Slovenske gorice
Key words: molluscs, Late Miocene, Early Pannonian, Zgornji Osek, Slovenske gorice, Slovenia

Izvleček

V prispevku so obravnavani ostanki mehkužcev iz profila Osek-2 v Slovenskih goricah blizu Zgornjega Oseka. Med mehkužci je ugotovljenih nekaj melanopsidnih polžev in školjka *Mytilopsis ornithopsis* (Brusina, 1892). Fosilna favna določa peščenim sedimentnim kamninam profila Osek-2 spodnjepanonijsko starost.

Abstract

Remains of molluscs from a small outcrop at Zgornji Osek (section Osek-2) in Slovenske gorice are described. Some melanopsid gastropods and a bivalve *Mytilopsis ornithopsis* (Brusina, 1892) were documented. The fossil assemblage from fluvio-lacustrine sediments at Osek-2 corresponds to the Early Pannonian.

Uvod

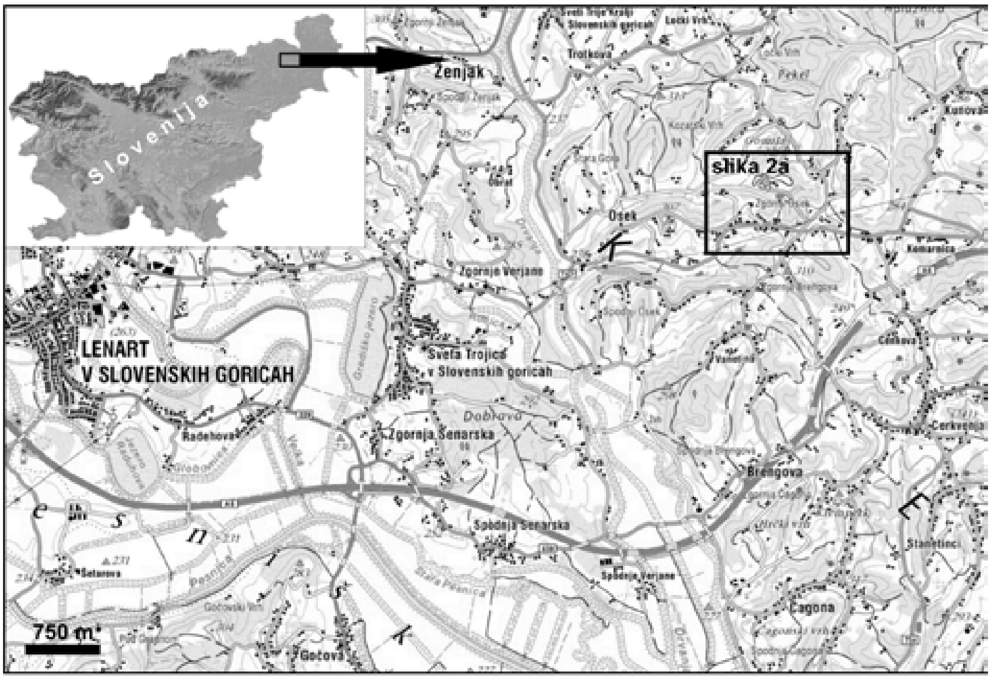
Panonijske plasti so v Sloveniji omejene predvsem na njen vzhodni del, vendar ni veliko krajev z bogato fosilno makrofavno. Med lokacije z več ostanki panonijske favne lahko uvrstimo najdišče Čanje pri Sevnici, Blatno severno od Globokega oziroma severnovzodno od Brežic, Ruhno vas na Dolenjskem in seveda Osek z zelo lepo ohranjenimi mehkužci, kjer prevladujejo melanopsidni polži in mitilopsidne školjke. Najdišče Osek-2 (sl. 1 in 2a) smo obiskali in raziskovali že leta 1997, takrat smo našli nekaj mehkužcev, predvsem polžev. Razen omenjenih polžev smo v raziskave vključili tudi školjke, ki jih je leta 2003 našel Franci Golob s Ptuja in jih kasneje podaril zbirki Prirodoslovnega muzeja Slovenije (PMS) v Ljubljani.

Nina Caf je v jeseni 2013 v okviru svoje diplomske naloge raziskovala in zbrala panonijske fosilne ostanke v najdišču Osek-2 pri Zgornjem Oseku. Našla je več melanopsidnih polžjih hišic, nekaj slabo ohranjenih školjčnih lupin, rastlinske ostanke in dva fragmentirana kosa sesalskih vretenc. V začetku leta 2014 je pridobila še fosilne školjke iz najdišča Osek, ki jih je prejela od uslužbencev Prirodoslovnega muzeja Slovenije.

Opis profila Osek-2

Žnidarčič in Mioč (1988; 1989) iz okolice najdišča Osek-2 omenjata peščen laporovec, glino, pesek in prod, ki sta jim pripisala panonijsko starost (M_3^2) in brakično sedimentacijsko okolje. Starost je potrjena z ostrakodi. Zanimivo je, da iz panonijskih plasti ne omenjata ostankov mehkužcev.

Caf in sodelavci (2014 in 2015) so naredili sedimentološko, paleontološko in stratigrafsko analizo profila Osek-2 (sl. 2b). V podlagi 5m debelega profila je meljast prod, sledi rumenkastorjav malo prodnat sljudnat meljevec z ostanki mehkužcev, rastlin in kostmi kopenskega sesalca. Do vrha profila je sljudnati meljevec z različnimi sedimentnimi teksturami. Caf (2015) navaja valovne sipinice, horizontalno, konvolutno in valovito laminacijo in bioturbacijo s plamenastimi teksturami. Omenjeni sedimenti so nastajali v spodnjem panoniju in ustrezajo najmlajšemu delu cone B v Centralni Paratetidi, na kar kažejo predvsem ostanki školjk vrste *Mytilopsis ornithopsis* (Brusina, 1892). Najverjetneje je bila sedimentacija v sprednjem delu lakustrine delte v bližini obale Panonskega bazena.



Sl. 1. Geografski položaj najdišča Zgornji Osek (Osek-2)

Fig. 1. Geographical position of site Zgornji Osek (Osek-2)

Sl. 2a. Položaj najdišča Osek-2 na satelitskem posnetku

Fig. 2a. Position of site Osek-2 on satelite image

Sl. 2b. Profil panonijskih plasti v najdišču Osek-2

Fig. 2b. Exposure of Pannonian beds in site Osek-2

Paleontološki del

Sistematska razvrstitev polžev po: Wenz 1938, 1960; Golikov & Starobogatov 1975 in Bouchet & Rocroi 2005

Classis Gastropoda Cuvier, 1797
Cladus Sorbeoconcha Ponder & Lindberg, 1997
Superfamilia Cerithioidea Fleming, 1822
Familia Melanopsidae H. Adams & A. Adams, 1854
Genus *Melanopsis* Férussac, 1807

Melanopsis bonellii Manzoni, 1870
Tab. 1, sl. 1-2, 5

1902 *Melanopsis Bonellii* Sismonda – Brusina, Tab. 5, Figs. 29-30, 31-32

1953 *Melanopsis impressa pseudonarzolina* n. ssp. – Papp, 132, Taf. 9, Figs. 14-18

1985 *Melanopsis impressa bonellii* Manzoni 1870 – Papp, 284, Taf. 32, Figs. 1-5

Material: Nekaj manjših in poškodovanih hišic (C/1, C/2, D in D/1) iz panonijskih plasti profila Osek-2.

Opis: Hišice so v obodu bikonične sestoje iz 5-6 nizkih, ozkih in deloma prekrivajočih zavojev. Največji zadnji zavoj zavzema dobri dve tretjini in prekriva starejše zavoje. Ustje je podolgovato, notranja ustna je debela oziroma široka, zunanja ustna je zelo tanka in zato le poredkoma cela. Ustje se zaključuje z ozko sifonalno režo. Nekako po sredini zadnjega zavoja poteka neizrazit spiralni greben.

Velikost primerkov (Size of specimens): VZZ = višina zadnjega zavoja (HLW = height of last whorl):

Primerki (Specimens)	Višina (Height) mm	Širina (Width) mm	VZZ (HLW) mm
C/1, T. 1, sl. 1	30	16	21
C/2, T. 1, sl. 2	26,5	14	20
D, T. 1, sl. 5	15,5	8,5	13
D/1	20	11	17,5

Primerjava: Primerka D in D/1 (tab. 1, sl. 5) iz Oseka sta najbolj podobna primerkom vrste *Melanopsis bonellii*, ki jih prikazuje Brusina (1902). Deloma sta primerljiva tudi s primerki podvrste *Melanopsis narzolina doderleini* Pantanelli, ki jih prikazuje Papp (1953: 132, Taf. 9, Figs. 5-8). V Dunajski kotlini so primerki podvrste *M. narzolina doderleini* najdeni v kongerijskih plasteh cone B. V Italiji je vrsta *Melanopsis narzolina* najdena v zgornjemiocenskih messinijskih plasteh.

Stratigrafska in geografska razširjenost: Brusina (1902) vrsto *Melanopsis bonellii* predstavlja iz neogenskih plasti najdišča Tinnye na Madžarskem in Grabovac v Srbiji. Papp (1953: 132) piše, da je ta melanopsidna oblika pogostna v kongerijskih plasteh cone B v južnem delu Češke in v Dunajski kotlini. Zelo redka je v mlajši coni C.

Melanopsis posterior Papp, 1953
Tab. 1, sl. 3a-3b, 4, 6-7

1953 *Melanopsis impressa posterior* n. ssp. – Papp, 133, Taf. 9, Figs. 19-23

1980 *Melanopsis posterior* Papp – Lueger, 129, Taf. 1, Fig. 27

1985 *Melanopsis impressa posterior* Papp 1953 – Papp, 284, Taf. 32, Figs. 6-10

2005 *Melanopsis impressa posterior* Papp, 1953 – Mikuž, 227, Tab. 1, sl. 2a-b

Material: Več primerkov (B/3–B/6, F, G/1–G/4), njihove hišice so zaradi krhkosti večinoma poškodovane.

Opis: Majhne hišice sestoje iz 5–6 zavojev, starejši zavoji so zelo nizki in ožji od zavojev vrste *Melanopsis bonelli*. Vrh hišice je izrazito koničast. Med zadnjim zavojem in ostalimi je nekakšna poglobljena stopnica in hišica je bolj trebušastega videza. Zadnji zavoj zavzema večino hišice, v zgornjem delu zavoja poteka spiralni greben. Ustje je solzaste oblike z ozko sifonalno režo. Notranja ustna je debela, zunanja tanjša. Po površini zadnjega zavoja potekajo številne tanjše in debelejše prirastnice.

Velikost primerkov (Size of specimens):

Primerki (Specimens)	Višina (Height) mm	Širina (Width) mm	VZZ (HLW) mm
B/3, T. 1, sl. 3a-3b	23	14	20,5
B/4	23	14	21
B/5	22	13,5	20
B/6	24,5	14,5	22,5
F, T. 1, sl. 4	21,5	15	20
G/1, T. 1, sl. 6	22	14	20
G/2, T. 1, sl. 7	26	15	23,5
G/3	22	13	19,5
G/4	25,5	14,5	22,5

Stratigrafska in geografska razširjenost: Papp (1953: 133) poroča, da je oblika *Melanopsis impressa posterior* zelo pogostna v panonijskih peskih cone B v Dunajski kotlini. Tipično najdišče je peskokop v Leobersdorfu. Lueger (1980: 129) omenja primerke te vrste iz panonijskih plasti Burgenlanda v Avstriji. Mikuž (2005: 229) predstavlja tovrstno hišico iz panonijskih plasti Čanja pri Sevnici.

Melanopsis fossilis (Gmelin, 1790)
Tab. 1, sl. 10a-10b, 11

1856 *Melanopsis Martiniana* Fér. – Hörnes, 594, Taf. 49, Figs. 5a-5b

1953 *Melanopsis fossilis fossilis* (Martini, Gmelin). – Papp, 133, Taf. 10, Figs. 1-8

1953 *Melanopsis fossilis coaequata* Handmann. – Papp, 134, Taf. 10, Figs. 11-12

1980 *Melanopsis coaequata* Handmann – Lueger, 129, Taf. 1, Fig. 22

1980 *Melanopsis constricta* Handmann – Lueger, 129, Taf. 1, Fig. 24

1985 *Melanopsis fossilis fossilis* (Martini–Gmelin 1790) – Papp, 284, Taf. 32, Figs. 11-14

1985 *Melanopsis fossilis coaequata* Handmann – Papp, 285, Taf. 33, Fig. 4

2002 *Melanopsis fossilis* (Gmelin, 1790) phenotype *handmanniana* Fischer, 1996 – Harzhauser, Kowalke & Mandic, 95, Pl. 6, Figs. 6, 9-10; Pl. 7, Figs. 11-12

2005 *Melanopsis fossilis coaequata* Handmann, 1887 – Mikuž, 227, Tab. 2, Sl. 3a-b

Material: Našli smo le nekaj primerkov, predstavljamo dve hišici z oznakama A in B/1. Najdeni sta v panonijskih peščenih sedimentih profila Osek-2 v letu 1997.

Opis: Hišice so večje, višje in bolj robustnega videza. Hišica sestoji iz 4–5 zavojev. Starejši zavoji so zelo nizki in ozki, zadnji zavoj je zelo velik in zavzema 4/5 celotne hišice. V zgornjem delu zadnjega zavoja poteka izrazit spiralni greben, ki tvori nekakšno stopnico. Ustje je dolgo ovalno s krajšo in ozko sifonalno režo. Notranja ustna je široka in dolga, zunanja ustna tanka in polkrožna. Površino zadnjega zavoja prekrivajo številne vzdolžne izrazite in šibke prirastnice.

Velikost primerkov (Size of specimens):

Primerki (Specimens)	Višina (Height) mm	Širina (Width) mm	VZZ (HLW) mm
A, T. 1, sl. 10a-10b	28	16	25
B/1, T. 1, sl. 11	28	16	26

Stratigrafska in geografska razširjenost: Papp (1953: 134) piše, da je podvrsta *Melanopsis fossilis coaequata* pogostna v coni C in redka v coni D panonijskih plasti Dunajske kotline. Lueger (1980: 129) vrsto *Melanopsis fossilis* omenja iz panonijskih plasti Burgenlanda v Avstriji. Papp (1985: 285) ne poroča več o njeni stratigrafski razširjenosti, piše pa, da je ta oblika tipična za mirno, zatišno vodno okolje. Harzhauser in sod. (2002:79, Fig. 3) prikazujejo v tabeli razširjenosti skupine *Melanopsis fossilis*, ki naj bi živela v panoniju od začetka cone C pa do konca cone D. Podobne panonijske polže iz Čanja pri Sevnici je predstavil Mikuž (2005: 231, Tab. 2). Naši podatki kažejo, da se vrsta *Melanopsis fossilis* pojavi že v coni B. Caf (2015: 13) jih opisuje iz panonijskih meljevcev s številnimi mehkužci in rastlinskimi ostanki profila Osek-2.

Melanopsis cf. senatoria Handmann, 1887
Tab. 1, sl. 9

cf.1953 *Melanopsis senatoria* Handmann. – Papp, 139, Taf. 12, Figs. 3-4

cf. 1980 *Melanopsis senatoria* Handmann – Lueger, 129, Taf. 1, Fig. 5

cf. 1985 *Melanopsis senatoria* Handmann – Papp, 322, Taf. 34, Figs. 10-11

cf. 2005 *Melanopsis senatoria* Handmann, 1887 – Mikuž, 228, Tab. 4, Sl. 1a-b

Material: V profilu Osek-2 smo leta 1997 našli en poškodovan primerek (E).

Opis: Hišica sestoji iz 5 do 6 zavojev, starejši zavoji so nizki in široki, zadnji zavoj je širok in krajši kot pri ostalih že opisanih vrstah. Obod hišice je podoben obodu konidnih polžev. Notranja ustna je široka in polkrožna, zunanja je odlomljena. Spiralni greben v zgornjem delu zadnjega zavoja ima nekakšne vozliče, nad njim je spiralna brazda.

Velikost primerkov (Size of specimens):

Primerki (Specimens)	Višina (Height) mm	Širina (Width) M m	VZZ (HLW) mm
E, T. 1, sl. 9	20,5	13	18

Stratigrafska in geografska razširjenost: Papp (1953: 139) piše, da je ta oblika v Dunajski kotlini v kongerijskih skladih con C in D. Iz panonijskih plasti Burgenlanda v Avstriji jih omenja tudi Lueger (1980: 129). Papp (1985: 322) jih navaja iz cone C panonijskih plasti najdišča Leobersdorf v Avstriji. Mikuž (2005: 239) predstavlja hišico vrste *Melanopsis senatoria* iz panonijskih plasti Čanja pri Sevnici, ki se nekoliko razlikuje od Oseških po velikosti in obliki.

Melanopsis sp.
Tab. 1, sl. 8

Material: Najdena sta dva primerka (B/2 in B/3) v panonijskem profilu Osek-2, ki odstopata od oblik opisanih melanopsidnih polžev.

Opis: Majhne hišice sestoje iz 4 do 5 zavojev. Hišica je visoka in ozka, starejši zavoji so nizki in široki, zadnji zavoj je največji. Na stiku med zavoji je ozek in poglobljen spiralni kanal, omejuje ga nazobčan greben. Ustje je ovalno in podaljšano v sifonalno režo, notranja ustna je široka, zunanja zelo ozka. Na površini zadnjega zavoja potekajo številne vzdolžne prirastnice.

Primerjava: Primerka B/2 in B/3 sta po obliki primerljiva s primerkom vrste *Melanopsis fossilis* (Gmelin, 1790), ki ga prikazujejo Harzhauser in sod. (2002: 126, Pl. 6, Fig. 5), le da sta hišici iz Oseka za polovico manjši.

Velikost primerkov (Size of specimens):

Primerki (Specimens)	Višina (Height) mm	Širina (Width) mm	VZZ (HLW) mm
B/2, T. 1, sl. 8	21	11	19
B/3	23	12,5	20

Sistematska razvrstitev školjk po: Cox et al. 1969 in Schultz 2005

Bivalvia Linné, 1758
Subclassis Heterodonta Neumayr, 1884
Ordo Veneroida H. Adams & A. Adams, 1856
Superfamilia Dreissenoidea Gray in Turton, 1840
Familia Dreissenidae Gray in Turton, 1840
Genus *Mytilopsis* Conrad, 1858

Mytilopsis ornithopsis (Brusina, 1892)
Tab. 2, sl. 1a-1c, 2-8

e. p. 1870 *Congeria triangularis* Partsch. – Hörnes, 363, Taf. 48, Figs. 1a-1c

1892 *Congeria ornithopsis* Brusina n. sp. – Brusina, 495

1902 *Congeria ornithopsis* Brus. – Brusina, Tab. 19, Figs. 12-14, 17

1953 *Congeria ornithopsis* Brusina. – Papp, 167, Taf. 15, Figs. 3-5

1985 *Congeria ornithopsis* Brusina 1892 – Papp, 295, Taf. 37, Figs. 1-3

1998 *Congeria ornithopsis* Brusina – Schultz, 138-139, Taf. 63, Fig. 7

2005 *Mytilopsis ornithopsis* (Brusina, 1892) – Schultz, 790, Taf. 106, Figs. 16-19

2015 *Mytilopsis ornithopsis* (Brusina, 1892) – Caf, 15, Tab. 2, sl. 2

Material: Deset kosov z mitilopsisi iz najdišča Osek je najditelj Franci Golob s Ptuja leta 2003 podaril Prirodoslovnemu muzeju Slovenije. Primerek (1974) v celoti ohranjenega mitilopsisa na kamnini, (1976/1) skoraj cela leva lupina na kamnini, (1976/2) leva lupina, na hrbtni strani kosa je polž rodu *Melanopsis*, (1976/3) poškodovana večja leva lupina, (1976/4) skoraj cela leva lupina na kamnini, (1976/5) manjša leva lupina, (1976/6) zelo poškodovana leva lupina na kamnini, (1976/7) obvršni del leve lupine, (1976/8) trije školjčni fragmenti v kamnini, na hrbtni strani je odtis školjke iz rodu *Limnocardium*, (1976/9) obvršni del manjšega mitilopsisa.

Opis: Lupine imajo obliko razprtega ptičjega krila. Razen oblike je za vrsto na sprednji strani značilen ozek in dolg greben z ovalnim anteriornim robom, ki se k zadnji strani spusti in razširi v krilo z ravnim posteriornim robom in močno ventralno zajedo. Vrh je ozek in povit, površina lupin je prekrita s številnimi vijugastimi koncentričnimi prirastnicami. Oblika lupin lahko variira.

Velikost primerkov iz Prirodoslovnega muzeja Slovenije (Size of specimens from Slovenian Museum of Natural History):

Primerki (Specimens)	Dolžina (Length) mm	Višina (Height) mm	Debelina (Thickness) mm
1974, T. 2, sl. 5a-5b	48	46	35
1976/1, T. 2, sl. 1a-1c	43	48	½ -17
1976/2, T. 2, sl. 2	38	47	½ -17
1976/3, T. 2, sl. 4	50	56	½ -18
1976/4, T. 2, sl. 3	45	45	½ -18
1976/5, T. 2, sl. 6	37	35	½ -16
1976/6, T. 2, sl. 8	37	37	½ -16
1976/7	-	-	½ -20
1976/8 – trije fragmenti	-	-	-
1976/9, T. 2, sl. 7	30	23	½ ~13

Stratigrafska in geografska razširjenost: Brusina (1892: 496) je novo vrsto opisal iz najdišča Wrbitz (Vrbice, severno od Prage v Republiki Češki), omenja pa jih še iz najdišč v Avstriji, na Madžarskem, v Bosni in na Hrvaškem (Duboki dol v Slavoniji). Brusina (1902: Tab. 19) predstavlja primerek vrste *Congeria ornithopsis* iz najdišča Tinnye na Madžarskem. Na Papp-ovi (1953: 187) tabeli o stratigrafski razširjenosti vrste je razvidno, da je ta školjka značilna za cono B spodnjega panonija v Dunajski kotlini. Papp (1960: 170-171) piše o neogenu Dunajske kotline, kjer plasti z vrsto *Congeria ornithopsis* pripisuje conama A/B spodnjega panonija. Papp (1985: 295) jo znova omenja iz cone B v Dunajski kotlini. Schultz (1998: 138) jo predstavlja iz najdišča Leobersdorf v Spodnji Avstriji. Najdena je v peščenem brakičnem faciesu panonijske cone B. Harzhauser in Kowalke (2002: 59) plasti s školjko *Mytilopsis ornithopsis* tudi uvrščata k panonijski coni B. Harzhauser in sod. (2002: 79, Fig. 3) so navedeno vrsto uvrstili v zgornji del panonijske cone B. Harzhauser in sod. (2004: 7) plasti s školjkami vrste *Mytilopsis ornithopsis* uvrščajo v Dunajski kotlini k spodnjemu panoniju, v coni A in B. Tudi Harzhauser in Tempfer (2004: 56) uvrščata vrsto *Mytilopsis ornithopsis* k spodnjepanonijskima conama A/B v Dunajski kotlini. Schultz (2005: 792-794) vrsto *Mytilopsis ornithopsis* omenja iz številnih avstrijskih najdišč. Vrsta je značilna za spodnji panonij, predvsem za cono B. Najdena je tudi drugod v Centralni Paratetidi, na Madžarskem, Slovaškem, Hrvaškem (Slavonija), v Srbiji, Bosni in Romuniji. Harzhauser in sod. (2011: 170, 174) tudi uvrščajo plasti s školjko *Mytilopsis ornithopsis* k conama A in B spodnjega panonija. Caf (2015: 15) jih opisuje in predstavlja iz panonijskih meljevcev profila Osek-2.

Zaključki

Raziskovali smo mehkužce iz panonijskega sljudnega meljevca pri Oseku. Med polži smo določili vrste *Melanopsis bonellii* Manzoni 1870, *M. posterior* Papp 1953, *M. fossilis* (Gmelin, 1790), *M.* cf. *senatoria* Handmann, 1887 in *Melanopsis* sp. Med školjkami prevladuje vrsta *Mytilopsis ornithopsis* (Brusina, 1892), najdenih je tudi nekaj odlomkov školjčnih lupin rodu *Congeria*.

Po določitvah panonijskih melanopsidnih polžev ugotavljamo, da se nekatere hišice vrste *Melanopsis fossilis* (Gmelin, 1790) medsebojno malo ali zelo razlikujejo. Zato je med njimi najverjetneje nekaj različnih vrst, obstaja pa tudi možnost, da je znotraj ene vrste pri njihovih hišicah večja variabilnost. Naštete vrste melanopsidnih polžev sicer potrjujejo panonijsko starost, školjčna vrsta *Mytilopsis ornithopsis* (Brusina, 1892) pa v Centralni Paratetidi zanesljivo določa plastem profila Osek-2 zgornji del spodnjepanonijskih con A/B (cf. Harzhauser & Tempfer, 2004; Harzhauser et al. 2011).

Pannonian moluscs from site Osek-2 in Slovenske gorice, Slovenia

Conclusions

From Osek-2 site we describe a mollusc assemblage with gastropods *Melanopsis bonellii* Manzoni 1870, *M. posterior* Papp 1953, *M. fossilis* (Gmelin 1790), *M.* cf. *senatoria* Handmann 1887 and *Melanopsis* sp. Bivalves are documented with species *Mytilopsis ornithopsis* (Brusina 1892) and some shell fragments of genus *Congeria*. Pannonian melanopsid gastropods of species *Melanopsis fossilis* (Gmelin, 1790) from Osek-2 are morphologicaly very diverse and some specimens could represents morphospecies or transitional species of melanopsids. Described melanopsid gastropods are characteristic of Pannonian age. The bivalve *Mytilopsis ornithopsis* (Brusina, 1892) dates site Osek-2 in Early Pannonian mollusc biozone A/B within the Central Paratethys (cf. Harzhauser & Tempfer 2004; Harzhauser et al. 2011).

Zahvale

Zahvaljujemo se gospodu Franciju Golobu s Ptuja za posredovane fosilne školjke iz najdišča pri Zgornjem Oseku. Za fotografiranje in izdelavo tabel se zahvaljujemo sodelavcu Mateju Fistru z Oddelka za geologijo NTF UL.

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TABLA 1 - PLATE 1

1 *Melanopsis bonellii* Manzoni, 1870; C/1, Osek-2, velikost 30×16 mm
Melanopsis bonellii Manzoni, 1870; C/1, Osek-2, size 30×16 mm

2 *Melanopsis bonellii* Manzoni, 1870; C/2, Osek-2, velikost 26,5×14 mm
Melanopsis bonellii Manzoni, 1870; C/2, Osek-2, size 26,5×14 mm

3 *Melanopsis posterior* Papp, 1953; B/3, Osek-2, velikost 23×15 mm
a-zadnja stran, b-sprednja stran
Melanopsis posterior Papp, 1953; B/3, Osek-2, size 23×15 mm
a-posterior view, b-anterior view

4 *Melanopsis posterior* Papp, 1953; F, Osek-2, velikost 21×15 mm
Melanopsis posterior Papp, 1953; F, Osek-2, size 21×15 mm

5 *Melanopsis bonellii* Manzoni, 1870; D, Osek-2, velikost 16×8 mm
Melanopsis bonellii Manzoni, 1870; D, Osek-2, size 16×8 mm

6 *Melanopsis posterior* Papp, 1953; G/1, Osek-2, velikost 22×14 mm
Melanopsis posterior Papp, 1953; G/1, Osek-2, size 22×14 mm

7 *Melanopsis posterior* Papp, 1953; G/2, Osek-2, velikost 27×14,5 mm
Melanopsis posterior Papp, 1953; G/2, Osek-2, size 27×14,5 mm

8 *Melanopsis* sp.; B/2, Osek-2, velikost 20×10,5 mm
Melanopsis sp.; B/2, Osek-2, size 20×10,5 mm

9 *Melanopsis* cf. *senatoria* Handmann, 1887; E, Osek-2, velikost 20,5×13 mm
Melanopsis cf. *senatoria* Handmann, 1887; E, Osek-2, size 20.5×13 mm

10 *Melanopsis fossilis* (Gmelin, 1790); A, Osek-2, velikost 27,5×15,5 mm
a-zadnja stran, b-sprednja stran
Melanopsis fossilis (Gmelin, 1790); A, Osek-2, size 27,5×15,5 mm
a-posterior view, b-anterior view

11 *Melanopsis fossilis* (Gmelin, 1790); B/1, Osek-2, velikost 28×15 mm
Melanopsis fossilis (Gmelin, 1790); B/1, Osek-2, size 28×15 mm

TABLA 1 - PLATE 1

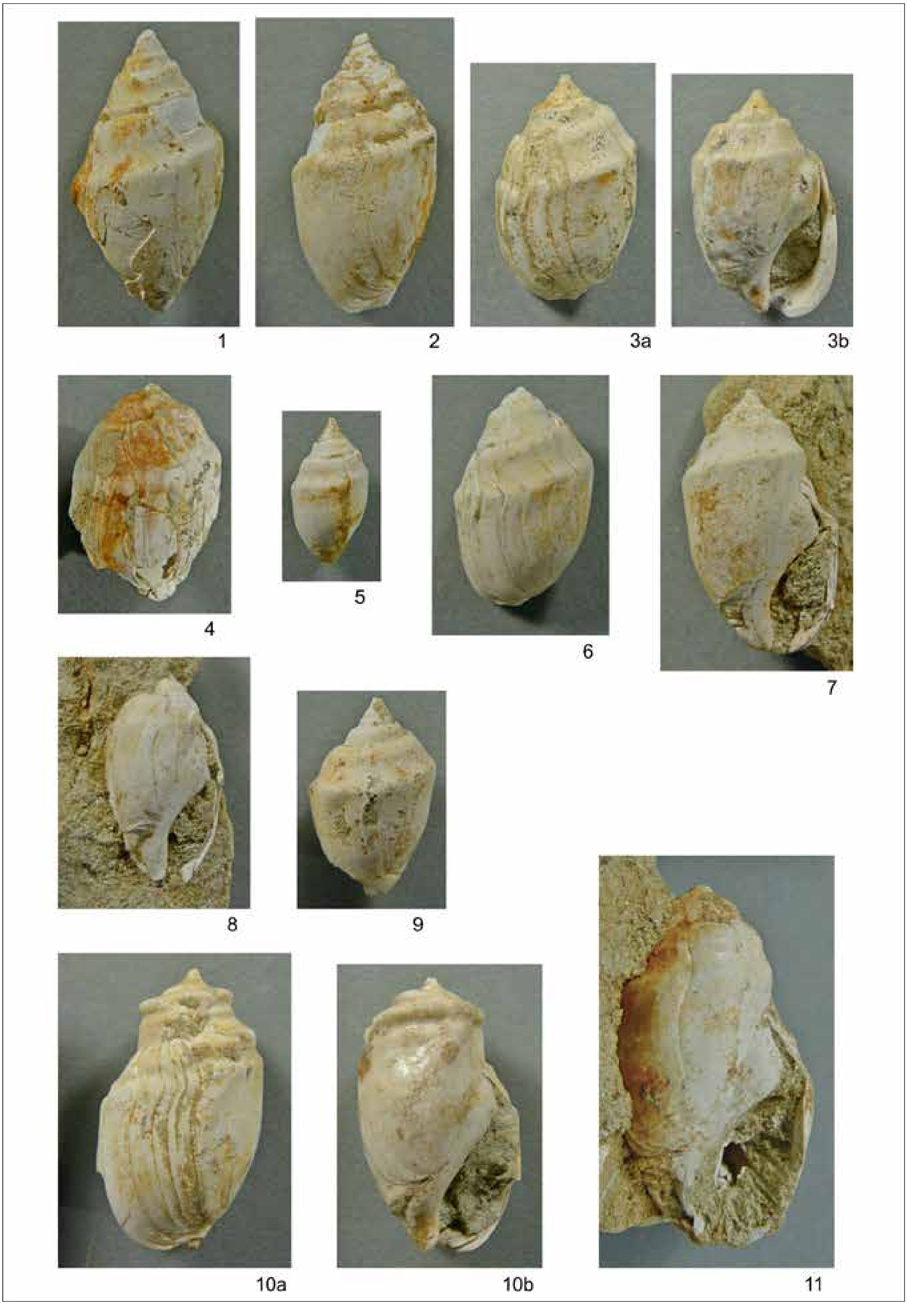

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TABLA 2 - PLATE 2

1 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/1, Osek-2, velikost 43x48 mm
a-zgornja stran, b-sprednja stran, c-zadnja stran
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/1, Osek-2, size 3×48 mm
a-upper view, b-anterior view, c-posterior view

2 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/2, Osek-2, velikost 8×47 mm
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/2, Osek-2, size 8×47 mm

3 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/4, Osek-2, velikost 45×45 mm
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/4, Osek-2, size 45×45 mm

4 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/3, Osek-2, velikost 50×56 mm
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/3, Osek-2, size 50×56 mm

5 *Mytilopsis ornithopsis* (Brusina, 1892), 1974, Osek-2, velikost 48×46 mm
a-zgornja stran leve lupine, b-sprednja stran školjke
Mytilopsis ornithopsis (Brusina, 1892), 1974, Osek-2, size 48×46 mm
a-upper view of left shell, b-anterior view of shells

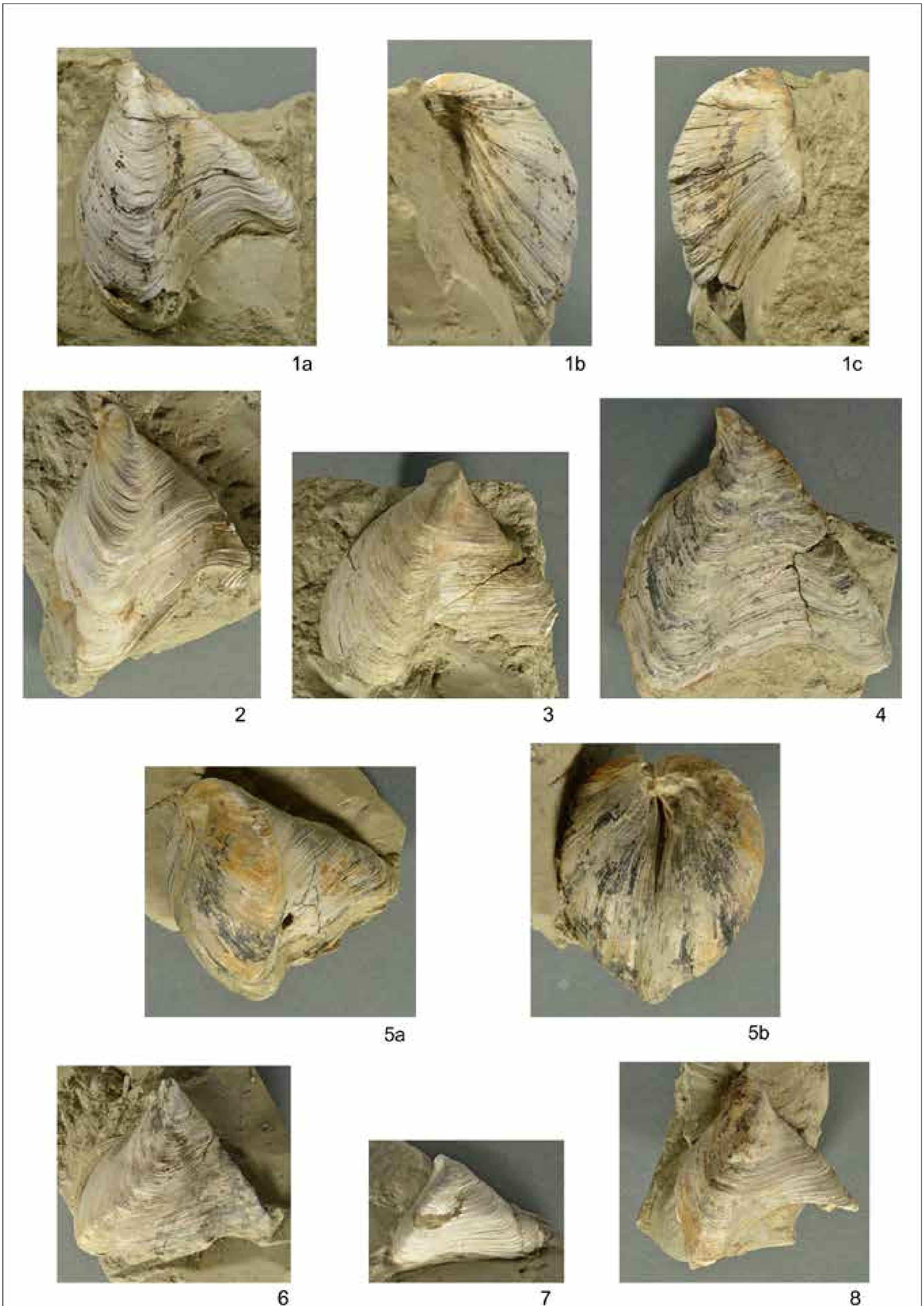
6 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/5, Osek-2, velikost 37×35 mm
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/5, Osek-2, size 37×35 mm

7 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/9, Osek-2, velikost 30×23 mm
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/9, Osek-2, size 30×23 mm

8 *Mytilopsis ornithopsis* (Brusina, 1892), leva lupina, 1976/6, Osek-2, velikost 37×37 mm
Mytilopsis ornithopsis (Brusina, 1892), left valve, 1976/6, Osek-2, size 37×37 mm

Fotografije (Photos): Matej Fister

TABLA 2 – PLATE 2



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Doliostrobus taxiformis iz soteških plasti pri Dobrni

Doliostrobus taxiformis from Socka beds in Dobrna area, Slovenia

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Key words: flora, Eocene, *Doliostrobus*, Socka beds, Slovenia

Izvleček

Prispevek obravnava ostanke iglavca vrste *Doliostrobus taxiformis* iz rjavosivih laporovcev zgornjeeocenskih soteških plasti, ki izdanjajo na južnih pobočjih med Vračkovim vrhom in Gruševcem severno od Dobrne. Med ostanki iglavcev so najpogostejše vejice z listi. Zelo redke so luske storžev.

Abstract

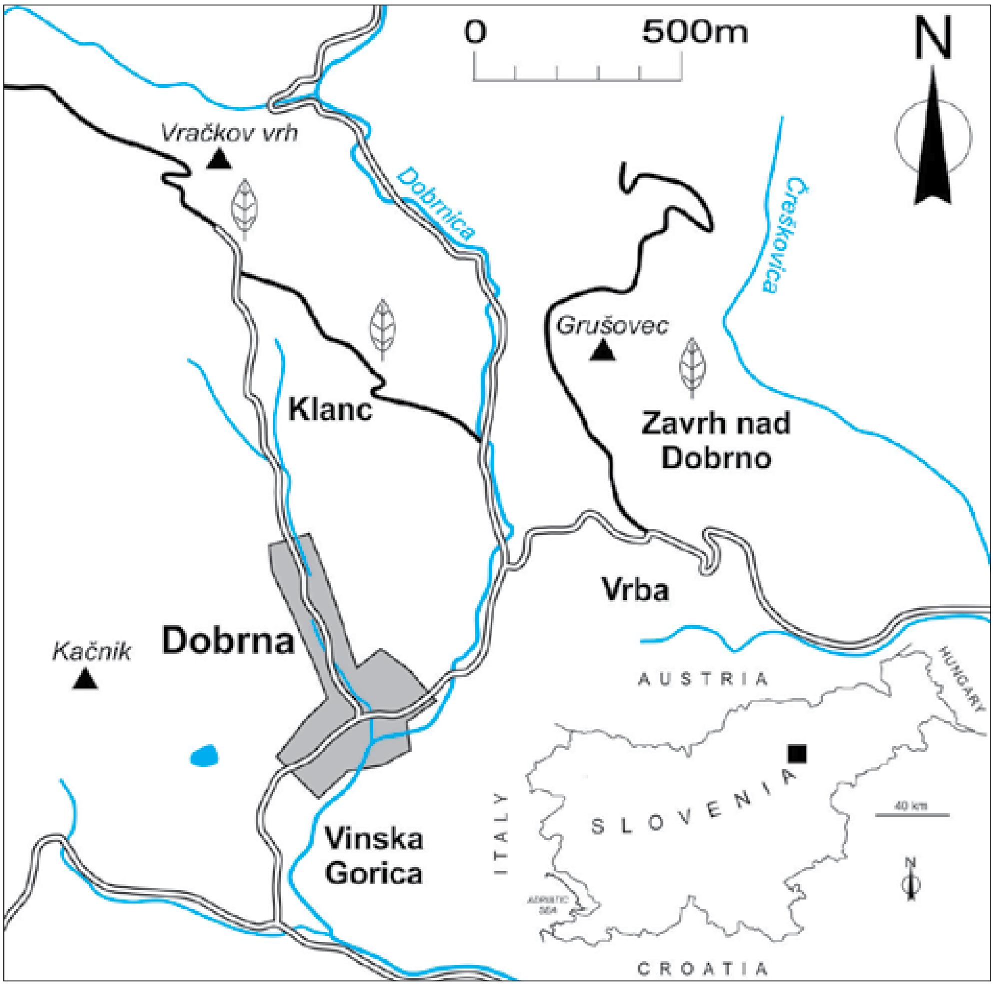
This paper is discussing remains of conifer species *Doliostrobus taxiformis* from brown-grey marls belonging to Upper Eocene Socka beds, which outcrop on the southern slopes of the Vračkov vrh and Gruševec north of Dobrna. The material consists mainly of leafy twigs and of rare cone scales.

Uvod

Na južnih pobočjih Paškega Kozjaka, severno od Dobrne, izdanjajo eocenske soteške plasti. V njih je na posameznih delih mogoče najti premogovne leče in zoglenele ostanke rastlin (sl. 1). Soteške plasti so plasti glinavca, laporovca in peščenjaka med katerimi se pojavljajo leče s premogom. Soteške plasti se razprostirajo med Dobrno in Socko, Konjiško goro, Bočem in Rogaško Slatino. Ponekod je na njihovi bazi, na triasnih karbonatih odložen konglomerat s premogom. Soteške plasti so v bazalnem delu razvite kot sladkovodna tvorba in po profilu navzgor prehajajo v brakična ter v tipična morska okolja; sprva v robnomorsko in nazadnje v globoka sublitoralna ali okolja zgornjega batiala (Mioč, 1972; Jelen et al., 2000; Cimerman et al., 2006; Pavšič, 2006). O najdbah fosilne flore z območja Socke, ki leži le nekaj kilometrov stran od Dobrne, sta pisala že Unger (1850) in Ettingshausen (1858), ki sta v svojih delih identificirala več kot 100 različnih fosilnih vrst rastlin. Od tedaj naprej pa podrobnejše obdelave in raziskav fosilne flore s tega območja ni bilo. Prve makrofloristične ostanke smo našli jeseni leta 2013 v vseku novo narejene gozdarske vlake pod Vračkovim vrhom, kjer smo odkrili razmeroma pestro združbo rastlinskih ostankov in mehkužcev. Raziskave smo nadaljevali leta 2014, kjer smo približno na isti koti na sosednjem hribu, imenovanem Gruševec, našli v materialu iz izkopa za stanovanjsko hišo bogato združbo rastlin, školjk in piritiziranih kamenih jeder polžev. V pisanje tega prispevka nas je vodila najdba izredno ohranjenega večjega skupka listnatih vejic, ki pripadajo izumrlemu iglavcu *Doliostrobus taxiformis*. Primerek je predstavljen na tabli 2. Poleg tega primerka je bilo najdenih še več manjših fragmentiranih vejic iste vrste, tri storževe luske, ter več ostankov listavcev.

Geološka zgradba območja

Južna pobočja Paškega Kozjaka gradijo paleozojske in mezozojske klastične in karbonatne kamnine, ki s stališča strukturne členitve pripadajo Južnim Alpam (Placer, 2008). Najstarejše kamnine predstavljajo paleozojski, zgornjekarbonski skrilavi glinavci, kremenovi peščenjaki in konglomerati ter apnenci, ki nastopajo v ozkih luskah in pripadajo Vitanjskemu nizu kamnin (Ramovš, 1960; Mioč, 1972). Sledijo jim mezozojski, spodnjetriasni klastični dolomiti in anizijski dolomit. Kenozojske kamnine s strukturnega vidika pripadajo Panonskemu sistemu bazenov, ki so jih skozi paleogen in neogen zapolnili sedimenti Paratetide. Sedimenti Panonskega bazena so na raziskovanem območju odloženi v pogreznjenih delih Južnih Alp (Placer, 2008). Paleogenu pripadajo zgornjeeocenske soteške plasti laporovcev in glinavcev z lečami premoga, ki jih najdemo severno in vzhodno od Dobrne (Cimerman et al., 2006; Brezigar, 2007). Prav tako je zgornjeeocenske starosti svetlo siv



Sl. 1. Situacijska skica nahajališč fosilne makroflore

Fig. 1. Situational drawing of fossil macroflora localities

grebenski loški apnenec, imenovan po vasi Loka severozahodno od Dobrne (Brezigar, 2007). Neogenu pripadajo spodnjemiocenski, egerijsko-eggenburgijski kremenovo glavkonitni peščenjaki in konglomerati, ki pripadajo govških plastem ter karpatijske klanške plasti. Klanške plasti gradijo morski peščenjaki, laporovci in breče s karbonatnim vezivom (Brezigar, 2007). Paleontološke raziskave, rezultate katerih podaja ta prispevek, so se izvajale v zgornjeeocenskih soteških plasteh severno in severovzhodno od Dobrne.

Material in metode

Obravnavan material predstavljajo vejice z listi in redkeje semenske luske, ki so bili najdeni na južnih pobočjih Paškega Kozjaka severno od Dobrne, natančneje pri zaselkih Klanc in Zavrh nad Dobrno (sl. 1). Fosilni material je najden v sivih do rjavih laporovcih. Fotografije za table so bile posnete z digitalnim foto aparatom »Canon PowerShot S2 IS«.

Dosedanje makroflorističnе raziskave soteških plasti

Prvi je makroflorističnе ostanke iz soteških plasti opisal Unger (1850) v svojem delu »Die fossile Flora von Sotzka«, ki je flori pripisal izjemen pomen. Določil je 121 različnih rastlinskih ostankov, ki jih je razvrstil v 68 rodov. Soteškim plastem je pripisal eocensko starost. Območje nastanka soteških plasti je interpretiral kot otok, kateri je bil del večje združbe otokov, ki so ležali v oceanu med Evropo in Afriko. Paleogeografsko je območje umestil na vzhodni del južne hemisfere, ter jo zaradi posebnega tropskega značaja primerjal s floro Oceanije, kjer srednja letna temperatura znaša med 18 in 22°C. Menil je, da so se ostanki dreves in grmovnic, ki predstavljajo floro soteških plasti, odlagali v lagunah, ki so postale izolirane od morja zaradi naravnih jezov; v teh lagunah so ostanke rastlin prekrili glinasti sedimenti (Unger, 1850). Kasneje Ettingshausen (1858) revidira Ungerjevo delo (1850) ter s primerjavo z recentnimi vrstami sklepa na napačno poimenovanje večine primerkov. Primerke ponovno klasificira in jih razvrsti v štiri skupine (»Arten des I, II, III, IV Grades«), med katerimi v prvo skupino uvršča makroflorističnе ostanke določene nedvomljivo, v ostalih skupinah pa pri njihovem določevanju in poimenovanju obstaja dvom o določljivosti oziroma jih po njegovem mnenju ni mogoče taksonomsko opredeliti. Hkrati Ettingshausen (1858) v svojem delu določi nekaj, za soteške plasti novih vrst in razširi popisano makroflorističnо združbo na danes poznanih 134 vrst, ki pripadajo 75 rodovom. S fosilno floro soteških plasti se je ukvarjal tudi Jungwirth (2003a, 2003b, 2004), ki je obravnaval taksonomske opredelitve paleogenskih rastlin iz najdišč v Sloveniji, na Hrvaškem ter v Bosni in Hercegovini in njeno problematiko.

Tabela 1. Preglednica velikosti primerkov
Table 1. Table of specimen sizes

Vzorec / Specimen	Tip materiala / Type of material	Višina / Height [mm]	Širina / Width [mm]
Tab. 1, Sl. / Fig. 1	Vejica z listi / leafy twig	71	10
Tab. 1, Sl. / Fig. 2	Vejica z listi / leafy twig	44	5
Tab. 1, Sl. / Fig. 3	Vejica z listi / leafy twig	103	26
Tab. 1, Sl. / Fig. 4	Vejica z listi / leafy twig	52	5
Tab. 1, Sl. / Fig. 5	Vejica z listi / leafy twig	17	8
Tab. 1. Sl. /Fig. 6	Storževa luska / cone scale	8	5
Tab. 1, Sl. / Fig. 7	Storževa luska / cone scale	18	10
Tab. 1, Sl. /Fig. 8	Storževa luska / cone scale	17	10
Tab. 2, Sl. / Fig. 9	Vejice z listi / leafy twigs	225	98

Paleontološki del

Sistematika po Kvaček, 2002
Ordo Pinales, Dumortier, 1829
Familia Doliostrobaceae Kvaček, 2002
Genus *Doliostrobus* Marion, 1888

Doliostrobus taxiformis (Sternberg) Kvaček, 1971
(Tab. 1, Sl. 1-8; Tab. 2, Sl. 9)

1850 *Araucarites sternbergii* Göpp. – Unger, p. 27, Taf. 3, Fig. 1-13.

1853 *Araucarites sternbergii* Göpp. – Ettingshausen, p. 36, Taf. 7, Fig. 1-10.

Non 1853 *Eucalyptus haeringiana* Ettingsh. – Ettingshausen, p. 84, Taf. 28, Fig. 20 [sed. *Doliostrobus taxiformis* (Sternberg) Kvaček]

1854 *Araucarites sternbergii* Göpp. – Ettingshausen, p. 12, Taf. 5, Fig. 1-3.

1855 *Araucarites sternbergii* Goepp. – Heer, p. 55, Taf. 21, Fig. 5.

1867 *Sequoia sternbergii* Heer. – Ettingshausen, p. 116, Taf. 13, Fig. 3-8.

1998 *Doliostrobus taxiformis* (Sternberg) Kvaček var. *hungaricus* (Rásky) stat. N. – Kvaček & Hably, p. 6, Tab. 1, Fig. 1-2.

2002 *Doliostrobus taxiformis* (Sternberg) Kvaček – Kvaček, p. 53, Pl. 1, Fig. 1.

L 2004 *Doliostrobus sternbergii* (Göppert) – Jungwirth, p. 188.

2007 *Doliostrobus taxiformis* (Sternb.) Kvaček – Kvaček & Teodoridis, Fig. 2 k, n.

L 2010 *Doliostrobus taxiformis* (Sternberg) Z. Kvaček – Hably, p. 406.

2011 *Doliostrobus taxiformis* (Sternberg) Kvaček var. *sternbergii* Mai et Walther ex Kvaček – Kvaček, p. 89, Pl. 1, Fig. 14-16.

Material

Obravnavanih je bilo skupno 9 primerkov makroflorističnih ostankov iglavca vrste *Doliostrobus taxiformis,* od tega 6 primerkov predstavljajo vejice (angleško leafy twigs) in 3 primerki izolirane storževe luske (angleško cone scales). Material je bil najden v zgornjem delu profila Vraček (*sensu* Cimerman et al., 2006; Profil Vr. 1) in na območju Grušovca pri Zavrhu nad Dobrno (sl. 1).

Opis materiala

Listnate vejice s spiralno in radialno razporejenimi igličastimi listi, ki ob osi delno ovijajo steblo. Listi so dolgi do 10 mm in široki 1-3 mm, so ukrivljeni in usmerjeni. Listi so zaobljeni do zaoblejno-suličasti. Konice listov so zašiljene (tab. 1, sl. 1-5; tab. 2, sl. 9). Storževe luske kažejo značilno vzdolžno progavost ter se na vrhu zaključujejo zašiljeno v ostanek apikalne bodice. Semena niso ohranjena. Semenske luske so izolirane in imajo eno lateralno krilo. Lateralno krilo je stožčasto in rahlo zamaknjeno (tab. 1, sl. 6-8).

Stratigrafska in geografska razširjenost

Doliostrobus taxiformis je razširjen med srednjim eocenom in spodnjim oligocenom (Kvaček, 2002), ter izumre v zgornjem oligocenu (Hably, 2010). V Sloveniji je *Doliostrobus taxiformis* evidentiran iz zgornjeeocenskih soteških plasti pri Socki (Unger, 1850; Ettingshausen, 1853; Jungwirth, 2004). Po podatkih Jungwrith-a je vrsta poznana tudi iz oligocenske Trboveljske formacije med Trbovljami in Zagorjem (Jungwirth, 2003a). S severozahoda Češke je vrsta poznana iz zgornjeeocenskih diatomitov in laporovcev z okolice Bíline (Bílin) in Kučlína (Ettinghausen, 1867; Kvaček, 2011). *D. taxiformis* je opisan tudi iz eocenskih laporovcev Spodnje sladkovodne molase (»Untern Sußwassermollase«) v Švicarskem molasnem bazenu. Heer (1855)

Spodnjo sladkovodno molaso enači s Soteškimi plastmi, plastmi pri Zagorju, Radoboju in Häringu na Tirolskem. V Avstriji je *Doliostrobus taxiformis* opisan iz spodnjeoligocenskih (rupelijskih) črno-rjavih terciarnih laporovcev in bituminoznih laporastih apnencev s premogom pri Häringu na Tirolskem (Ettingshausen, 1853; Butzmann et al., 2009). Iz spodnjega oligocena je vrsta najdena tudi v glinah formacije Tard na severnem Madžarskem pri mestu Eger. Prav tako je spodnjeoligocenske starosti najdišče blizu Santa Giustina v italjanski Liguriji (Hably, 2010).

Taksonomija

Doliostrobus taxiformis je izumrla vrsta iglavca, ki je v preteklosti zaradi svojega morfološkega polimorfizma bila pripisana različnim rodovom: *Araucarites*, *Cryptomeria* in *Sequoia* (Jungwirth, 2004; Kvaček, 2011). Kljub razlikam ima *Doliostrobus* skupne lastnosti z araukaridami; imajo podobno morfologijo pelodov ter po eno seme na storževo lusko (Kvaček, 2011). Samostojno družino Doliostrobaceae je leta 2002 postavil Kvaček. V omenjeno družino spadajo tipski rod *Doliostrobus* Marion in dva fosilna rodova: *Araucarites* Krutzsch – *Araucarites europaeus* Krutzsch, 1971 zaradi razpršenih pelodov; in *Doliostoboxylon* Dolezych zaradi strukture lesa (Kvaček, 2011). Na podlagi lesa, določenega kot *Doliostoboxylon,* velja *D. taxiformis* za veliko lesnato drevo. *Doliostrobus taxiformis* v Evropskem paleogenu nastopa v treh oblikah; *D. taxiformis* (Sternberg) Z. Kvaček var. *taxiformis*, var. *sternbergii* Mai et Walther ex Z. Kvaček in var. *hungaricus* (Rásky) Z. Kvaček et Hably), ki se med seboj ločijo po strukturi kutikularnih celic.

Razprava

V soteških plasteh na območju Dobrne je ostanke *Doliostrobus taxiformis* mogoče najti v obliki igličastih vejic in fragmentov storževih lusk. Na terenu nismo opazili *in situ* ali *ex situ* debel, panjev ali korenin, zato lahko rečemo, da so ostanki fosilne makroflore bili podvrženi transportu zato lahko nahajališče opredelimo kot hipavtohtono ali alohtono. Ohranjene so le bolj obstojne rastlinske komponente, kot so kutikule in smole (Drovenik, 1984). Mikroskopskega preparata kutikule nismo napravili, za to ne moremo določiti variacijske oblike, lahko pa glede na obliko semenske luske (tab. 1, sl. 6-8) sklepamo na variacijo *sternbergii* Mai et Walther ex Z. Kvaček (Kvaček, 2002; fig. 3c). Vendar na podlagi semenskih lusk ne moremo vseh primerkov enoznačno pripisati tej variaciji.

TABLA 1 - PLATE 1

1 a *Doliostrobus taxiformis* (Sternberg) Kvaček, vejica z listi. Naravna velikost.
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twig. Natural size.

1 b *Doliostrobus taxiformis* (Sternberg) Kvaček, vejica z listi.
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twig, same specimen, other side.

2 *Doliostrobus taxiformis* (Sternberg) Kvaček, vejica z listi (2×)
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twig (2×)

3 *Doliostrobus taxiformis* (Sternberg) Kvaček, vejice z listi (1,2×)
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twigs (1.2×)

4 *Doliostrobus taxiformis* (Sternberg) Kvaček, vejica z listi. Naravna velikost.
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twig. Natural size.

5 a *Doliostrobus taxiformis* (Sternberg) Kvaček, vejica z listi (2×)
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twig (2×)

5 b *Doliostrobus taxiformis* (Sternberg) Kvaček, vejica z listi, isti primerek (3,5 ×)
Doliostrobus taxiformis (Sternberg) Kvaček, leafy twig, same specimen (3.5×)

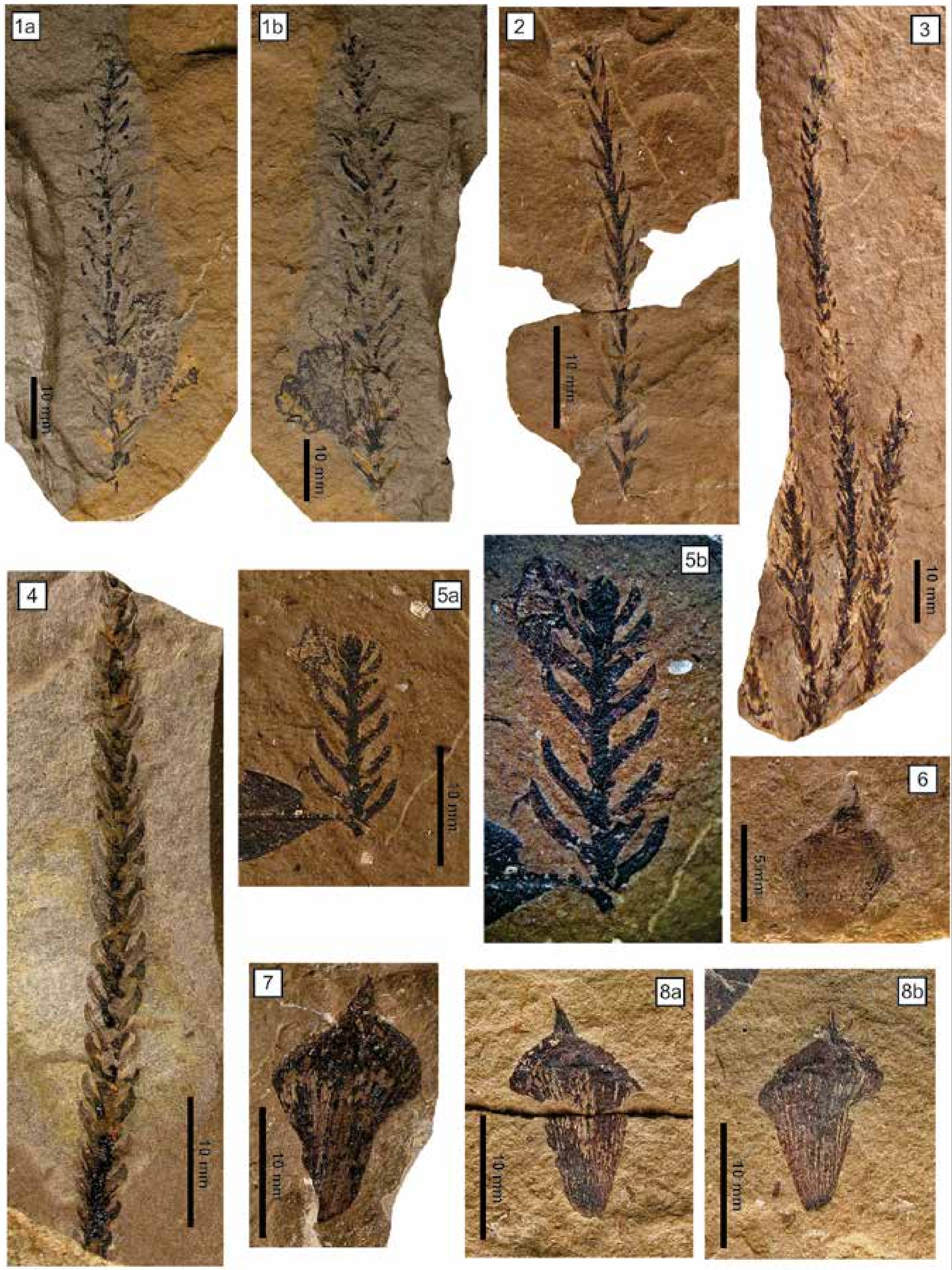
6 *Doliostrobus taxiformis* (Sternberg) Kvaček, storževa luska (2,5×)
Doliostrobus taxiformis (Sternberg) Kvaček, cone scale (2.5×)

7 a *Doliostrobus taxiformis* (Sternberg) Kvaček, storževa luska (2×)
Doliostrobus taxiformis (Sternberg) Kvaček, cone scale (2×)

7 b *Doliostrobus taxiformis* (Sternberg) Kvaček, storževa luska. Druga stran (2×)
Doliostrobus taxiformis (Sternberg) Kvaček, cone scale, other side (2×)

8 *Doliostrobus taxiformis* (Sternberg) Kvaček, storževa luska (3,7×)
Doliostrobus taxiformis (Sternberg) Kvaček, cone scale (3.7×)

TABLA 1 - PLATE 1



Zaključki

V zgornjeeocenskih rjavo sivih laporovcih soteških plasti severno od Dobrne je bila odkrita razmeroma pestra združba fosilne flore. Prispevek obravnava del najdenih makrofloristični h ostankov, ki pripadajo izumrli vrsti iglavca *Doliostrobus taxiformis* (Sternberg) Kvaček. Primerki so bili najdeni v useku gozdarske vlake pod Vračkovim vrhom in v izkopanem materialu za stanovanjsko hišo na območju Gruševca. Najdeni ostanki predstavljajo zlasti vejice z listi in storževe luske brez ohranjenih semen. Akumulacija rastlinskega drobirja je hipavtohtona ali alohtona, saj na terenu nismo opazili debel, korenin ali čokov. So pa med materialom ohranjeni bolj obstojni deli rastlin, kot so kutikule in drobne kapljice smole. Analiza kutikule ni bila narejena, ker pa je študija kutikule nujna za določitev variacije, smo pri določevanju ostali na nivoju vrste. Med plastmi laporovcev soteških plasti so opazne tudi akumulacije nedoločljivih polžev in školjk.

Doliostrobus taxiformis from Socka beds in Dobrna area, Slovenia

Conclusions

In Upper Eocene brownish-gray marlstones of Socka beds north of Dobrna a relatively diverse fossil flora assemblage has been found. This paper deals with a part of macrofloristic remains belonging to conifer species *Doliostrobus taxiformis* (Sternberg) Kvaček. Fossil specimens were collected from a new forestry trail under Vračkov vrh and from material excavated for residental house in the area of the Gruševec. Fossil material consists mainly of leafy twigs and of cone scales, without seed preserved. Accumulation of plant debris is hypautochthonous or allochthonous, since no roots, logs or tree stumps were observed. Among the material, only most resistant parts of the plants, such as cuticle and tiny resinous droplets are preserved. Cuticle analysis was not performed; since its analysis is mandatory for determening the variety of the species our determination stays at the species level. Between the marlstone strata, accumulations of indeterminate gastropods and bivalves are found.

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TABLA 2 - PLATE 2

9 *Doliostrobus taxiformis* (Sternberg) Kvaček, vejice z listi (0,9×)
Doliostrobus taxiformis (Sternberg) Kvaček,, leafy twigs (0.9×)

Fotografije (Photos): Aleš Šoster & Barbara Potočnik Krajnc

TABLA 2 - PLATE 2

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Simplified structural map of Kras
Kras (Slovene), Carso (Italian) = Geographical unit

Poenostavljena strukturno-geološka karta Krasa
Kras (slovensko), Carso (italjansko) = geografska enota

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Ključne besede: Kras, tektonika, tektonska geomorfologija, Slovenija

Abstract

With this contribution comes a printed copy of the *Simplified structural map of Kras*, comprising an area on both sides of the state border between Slovenia and Italy, as well as its short description. The map conveys updated information on faults and newly discovered geomorphologically indicated joint-fault zones in the area.

Izvleček

Prispevek prinaša natis *Poenostavljene strukturno-geološke karte Krasa*, ki zajema ozemlje na slovenski in italijanski strani državne meje ter kratek opis. Karta vsebuje dopolnjene podatke o poteku prelomov in o novoodkritih geomorfološko izraženih razpoklinsko-prelomnih conah.

In this issue of Geologija, the *Simplified structural map of Kras* is published in order to provide some information about the progress of research conducted in the Kras region (Classical Karst Region – Kras). The map has been compiled as an essential appendix of a more extensive work, *Geomorphology of Kras*, which is being prepared in co-authorship by L. Placer and A. Mihevc.

In the Slovenian part, the map is based on works published by Jurkovšek et al. (1996), Jurkovšek (2010, 2013) and Placer (2005, 2007), and in the Italian part on those by Cucchi & Piano (2013), Cucchi et al. (2015) and Rižnar (2014). Moreover, data gathered during sea bottom research of the Gulf of Trieste (Busetti et al., 2010; Carulli, 2011) are also included. The interpretation of structure is based on the before mentioned works and on the reconnaissance structural profiling of the entire area of the map, made in 2010 to 2013.

The interpretation of structure and geomorphology of the Kras region was based on the findings published in a paper entitled *The bases for understanding of the NW Dinarides and Istria Peninsula tectonics* (Placer et al., 2010). By applying the mentioned maps, recent structural profiling and study of remote sensing data, we identified several kinematic phases that reflect in the geological structure and geomorphology of the surface. Most of the faults underwent one or more reactivations in various directions, and therefore were not marked by map symbols of movement directions of their fault blocks. Some symbols appear only on the most important faults of the Istria-Friuli Underthrust Zone, which is the most stable in this sense. Interestingly, among the more important newly established features there are three geomorphologicaly active joint-fault zones within which structural escarpment have developed. The first one is the *Doberdo (Doberdob) joint-fault zone* along which the larger part of Vallone di Doberdo (Doberdobski dol) has formed, and the *Opajsko selo structural escarpment,* that separates the peneplains of the Kostanjevica and Doberdo (Doberdob) Kras. The latter subsided along the joint-fault zone for 60 to 70 m. The second one is the *Sežana joint-fault zone* with the *Lipica structural escarpment,* along which the west block has subsided for about 15 to 20 m. The third one is the *Matavun joint-fault zone* with the *Škocjan structural escarpment,* along which the eastern block has subsided. Systems of fissures in various directions, predominately north-south, are quite abundant on the Kras plateau, but hitherto they have been considered mostly in connection with the processes leading to the formation of dolines, caves and sinkholes.

Among the plicative deformations, larger and smaller ones have been distinguished. I would like to emphasize the larger ones located on the borders between the Trieste-Komen anticlinorium and the Čičarija anticlinorium (after Buser 1976, Čičarija anticline) and the Brkini synclinorium (after Buser 1976, Reka synclinorium) respectively, and the ones between the Vipava synclinorium and the Ravnik anticlinorium (after Placer 2005, Ravnik anticline). On previous maps some of these were not depicted as folds; they are, however, very important for the understanding of structure and geomorphology.

The *Geomorphology of Kras* is conceive as an extended guidebook to the *Simplified structural map of Kras*. It comprises a discussion on the influence of the Istria Pushed Area on the postorogenic evolution of the External Dinarides and their geomorphology. From this basis follows a schematic morphotectonic subdivision of the Dinaric Karst in the area of the External Dinarides, and a concept of morphogenetic evolution of the area of Classical Karst (between the Gulf of Trieste and Ljubljansko barje / the Ljubljana Marsh) with Istria Peninsula and Kras. The latter is considered in detail. The evolution of morphology is presented in terms of synergistic effects of lithostratigraphy, structure, exogenic processes and tectonics. In the frame of the latter, we attempted to provide some answers to the complex question of causes that lead to the formation of the Istria Pushed Area.

Poenostavljena strukturno-geološka karta Krasa Kras (slovensko), Carso (italjansko) = geografska enota

V tej številki Geologije je objavljena *Poenostavljena strukturno-geološka karta Krasa*, kar predstavlja prispevek k obveščanju o poteku raziskav na Krasu. Izdelana je kot osnovna priloga obsežnejšega dela *Geomorfologija Krasa*, ki se pripravlja v soavtorstvu L. Placerja in A. Mihevca.

Na območju Slovenije je karta sestavljena iz del, ki so jih objavili Jurkovšek et al. (1996), Jurkovšek (2010, 2013) in Placer (2005, 2007), na območju Italije pa Cucchi & Piano (2013), Cucchi et al., (2015) in Rižnar (2014). Poleg tega so zajeti tudi podatki raziskav morskega dna Tržaškega zaliva (Busetti et al., 2010; Carulli, 2011). Interpretacija strukture sloni na omenjenih delih in na preglednem strukturnem profiliranju, ki je bilo opravljeno na celotnem ozemlju v letih 2010-2013.

Raziskovanje strukture in geomorfologije Krasa je bilo zasnovano na ugotovitvah razprave *The bases for understanding of the NW Dinarides and Istria Peninsula tectonics = Osnove razumevanja tektonske zgradbe NW Dinaridov in polotoka Istre* (Placer et al., 2010). Na podlagi podatkov zgoraj omenjenih kart, novega strukturnega profiliranja in proučevanja daljinskih posnetkov, je bilo mogoče določiti več kinematskih faz, ki se odražajo v geološki zgradbi in geomorfologiji površja. Prelomi so večinoma doživeli eno ali več reaktivacij v različnih smereh, zato nimajo oznak, ki bi nakazovale smer premika prelomnih kril. Te so zabeležene le pri najpomembnejših prelomih Istrsko-furlanske podrivne cone, ki so v tem smislu najbolj stabilni. Od pomembnejših novosti so zanimive tri geomorfološko tvorne razpoklinsko-prelomne cone, znotraj katerih so se razvili strukturni pragovi; prva je *doberdobska razpoklinsko prelomna cona* po kateri je nastal večji del Doberdobskega dola in *opajski strukturni prag*, ki loči uravnavi Kostanjeviškega in Doberdobskega Krasa. Slednja je ob njej ugreznjena okoli 60 do 70 m. Druga je *sežanska razpoklinsko-prelomna cona* z *lipiškim strukturnim pragom* ob katerem je zahodno krilo ugreznjeno okoli 15 do 20 m. Tretja je *matavunska razpoklinsko-prelomna cona* s *škocjanskim strukturnim pragom* ob katerem pa je ugreznjeno vzhodno krilo. Snopi razpok v različnih smereh, posebno v smeri sever-jug, so na Krasu številni, toda doslej smo menili, da so pomembni predvsem za nastajanje vrtač, jamskih objektov in udornic.

Plikativne deformacije so ločene na večje in manjše. Opozoril bi na večje na mejah Tržaško-komenskega antiklinorija s Čičarijskim antiklinorijem (po Buserju 1976, Čičarijska antiklinala) in Brkinskim sinklinorijem (po Buserju 1976, Reški sinklinorij) ter med Vipavskim sinklinorijem in Ravniškim antiklinorijem (po Placerju 2005, Ravniška antiklinala), od katerih nekatere na dosedanjih kartah niso bile prikazovane kot gube, vendar imajo za razumevanje strukture in geomorfologije velik pomen.

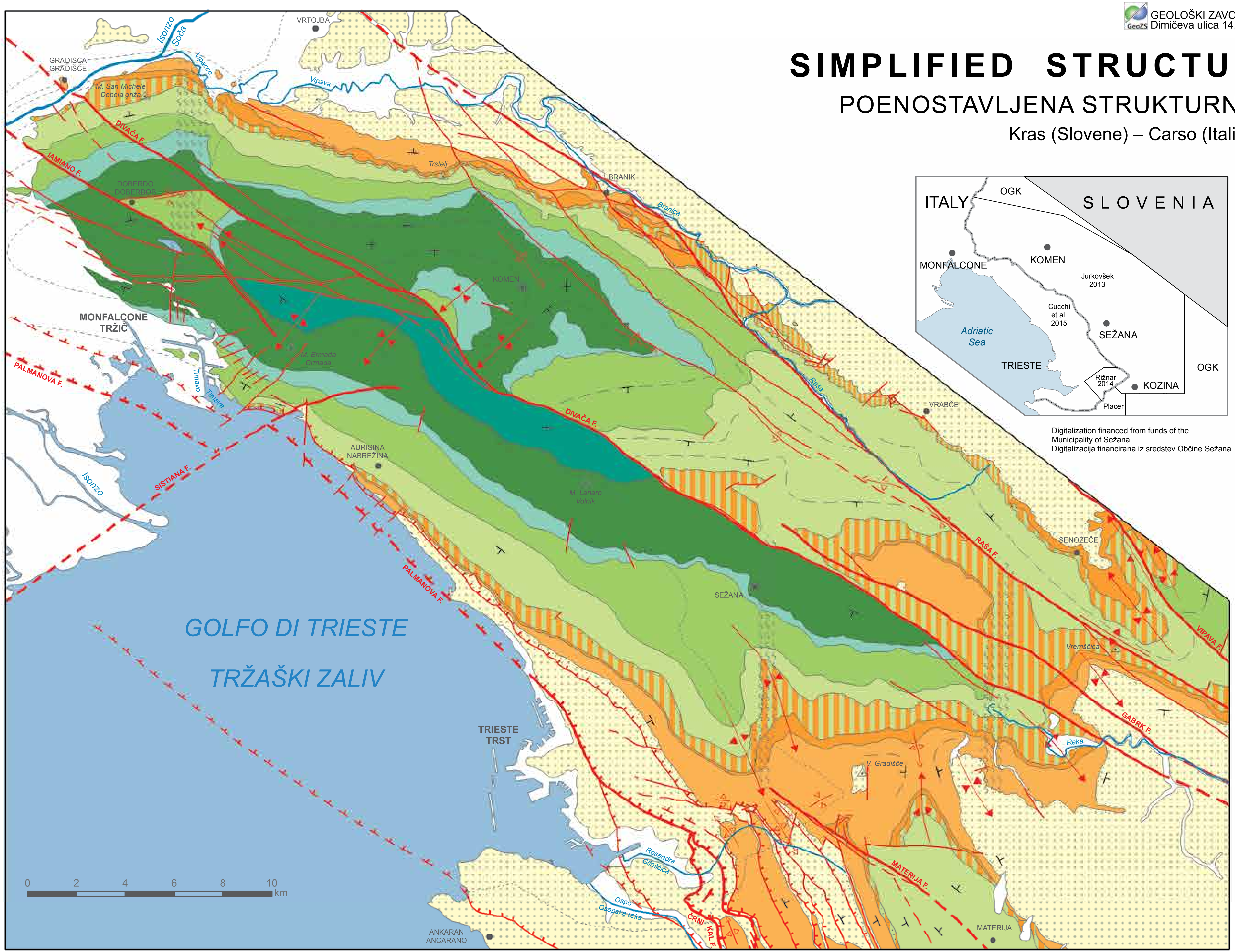
Geomorfologija Krasa je zasnovana kot razširjeni tolmač Poenostavljene strukturno-geološke karte Krasa. V njej bo tekla razprava o vplivu Istrskega potisnega območja na postorogeni razvoj Zunanjih Dinaridov in njihovo geomorfologijo. Iz tega bo izveden pogled na morfotektonsko rajonizacijo dinarskega krasa na prostoru Zunanjih Dinaridov ter pogled na morfogenetski razvoj ozemlja klasičnega krasa (med Tržaškim zalivom in Ljubljanskim barjem) z Istro in na Krasu. Slednji bo obdelan podrobneje. Razvoj reliefa bo prikazan kot sinergija litostratigrafije, strukture, eksogenih procesov in tektonike. V okviru slednje bomo skušali odgovoriti na kompleksno vprašanje vzrokov, ki so pripeljali do nastanka Istrskega potisnega območja.

GEOLOŠKI ZAVOD SLOVENIJE
Dimičeva ulica 14, 1000 Ljubljana

SIMPLIFIED STRUCTURAL MAP OF KRAS

POENOSTAVLJENA STRUKTURNO-GEOLOŠKA KARTA KRASA

Kras (Slovene) – Carso (Italian) = Geographical unit



Digitalization financed from funds of the Municipality of Sežana
Digitalizacija financirana iz sredstev Občine Sežana

Geological data after / Geološki podatki po:
Jurkovšek, B. et al. 1996: Formacijska geološka karta južnega dela Tržaško-komenske planote 1:50.000 = Geological Map of the Southern Part of the Trieste-Komen Plateau 1:50.000. Inštitut za geologijo, geotehniko in geofiziko, Ljubljana.
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OGK. Osnovna geološka katra SFRJ 1:100.000, listi Gorica, Trst, Postojna, Ilirska Bistrica = Basic Geological Map of Yugoslavia 1:100.000, sheets Gorica (Gorizia), Trst (Trieste), Postojna, Ilirska Bistrica. Savezni geološki zavod, Beograd.
Placer, L.: Field notes = Terenski zapisi. **Rižnar, I. 2014**: The flysch/carbonates junction in the S. Dorligo delle Valle / Dolina Municipality. **Busetti et al. 2010**: Meso-Cenozoic seismic stratigraphy and the tectonic setting of the Gulf of Trieste (northern Adriatic). **Carulli, G. B. 2011**: Structural model of the Trieste Gulf: A proposal.

Structure supplemented and edited by / Strukturo dopolnil in uskladil: **Ladislav PLACER**

STRATIGRAPHIC CHART after / STRATIGRAFSKA TABELA po: Jurkovšek, B. et al. 2013

AGE STAROST			FORMATION FORMACIJA			MAP KARTA
QUATERNARY KVARTAR			KV			
TERTIARY - TERCIAR	PALEOGENE PALEOGEN	EOCENE EOCEN	F	PP		
			ANA		KRAS GROUP KRAŠKA GRUPA	
		PALEOCENE PALEOCEN	TF	TF2		
				TF1		
			LIB			
CRETACEOUS - KREDA	UPPER CRETACEOUS ZGORNJA KREDA	MAASTRICHTIAN MAASTRICHTIJ				
		CAMPANIAN CAMPANIJ SANTONIAN SANTONIJ	LF			
		CONIACIAN CONIACIJ	SF			
		TURONIAN TURONIJ	RF			
		CENOMANIAN CENOMANIJ	PF			
	LOWER CRETACEOUS SPODNJA KREDA	ALBIAN ALBIJ				
		APTIAN APTIJ VALANGINIAN VALANGINIJ	BF			

DESCRIPTION OF FORMATIONS after / OPIS FORMACIJ po: Jurkovšek, B. 2008

KV: Quaternary deposit
Kvartarni nanos

F: FLYSCH. Alternation of marlstone, sandstone, breccia and conglomerate. Calcarenite intercalations and olistostromes. In the basis Transitional Beds (PP): breccia and basal marl
FLIŠ. Menjavanje laporovca, peščenjaka, breče in konglomerata. Vložki kalkarenita in olistostrome. V podlagi prehodne plasti (PP): breča in bazalni lapor

ANA: ALVEOLINID-NUMMULITID LIMESTONE. Bedded and massive limestone
ALVEOLINSKO-NUMULITNI APNENEC. Plastnati in masivni apnenec

TF: TRSTELJ FORMATION. Upper Trstelj Beds (TF2): Bedded calcarenite with foraminifers. Lower Trstelj Beds (TF1): Bedded, mainly miliolid limestone
TRSTELJSKA FORMACIJA. Zgornje trsteljske plasti (TF2): Plastnati kalkarenit s foraminiferami. Spodnje trsteljske plasti (TF1): Plastnati, pretežno miliolidni apnenec

LIB: LIBURNIA FORMATION. Bedded limestone, marly limestone and limestone breccia
LIBURNIJSKA FORMACIJA. Plastnati apnenec, laporasti apnenec in apnenčeva breča

LF: LIPICA FORMATION. Bedded and massive limestone with rudist biostromes and bioherms. Intercalations of platy and laminated Tomaj Limestone with chert
LIPIŠKA FORMACIJA. Plastnati in masivni apnenec z rudistnimi biostromami in biohermami. Vmes ploščasti in laminirani tomajski apnenec z rožencem

SF: SEŽANA FORMATION. Bedded limestone with rare rudist biostromes. Intercalations of bedded Pliskovica Limestone with chert and with pelagic microfossils and platy laminated Komen Limestone with chert. In the basis bedded limestone with oncoids and desiccation pores and thickly bedded to massive limestone with large amount of rudists
SEŽANSKA FORMACIJA. Plastnati apnenec z redkimi rudistnimi biostromami. Vmes plastnati pliskovški apnenec z rožencem in pelagičnimi mikrofosil ter ploščasti in laminirani komenski apnenec z rožencem. V podlagi plastnati apnenec z onkoidi in izsušitvenimi porami ter debeloplastnati do masivni apnenec z veliko količino rudistov

RF: REPEN FORMATION. Bedded limestone with chert and pelagic microfossils. Intercalations of platy and laminated Komen Limestone with chert and pelagic microfossils. In the basis massive, partly recrystallized Kopriva Limestone with displaced, locally broken and rounded rudist shells
REPENSKA FORMACIJA. Plastnati apnenec z rožencem in pelagičnimi mikrofosili. Vmes ploščasti in laminirani komenski apnenec z rožencem in pelagičnimi mikrofosili. V podlagi masivni in delno rekristalizirani koprivski apnenec s premeščenimi, mestoma zdrobljenimi in zaobljenimi lupinami rudistov

PF: POVIR FORMATION. Bedded, locally platy limestone with thicker dolomite intercalations and with rare intercalations of dolomitic breccia and limestone breccia. In upper part platy and laminated Komen Limestone with chert. In the basis emergence breccia
POVIRSKA FORMACIJA. Plastnati, lokalno ploščasti apnenec z debelejšimi vložki dolomita in redkimi vložki dolomitne breče ter apnenčeve breče. V zgornjem delu ploščasti in laminirani komenski apnenec z rožencem. V podlagi emerzijska breča

BF: BRJE FORMATION. Bedded limestone and dolomite with intercalations of dolomitic breccia and limestone breccia
BRSKA FORMACIJA. Plastnati apnenec in dolomit z vložki dolomitne in apnenčeve breče

LEGEND OF SYMBOLS / LEGENDA ZNAKOV

Normal boundary: visible, covered
Normalna meja: vidna, pokrita

Erosional boundary
Erozijska meja

Beds: horizontal, inclined, vertical
Plasti: vodoravne, poševne, navpične

Axis of syncline and anticline: hundreds of metres, of kilometres
Os sinklinale in antiklinale: stometrske, kilometrske

Axis of plunging syncline and anticline: hundreds of metres, of kilometres
Os toneče sinklinale in antiklinale: stometrske, kilometrske

Fault: visible, approximately defined
Prelom: viden, približno določen

Reverse fault
Reverzni prelom

Thrust fault: visible, approximately defined, hypothetical
Narivni prelom: viden, približno določen, domneven

Important fault: visible, approximately defined, hypothetical
Pomemben prelom: viden, približno določen, domneven

Geomorphologically significant joint-fault zone
Geomorfološko pomembna razpoklinsko-prelomna cona

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Jurkovšek, B. 2010: Geološka karta severnega dela Tržaško-komenske planote = Geological map of the Northern part of the Trieste-Komen Plateau (Slovenia) 1:25.000. Geološki zavod Slovenije, Ljubljana.

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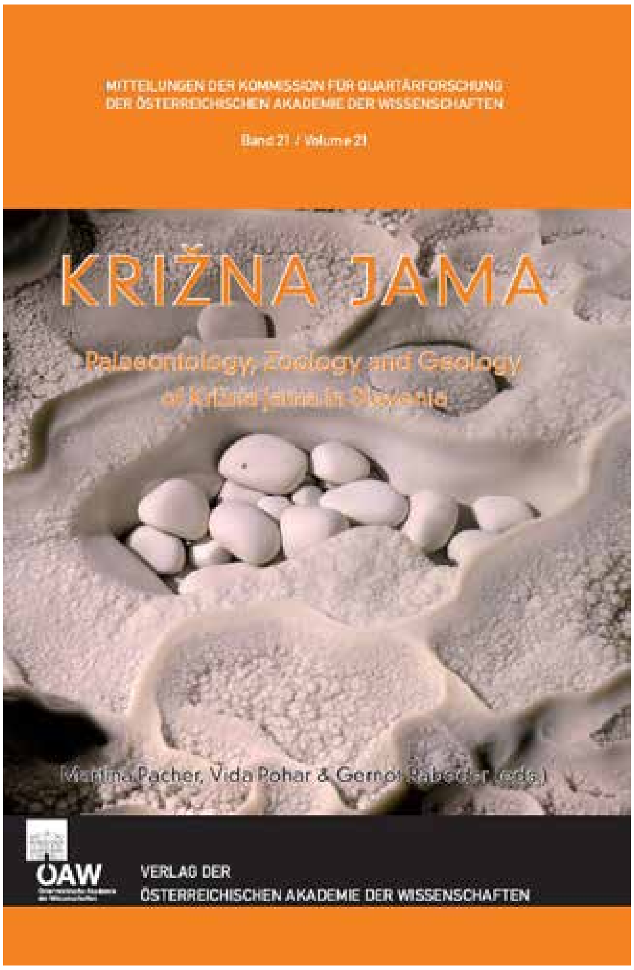
Nova knjiga

Uredniki / Editors: Martina PACHER, Vida POHAR & Gernot RABEDER, 2014:
Križna jama – Palaeontology, Zoology and Geology of Križna jama in Slovenia. Mitteilungen der Kommission für Quartärforschung, 21. Verlag der Österreichischen Akademie der Wissenschaften, Dunaj: 136 p.



Križna jama je ena izmed najbolj znanih in raziskanih kraških jam v Sloveniji. Poleg njene speleološke dediščine so njeni sedimenti ponekod polni kosti jamskih medvedov. Tako je na prelomu 21. stoletja gostila raziskovalce iz Avstrije in Slovenije, ki so izvedli izkopavanja v nekaterih suhih predelih jame. Rezultat teh izkopavanj je predstavljena monografija o Križni jami. Publikacija je nekakšna združitev zooloških, geoloških in paleontoloških spoznanj, čeprav uredniki niso izpustili niti speleoloških niti hidroloških tem. Sprehod po publikaciji nas vodi skozi zgodovino raziskovanja Križne jame in zadnjih izkopavanj ne izpusti pa niti pregleda današnje jamske favne. Glavnina monografije je namenjena predstavitvi izsledkov izkopavanj oziroma analizi ostankov jamskega medveda (vrsta *Ursus ingressus*). Obsežna publikacija je nastala v sodelovanju s štirinajstimi raziskovalci iz različnih evropskih raziskovalnih ustanov. Opremljena je s kvalitetnimi slikami in risbami, ki nazorno prikazujejo obravnavano temo.

Na žalost je publikacija nekako zaobšla zainteresirano slovensko publiko s tem, da je bila izdana v Avstriji. Vsekakor bi si podobne monografije zaslužile svojo (nekoliko bolj obširno) predstavitev tudi v Sloveniji, navsezadnje je to naša bogata paleontološka, geološka in speleološka dediščina, ki jo premore le redkokatera dežela.

Matija Križnar

Poročila

Letna skupščina Slovenskega združenja za geodezijo in geofiziko (SZGG)

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V Ljubljani je 29. januarja 2015 na Fakulteti za gradbeništvo in geodezijo bila letna skupščina Slovenskega združenja za geodezijo in geofiziko (SZGG). Po skupščini pa je sledilo dvajseto srečanje z naslovom »Raziskave s področja geodezije in geofizike – 2014«. SZGG je združenje, ki povezujejo zelo različne profile strokovnjakov, ki se ukvarjajo z raziskavami Zemlje, tudi geologov in omogoča zanimivo izmenjavo različnih znanj.

Na skupščini je najprej podal kratko poročilo o delu v preteklem letu predsednik združenja R. Čop, nato pa je sledilo poročilo tajnika združenja M. Kuharja. V SZGG deluje osem sekcij, katerih vodje so hkrati predstavniki Slovenije v mednarodnih združenjih, ki delujejo v Mednarodni zvezi za geodezijo in geofiziko (International Union of Geodesy and Geophysics – IUGG). Predstavniki posameznih sekcij so predstavili kratka poročila o delu v preteklem letu: B. Stopar (Sekcija za geodezijo), A. Gosar (Sekcija za seizmologijo in fiziko notranjosti Zemlje), R. Čop (Sekcija za geomagnetizem), G. Skok (Sekcija za meteorologijo), M. Ličer (Sekcija za oceanografijo), M. Kobold (Sekcija za hidrologijo) in P. Vreča (Sekcija za kriosfero). Predstavitve so dostopne na http://www.fgg.uni-lj.si/sugg/.

Na strokovnem srečanju je trinajst predavateljev predstavilo rezultate raziskovalnega dela. R. Čop je predstavil rezultate raziskav razelektritve v ionosferi, S. Šebela rezultate večletnih merjenj tektonskih mikro premikov v kraških jamah, M. Merih je predstavil vpliv podnebne spremenljivosti na rezultate verjetnostih analiz visokovodnih konic s primerom vodomerne postaje Litija na reki Savi, V. Hladnik pa rezultate objektne analize padavin iz satelitskih meritev, reanaliz ERA-Interim ter modela WRF na območju Evrope in Severnega Atlantika. Nadalje je M. Z. Božnar predstavila modeliranje difuznega sončnega obseva, M. Triglav Čekada aerofotografiranje in aerolasersko skeniranje Slovenije, P. Pavlovčič Prešeren problematiko geodetskih terenskih meritev z GNSS in simulacije vodostaja na podlagi DMR na delu Cerkniškega jezera, M. Petek določanje kazalnikov nizkih pretokov s prikazom na primeru vodomerne postaje Kokra I na reki Kokri, T. Podobnikar pa je govoril o geomorfometrični analizi vršajev planeta Marsa za uporabo na Zemlji. Sledila so še predavanja M. Pavška o snežnih plazovih in preventivi v Srednjih Karavankah, M. Kobold o analizi poplavnega dogodka v maju 2014 v Bosni in Hercegovini za porečje reke Bosne, D. Deželjina o prenosu merilnih podatkov iz geomagnetnega observatorija po obstoječem komunikacijskem omrežju ter A. Mihevca o eroziji arheološkega najdišča v Dabarski pečini pri Sanskem mostu ob poplavi maja 2014. Prispevki so objavljeni v zborniku del in so dostopni na http://www.fgg.uni-lj.si/sugg/.

V spomin mag. Francu Cimermanu

Na večer 1. junija 2015 nas je zapustil priznani mikropaleontolog in vsestranski geolog mag. Franc Cimerman. Rodil se je 22. novembra 1933 v Kranju. Po maturi na kranjski gimnaziji leta 1952 se je vpisal na študij geologije s paleontologijo na Prirodoslovno-matematični fakulteti Univerze v Ljubljani, kjer je leta 1958 diplomiral. Strokovno se je izpopolnjeval na Univerzi na Dunaju (1963) in na École pratique des hautes études v Parizu (1976). Leta 1984 je magistriral na Fakulteti za naravoslovje in tehnologijo Univerze v Ljubljani.

Že pred diplomo se je konec leta 1956 zaposlil v Prirodoslovnem muzeju Slovenije, kjer je najprej delal kot preparator in po diplomi kot kustos. Od leta 1979 je bil zaposlen kot raziskovalec na Paleontološkem inštitutu SAZU, pozneje preimenovanem v Paleontološki inštitut Ivana Rakovca ZRC SAZU. Leta 1997 se je upokojil, vendar je še naprej znanstveno delal in aktivno sodeloval pri inštitutskih projektih.

Osrednja tema njegovega raziskovanja so bile male bentoške foraminifere, s katerimi se je začel ukvarjati že v diplomski nalogi z naslovom *Razvoj oligocena pri Poljšici*. V šestdesetih letih je v okviru raziskovalne naloge *Terciar Posavskih gub*, ki jo je vodil prof. dr. Dušan Kuščer, preučeval oligocensko in pozneje miocensko foraminiferno favno. Glavnina rezultatov je žal ostala samo v rokopisnih poročilih, objavil pa je taksonomski študiji rodov *Pavonitina* in *Halkyardia*. Za rod *Pavonitina* in miocensko vrsto *Pavonitina styriaca* Schubert je ugotovil, da je začetni del biserialen in ne triserialen, kot je veljalo dotlej. Iz oligocenske morske gline pri Poljšici je leta 1969 opisal novo vrsto *Halkyardia maxima,* ki je značilen oligocenski mikrofosil in se že po velikosti razlikuje od starejše vrste *Halkyardia minima* (Liebus, 1911), opisane iz eocenskih laporjev v Dalmaciji. Da bi obe vrsti bolje spoznal, je na tipični lokaliteti pri vasi Smoković v Dalmaciji nabral primerjalni material in na preparatih iz izoliranih hišic prvi opisal notranjo zgradbo te foraminifere. Originalni Liebusov opis namreč podaja samo zunanjo obliko. Pozneje je preučeval še eocenske foraminifere Vipavske doline (rokopisna poročila) in paleogenske planktonske foraminifere v Goriških Brdih (objavljeno 1974).

V 70. letih se je na pobudo in v sodelovanju z dr. Katico Drobne lotil raziskovanja recentnih foraminifer Jadranskega morja. Najprej je študiral foraminiferno favno kvartarnih sedimentov iz vrtin v Sečovljah in v Koprskem zalivu. Pozneje se je posvetil vzorcem s sten podvodne vzpetine Kampanel pri Paklenih otokih južno od Hvara in material uporabil za magistrsko nalogo z naslovom *Recentne foraminifere iz morja zahodno od otoka Hvara (srednja Dalmacija) v luči aktuopaleontologije*. Nazadnje je obdelal foraminiferno favno iz sedimentov v Velikem jezeru na Mljetu. O raziskavah jadranskih foraminifer je poročal na kongresih CIESM (Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée) in na drugih znanstvenih sestankih. Več let je bil pri CIESM tudi član Komiteja za bentos. Sinteza vseh raziskav v tem sklopu je monografija *Mediterranean Foraminifera*, ki jo je leta 1991 objavil v soavtorstvu z dr. Martinom Langerjem, in se v svetu še danes uporablja kot temeljno delo za raziskave recentnih foraminifer.

V 90. letih in po upokojitvi se je ponovno več posvečal fosilnim foraminiferam. Sodeloval je v skupini, ki je pod vodstvom dr. Bogomirja Jelena preučevala Soteške plasti na tipičnem ozemlju med Socko in Dobrno. V teh plasteh je določil foraminiferno združbo, značilno za zgornji eocen. Tako je razrešil poldrugo stoletje ugibanj o starosti Soteških plasti, ki so jim vse od njihovega prvega poimenovanja leta 1858 pripisovali različne starosti, od eocena in oligocena do miocena. S temi raziskavami je tudi dokazal, da so klasične Soteške plasti starejše od podobnih razvojev v Zasavju, ki so oligocenske starosti in torej ne morejo pripadati Soteškim plastem, kamor so jih uvrščale prejšnje raziskave. Po letu 2000 je največ delal na projektih, ki jih je Paleontološki inštitut Ivana Rakovca izvajal v okviru varstva geološke naravne dediščine na gradbiščih avtocest. V poročila je prispeval poglavja o terciarni foraminiferni favni na odsekih Peračica–Podtabor, Vrba–Črnivec in Spodnja Senarska–Cogetinci. V zadnjem članku se je vrnil k oligocenskim foraminiferam iz svoje mladosti. S študijem notranje strukture mikrosferičnih in makrosferičnih oblik je pojasnil morfogenezo foraminifere *Halkyardia maxima* Cimerman, ki jo je opisal pred 46 leti. Izida članka ni dočakal.

V letih, ko je bil kustos v Prirodoslovnem muzeju, se je veliko ukvarjal s poljudnimi predstavitvami geologije. Razstavne zbirke je takrat preurejal iz starega načina postavitve, pri katerem je bil glavni poudarek na sistematiki, v modernejši, tedaj sodobni dioramski način. Pripravil je načrte za dioramsko predstavitev življenja na Zemlji od paleozoika do pleistocena. V naslednjih letih je postavil dve obsežnejši občasni razstavi: *Ledena doba* s tiskanim vodnikom (1961) in *Okamnine, priče izumrlega življenja*, prav tako s tiskanim vodnikom (1971). Takrat in tudi pozneje je zavzeto pisal poljudne paleontološke članke, največ v revijo Proteus. Na poljudne prispevke je nasploh gledal kot na pomembno dolžnost stroke, bil pa je neprizanesljiv kritik pretirano poenostavljenih razlag, ki negeologe zavajajo, namesto da bi jim približale logiko geološkega razmišljanja.

Od nekdaj se je zanimal tudi za zgodovino geologije. Bil je izvrsten poznavalec življenja in dela geologov, ki so slovensko ozemlje raziskovali v 19. in na začetku 20. stoletja. Kot pisec njihovih biografij je v 80. letih sodeloval pri Enciklopediji Slovenije. Od leta 2011, že kot upokojenec, je bil področni urednik za naravoslovje pri Novem Slovenskem biografskem leksikonu.

V zgodovini geologije bo Franc Cimerman zapisan kot odličen raziskovalec foraminifer z izostrenim občutkom za taksonomske detajle. Enako pomembni so rezultati njegovih biostratigrafskih raziskav, s katerimi je odločilno prispeval k natančnejši stratigrafski razčlenitvi terciarja v Sloveniji.

Vsi, ki smo Francija poznali osebno, se ga bomo spominjali po veliki ljubezni do geologije in široki splošni razgledanosti. Odlikovala sta ga iskriva duhovitost in spoštljivo prijateljstvo do vseh ljudi, s katerimi se je v življenju srečeval. Še dolga leta po upokojitvi, vse do lanske jeseni, ko je hudo zbolel, je redno prihajal na inštitut. Najbližji sodelavci smo ga cenili zaradi bogatega geološkega znanja in izkušenj, pogosto pa smo se nanj obračali tudi z manj strokovnimi vprašanji. Bil je neprecenljiv svetovalec pri pisanju poljudnih člankov in za vsak tehnični problem je vedno našel domiselno praktično rešitev. Z inteligentnim spontanim humorjem in igralskim talentom je znal ustvariti sproščeno razpoloženje in poskrbeti za prijazno delovno okolje. Izgubili smo vrhunskega strokovnjaka, plemenitega človeka in dragega prijatelja. Zelo ga bomo pogrešali.

Špela Goričan

Mag. Franc Cimerman: bibliografija 1961–2015

Seznam obsega objavljena znanstvena in strokovna dela. Povzetki predavanj, poljudni članki in prispevki v enciklopedijah v pregledu niso zajeti. Popoln seznam bibliografskih enot je dostopen na spletnih straneh v sistemu COBISS.

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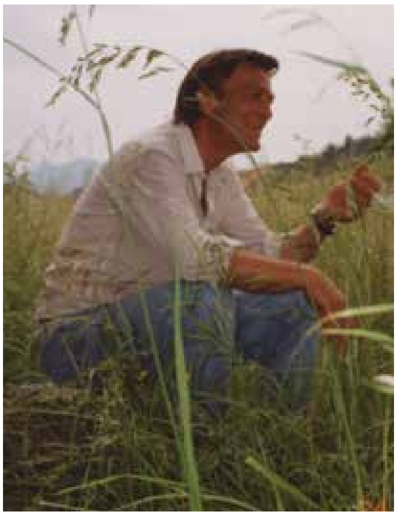
V spomin Igorju Špacapanu



Dne 17. marca 2015 smo se na pokopališču v Šmarju – Sap z globoko žalostjo v srcih poslovili od izjemnega človeka, Igorja Špacapana. Igor ni bil samo izjemno dober strokovnjak s področja inženirske geologije, bil je zvest soprog in skrben oče trem otrokom ter prijazen dedek številnim vnukom.

Igor Špacapan se je rodil 27. 8. 1947 v Postojni, mladost pa je preživljal v Vipavski dolini. Po zaključku osnovne šole, ki jo je obiskoval v Ajdovščini, je z vpisom na gimnazijo Jurija Vege v Idriji nakazal, da mu je naravoslovje zelo pri srcu. Razumljivo je, da je svoje izobraževanje nadaljeval na Fakulteti za naravoslovje in tehnologijo. Odločil se je za študij geologije. Po zaključku študija in opravljenem služenju vojaškega roka se je leta 1976 zaposlil na Zavodu za raziskavo materialov in konstrukcij, kjer je služboval vse do upokojitve konec leta 2014. V inženirsko geologijo ga je v prvih letih službovanja vpeljal Anton Grimšičar, ki je bil v tistem obdobju vodilni inženirski geolog v Sloveniji.

Prvi izzivi so bili geološki pregledi gradbenih jam za gradbene konstrukcije na območju Velenja. Na ta način je spoznal, kako sta geološka in gradbena stroka povezani in prepleteni. Ta dognanja je koristno uporabil pri izdelavi geološko geotehničnih podlog za projekte številnih infrastrukturnih objektov. Strokovni razcvet je dosegel v obdobju Nacionalnega programa izgradnje slovenskih avtocest (NPIAC), ki se je pričel leta 1993. Brez pretiravanja lahko rečemo, da je bil Igor Špacapan glavni tvorec omenjenega nacionalnega projekta, saj je od 514 km avtocest geološko in geotehnično obdelal več kot polovico odsekov. Kronološko je odsek HC Razdrto – Vipava eden prvih projektov, za katere je pripravil geotehnične podloge. Sledil je odsek AC Arja vas – Vransko, nato dograditev AC Arja vas – Celje – Dramlje – Sl. Konjice – Sl. Bistrica – Fram. Po štajerski »etapi« je sledila Dolenjska, kjer je izdelal geološko geotehnična poročila za vse projektne nivoje odsekov Trebnje – Hrastje, Korenitka – Pluska, Novo mesto – Kronovo in Kronovo – Dobruška vas. V letu 2004 se je ponovno pričelo načrtovanje avtocest na Štajerskem in v Prekmurju. Podpisan je pod geološko geotehniško dokumentacijo odsekov sp. Senarska – Cogetinci - Vučja vas – Beltinci in Beltinci – Pince. V zadnjem obdobju je sodeloval pri projektiranju AC odseka Slivnica – Draženci. Na projektih zadnjega AC odseka v okviru NPIAC Draženci – Gruškovje, ki se bo pričel graditi v letošnjem letu, pa je Špacapan podpisan kot odgovorni projektant geotehnike. Bil je glavni in odgovorni geolog in geotehnik pri načrtovanju tretje razvojne osi in sicer tako na severu (Sl. Gradec – Dravograd) kakor na jugu (Novo mesto – Metlika – Črnomelj). Poleg aktivne vloge v NPIAC je igral pomembno vlogo pri načrtovanju železnic in sicer pri projektu drugega tira od Divače do Kopra in od Maribora do Šentilja, izgradnji izven-nivojskih križanj železnice in ceste na odseku Pragersko – Hodoš, idejnih zasnovah za izgradnjo železniškega Ljubljanskega vozlišča in obnovi železniške proge Beltinci – Lendava. Nabor izdelanih geološko geotehničnih poročil kolega Špacapana je še bistveno daljši in je shranjen v arhivu Gradbenega inštituta ZRMK. V tem zapisu so namreč navedeni le glavni projekti infrastrukturnih objektov.

Ne glede na izjemno bibliografijo strokovne dokumentacije je bilo za Igorja Špacapana značilno, da so vsi izdelani dokumenti enako kvalitetni ne glede na pomembnost in odmevnost posameznega projekta. Vsa poročila so vsebinsko in grafično vrhunsko obdelana. Poleg preglednega in natančnega opisa obravnavanega prostora so bile jasno navedene vse raziskave, ki so bile vedno racionalne ne glede na naročnika. Obdelava pridobljenih podatkov je bila brezhibna in je projektantom podala vhodne podatke za izdelavo kvalitetnega projekta. Tega so se projektanti dobro zavedali, zato je bila njihova želja po sodelovanju prav s kolegom Špacapanom pogosto izražena. O kvaliteti njegovih izdelkov nazorno pričajo poročila recenzentov njegovih poročil, ki običajno niso imeli nikakršnih pripomb in so jih dajali za vzor ostalim geologom in geotehnikom.

Čeravno kolega Špacapan v svojem aktivnem obdobju ni uporabljal osebnega računalnika, je sledil računalniškim programom s področja geotehnike, ki ob primernih vhodnih podatkih omogočajo hitre izračune in preveritve stabilnosti in nosilnosti. Delo je zaupal svojim mlajšim sodelavcem pri tem, da je na »svoj način« redno kontroliral ustreznost dobljenih rezultatov. Uporabljal je rezultate in nova znanja s področja terenskih in laboratorijskih raziskav, tehnološke možnosti za grafično in tekstualno pripravo končnega poročila, bistveno pa je bilo njegovo inženirsko geološko znanje in sposobnost, da je vse to združil v končna poročila, ki so berljiva, natančna, razumljiva in vzor tistim, ki bodo na tem področju delali naprej.

Vsi, ki smo bili z Igorjem v poslovnih kontaktih, smo prej ali slej ugotovili da je njegova predanost delu neizmerna. Ob velikih obsežnih nalogah pa je bil sposoben problem, ki se je pojavil na terenu med gradnjo, hitro razumeti in kar takoj najti enostavno inženirsko rešitev. V obdobju zadnjih 10 let je nekatere faze dela zaupal svojim sodelavcem, ogromen delež pa je vedno opravil sam. Od sodelavcev je prav tako pričakoval doslednost in predanost delu, po dobro opravljenem delu pa je z njimi delil tudi zadovoljstvo ob pohvalah.

S sodelavci je v pisarni in na terenu v zadnjih letih preživel verjetno več časa kot med domačimi. Pa vendar bi lahko rekli, da mu je veselje prinašalo uspešno delo in občasni kratki dopusti ali pa drobne družinske obveznosti, od nakupov pa do občasnih prevozov vnukov, ki jim je z veseljem prilagodil svoj res dolg delovni dan.

Z odhodom kolega Igorja Špacapana bo v slovenski inženirski geologiji in gradbeni geotehniki zazevala velika praznina. Nam, ki smo ga imeli privilegij poznati, bo ostal lep spomin na izjemnega človeka. Mlajšim generacijam pa bodo ostali številni vsebinsko bogati in tehnično natančni dokumenti kot primer popolnosti. Na ta način bo Igor Špacapan za vedno ostal med nami.

Andrej Ločniškar
Duška Brožič
Matjaž Kromar

Navodila avtorjem

GEOLOGIJA objavlja znanstvene in strokovne članke s področja geologije in sorodnih ved. Revija od leta 2000 izhaja dvakrat letno. Članke recenzirajo domači in tuji strokovnjaki z obravnavanega področja. Ob oddaji člankov avtorji predlagajo **tri recenzente**, vendar pa si uredništvo pridržuje pravico do izbire recenzentov po lastni presoji. Avtorji morajo članek popraviti v skladu z recenzentskimi pripombami ali utemeljiti zakaj se z njimi ne strinjajo.

Avtorstvo: Za izvirnost podatkov, predvsem pa mnenj, idej, sklepov in citirano literaturo so odgovorni avtorji. Z objavo v GEOLOGIJI se tudi obvežejo, da ne bodo drugje objavili prispevka z isto vsebino.

Jezik: Članki naj bodo napisani v angleškem, izjemoma v slovenskem jeziku, vsi pa morajo imeti slovenski in angleški izvleček. Za prevod poskrbijo avtorji prispevkov sami.

Vrste prispevkov:

Izvirni znanstveni članek
Izvirni znanstveni članek je prva objava originalnih raziskovalnih rezultatov v takšni obliki, da se raziskava lahko ponovi, ugotovitve pa preverijo. Praviloma je organiziran po shemi IMRAD (**I**ntroduction, **M**ethods, **R**esults, **A**nd **D**iscussion).

Pregledni znanstveni članek
Pregledni znanstveni članek je pregled najnovejših del o določenem predmetnem področju, del posameznega raziskovalca ali skupine raziskovalcev z namenom povzemati, analizirati, evalvirati ali sintetizirati informacije, ki so že bile publicirane. Prinaša nove sinteze, ki vključujejo tudi rezultate lastnega raziskovanja avtorja.

Strokovni članek
Strokovni članek je predstavitev že znanega, s poudarkom na uporabnosti rezultatov izvirnih raziskav in širjenju znanja.

Diskusija in polemika
Prispevek, v katerem avtor ocenjuje ali dokazuje pravilnost nekega dela, objavljenega v Geologiji, ali z avtorjem strokovno polemizira.

Recenzija, prikaz knjige
Prispevek, v katerem avtor predstavlja vsebino nove knjige.

Oblika prispevka: Besedilo pripravite v urejevalniku Microsoft Word. Prispevki naj praviloma ne bodo daljši od 20 strani formata A4, v kar so vštete tudi slike, tabele in table. Le v izjemnih primerih je možno, ob predhodnem dogovoru z uredništvom, tiskati tudi daljše prispevke.

Članek oddajte uredništvu vključno z vsemi slikami, tabelami in tablami v elektronski obliki po naslednjem sistemu:
- *Naslov članka (do 12 besed)*
- *Avtorji (ime in priimek, naslov, e-mail naslov)*
- *Ključne besede (do 7 besed)*
- *Izvleček (do 300 besed)*
- *Besedilo*
- *Literatura*
- *Podnaslovi k slikam in tabelam*
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Citiranje: V literaturi naj avtorji prispevkov praviloma upoštevajo le tiskane vire. Poročila in rokopise naj navajajo le v izjemnih primerih, z navedbo kje so shranjeni. V seznamu literature naj bodo navedena samo v članku omenjena dela. Citirana dela, ki imajo DOI identifikator, morajo imeti ta identifikator izpisan na koncu citata. Za citiranje revije uporabljamo standardno okrajšavo naslova revije. Med besedilom prispevka citirajte samo avtorjev priimek, v oklepaju pa navajajte letnico izida navedenega dela in po potrebi tudi stran. Če navajate delo dveh avtorjev, izpišite med tekstom prispevka oba priimka (npr. Pleničar & Buser, 1967), pri treh ali več avtorjih pa napišite samo prvo ime in dodajte et al. z letnico (npr. Mlakar et al., 1992). Citiranje virov z medmrežja v primeru, kjer avtor ni poznan, zapišemo (Internet 1). V seznamu literaturo navajajte po abecednem redu avtorjev.

Imena fosilov (rod in vrsta) naj bodo napisana poševno, imena višjih taksonomskih enot (družina, razred, itn.) pa normalno. Imena avtorjev taksonov naj bodo prav tako napisana normalno, npr. *Clypeaster pyramidalis* Michelin, *Galeanella tollmanni* (Kristan), Echinoidea.

Primeri citiranja članka:

Mali, N., Urbanc, J. & Leis, A. 2007: Tracing of water movement through the unsaturated zone of a coarse gravel aquifer by means of dye and deuterated water. Environ. geol., 51/8: 1401–1412, doi:10.1007/s00254-006-0437-4.

Pleničar, M. 1993: *Apricardia pachiniana* Sirna from lower part of Liburnian beds at Divača (Triest-Komen Plateau). Geologija, 35: 65–68.

Primer citirane knjige:

Flügel, E. 2004: Mikrofacies of Carbonate Rocks. Springer Verlag, Berlin: 976 p.

Jurkovšek, B., Toman, M., Ogorelec, B., Šribar, L., Drobne, K., Poljak, M. & Šribar, Lj. 1996: Formacijska geološka karta južnega dela Tržaško-komenske planote – Kredne in paleogenske kamnine 1: 50.000 = Geological map of the southern part of the Trieste-Komen plateau – Cretaceous and Paleogene carbonate rocks. Geološki zavod Slovenije, Ljubljana: 143 p., incl. Pls. 23, 1 geol. map.

Primer citiranja poglavja iz knjige:

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In an original scientific paper, original research results are published for the first time and in such a form that the research can be repeated and the results checked. It should be organised according to the IMRAD scheme (**I**ntroduction, **M**ethods, **R**esults, **A**nd **D**iscussion).

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In a review scientific paper the newest published works on specific research field or works of a single researcher or a group of researchers are presented in order to summarise, analyse, evaluate or synthesise previously published information. However, it should contain new information and/or new interpretations.

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