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Cover page: Example of a landslide triggered in August 2023 in the Laniše area, Kamnik municipality (photo: Andrej Novak).

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Upper Triassic–to Lower Cretaceous Slovenian Basin successions in the northern margin of the Sava Folds

Zgornjetriasno do spodnjekredno zaporedje Slovenskega bazena iz severnega roba Posavskih gub

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Ključne besede: Južne Alpe, Posavske gube, Slovenski bazen, Ponikvanska breča, stratigrafija, foraminifere

Abstract

The evolution of the Slovenian Basin southern margin is currently interpreted based on the successions outcropping in the surroundings of Škofja Loka, on the Ponikve Plateau and in the foothills of the Julian Alps in western Slovenia, as well as from the valley of the Mirna River in south-eastern Slovenia. However, no extensive research on this paleogeographic unit has been carried out in the northern part of the Sava Folds region. Recent field observations permitted the recognition of Upper Triassic to lowermost Cretaceous successions of the Slovenian Basin, including the recently described Middle Jurassic Ponikve Breccia Member of the Tolmin Formation. Based on reambulation-type geological mapping, macroscopic facies observations supported by microfacies analysis and biostratigraphy, three stratigraphic columns were constructed showcasing Slovenian Basin formations on the northern flank of the Trojane Anticline (Sava Folds region). These newly described successions encompass Upper Triassic (Bača Dolomite Formation) and Jurassic–lowermost Cretaceous resedimented limestones and pelagic formations, while the attribution of the Pseudozilian Formation is complex. Based on facies characteristics these successions are similar to those preserved in the Podmelec Nappe (lowermost thrust unit of the Tolmin Nappe) in western Slovenia. The connection between the western and the eastern Slovenian Basin during the Late Triassic-Early Cretaceous interval could be thus recognised.

Izvleček

Razvoj južnega obrobja Slovenskega bazena je trenutno poznan na podlagi zaporedij, ki izdanjajo v okolici okrog Škofje Loke, na Ponikvanski planoti in iz predgorja Julijskih Alp v zahodni Sloveniji ter iz doline reke Mirne v jugovzhodni Sloveniji. Nasprotno do sedaj še ni bilo celostne stratigrafske študije globljemorskih zaporedij iz severnega dela Posavskih gub. Tekom nedavnih terenskih raziskav smo na tem območju prepoznali zgornjetriasno do spodnje kredno zaporedje Slovenskega bazena, ki vsebuje tudi nedavno opisan člen Ponikvanske breče Tolminske formacije. Na podlagi reambulacijskega geološkega kartiranja, makroskopskega opazovanja faciesov, katerega smo podprli z mikroskopsko analizo in biostratigrafijo, smo izdelali tri stratigrafske stolpce, ki prikazujejo zaporedje Slovenskega bazena vzdolž severnih obronkov Posavskih gub (Trojanske antiklinale). Novo prepoznano zaporedje vključuje zgornjetriasni Baški dolomit in jurske do spodnjekredne presedimentirane apnence in pelagične sedimente. Faciesne značilnosti kažejo, da ta del Posavskih gub pripada vzhodno nadaljevanje Podmelškega pokrova (spodnje podenote Tolminskega pokrova). S tem je prepoznana povezava med zahodnimi in vzhodnimi zaporedji Slovenskega bazena.

Introduction

The transitional zone between the Dinarides and the Southern Alps is characterized by a deep marine succession of the Slovenian Basin (SB) (Placer, 1998a, 2008). It was a large-scale inter-platform basin between the Dinaric (Adriatic, Friuli) and Julian Carbonate Platforms that opened during the Middle Triassic and lasted until the end of the Cretaceous (e.g., Buser, 1989, 1996; Rožič, 2006). SB is well-studied in western Slovenia and this part is also known as the Tolmin Basin (Cousin, 1981; Rožič, 2009). Today the SB successions compose the Tolmin Nappe between variable Dinaric nappe units and the Julian Nappes (Buser, 1989; Placer, 1998a; Goričan et al., 2012a, 2018).

Despite the long research history of the classic occurrences of the SB in the West, very little research has been done in eastern Slovenia within the Posavje Hills, which is the Sava Folds region in structural term. On the Basic Geological Map of Yugoslavia, Jurassic formations were recognised only in the east but were not subdivided in detail (Buser, 1978). With reambulation of these maps, (Buser, 2010) assigned this succession to the Biancone Limestone Formation. He also recognized the Bača Dolomite Formation in the northern part of the Sava Folds east of Ljubljana. The possibility of evidence for other SB lithostratigraphic units rose when, recently, within the Middle Jurassic Tolmin Formation of the SB succession a new member, known as the Ponikve Breccia Member, has been described (Rožič et al., 2022). This member is typical for the southernmost SB outcrops characterized by stratigraphic gap in successions. The Ponikve Breccia is up to 90 m thick, coarse limestone breccia that documents evidence of Jurassic platform back-stepping and erosion (Rožič et al., 2019, 2022). The Ponikve Breccia was investigated in western Slovenia between Tolmin and Škofja Loka, whereas in the east it was logged solely in the Mirna Valley (Rožič et al., 2019, 2022). The northern part of the Sava Folds represents another potential area for the existence of the SB successions, which would represent the much-needed connection between the eastern and the western outcrops of the SB. Our work aims to fill in these missing gaps by providing new data and successions of SB from three different parts of the northern Sava Folds; from outcrops in the Tuhinj Valley, the Flinskovo Ridge with the eastern slope of the Čemšeniška Planina, and the Mt. Mrzlica northern and northeastern ridges. In this paper, we introduce in detail those locations where the SB succession, including the Krikov Formation and the Ponikve Breccia Member of the Tolmin Formation, has been identified.

Geological setting

The Trojane Anticline in the central Sava Folds is a stratigraphically and structurally complex area. According to Placer (1998b), it consists of three thrust sheets, these were later folded from the Late Miocene to Pliocene. The folding took place as a result of N-S compression between the Idrija and the Mid-Hungarian tectonic zones creating the Sava compressional wedge (Vrabec & Fodor 2006). The research areas (Fig. 1a, b, c/logs 10, 11, 12) are on the southern edge of the Alpine nappe system, which thrust over the Dinarides probably in the Miocene. Locally only klippen contain the SB sediments (Placer, 1998a, 2008). Basic geological maps of Yugoslavia 1:100,000 (Premru, 1983) have marked only the Triassic and Cretaceous formations in the Tuhinj and Čemšeniška Planina areas. Buser (1978) marked merged Jurassic rocks at Mt. Mrzlica within the studied area. Part of the Upper Triassic and Cretaceous rocks were later re-evaluated by Buser (2010) as the Bača Dolomite Formation, Biancone Limestone and Aptian-Cenomanian flysch, i.e. the Lower Flyschoid Formation of Cousin (1981) and Rožič (2005). These formations could be part of the southernmost SB sedimentary succession, which is the most complete at Ponikve Klippe near Tolmin and Škofja Loka (Rožič et al., 2019).

Methods

Classic field mapping was executed in detail with the aid of the digital mapping software of Field Move (Petroleum Experts Ltd.) implemented on iPad. High-resolution pictures were taken by Panasonic DMC-FZ200. Measured data were processed in MOVE (Structural Geology Modelling Software of Petroleum Experts Ltd.) in which cross-sections were also prepared. The basis of the recognition of the formations was the field observation of the rocks involving their tectonic position, structure, composition, texture, and fossil content, their comparison to the explanatory notes of the existing 1:100,000 maps of Yugoslavia and previously described lithostratigraphic units from the SB (e.g., Gale, 2010; Rožič et al., 2019, 2022). Digital terrain data were derived using the dataset of the Ministry of the Environment and Spatial Planning, Slovenian Environment Agency.

Altogether 76 rock samples were collected, cut and polished. For the identification of the formation, detailed microfacies and microfossil analyses was carried out by Ágnes Görög on 15 thin sections 5 × 5 cm in size. For the microfacies analysis, we followed Dunham (1962), Folk (1962) and Lokier and Junaibi (2016). The images with small magnification were made with Zeiss Axioskop 40 micro-

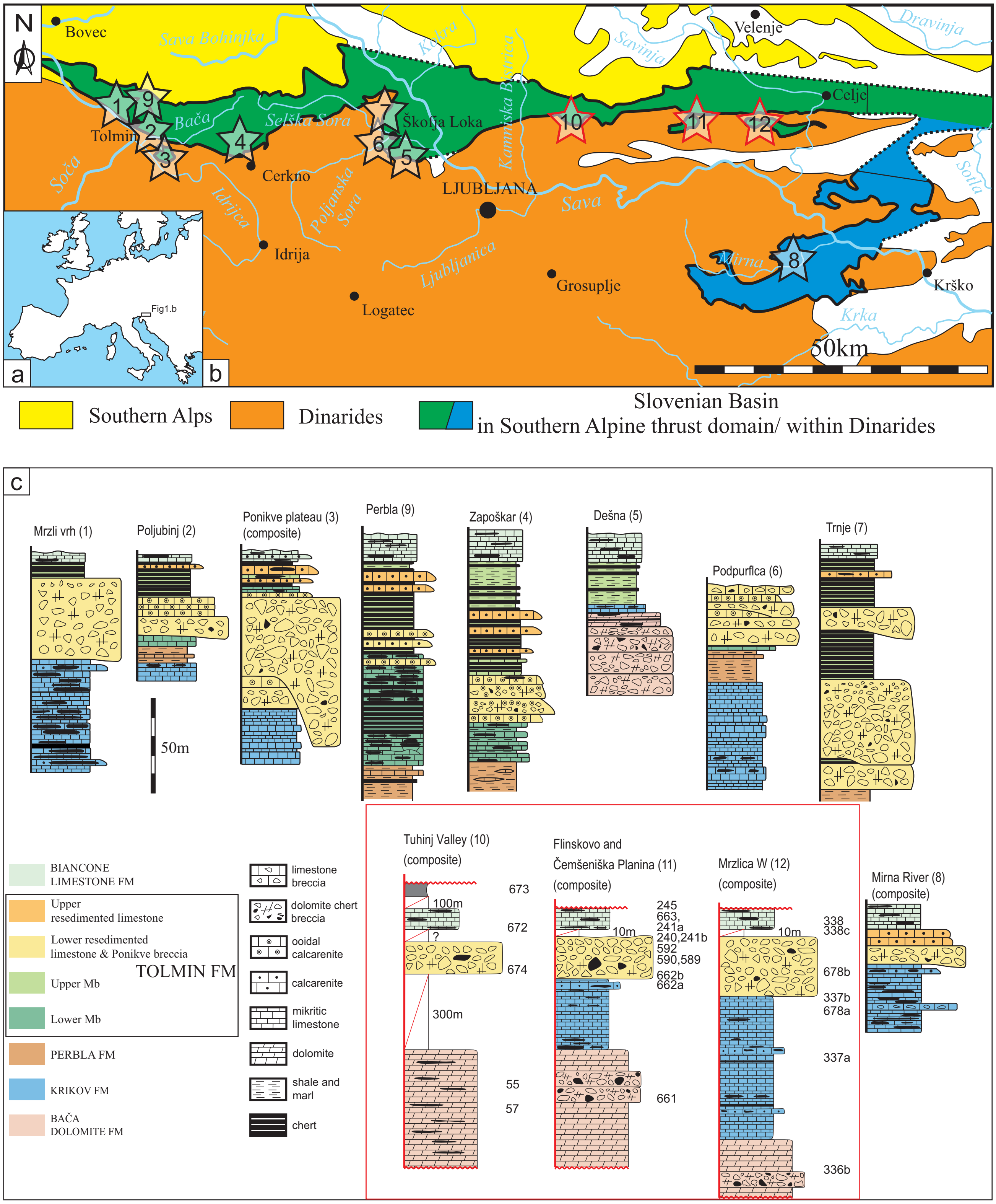

Fig. 1. Location and lithology of studied stratigraphic successions of the Slovenian Basin (SB): a – location of the research area in Europe, b – the black stars mark the sections 1–9 of SB units previously studied by Rožič et al., 2022), while red stars indicate the recently investigated sections; c) Log of the sections, sections 1–9 after (Rožič et al., 2022), sections 10-12 discussed in this work. Thickness of formations was calculated from outcrop distance, elevation differences and bedding dip. In the Tuhinj valley section the formation thicknesses are uncertain due to discontinuous outcrops. The total thickness of the starting and finishing formations could be larger and truncated, indicated by red undulating lines.

scope with AxioCam MRc5 (Zeiss) camera by 1 × zoom at the Department of Geology of Eötvös Loránd University, Budapest. Image composite editor was used to create large composite images. The photomicrographs of the microfacies and the microfossils were taken with a Canon EOS 2000D camera mounted on Olympus BH2 –BHS microscope, at the Hantken Foundation. An abbreviated list of the fossil taxa with their stratigraphic distribution and ecological preferences is given in the Appendix.

Short description of the location of studied successions

Within the studied area three composite geological columns were established from scattered outcrops in the Tuhinj Valley; from the Flinskovo ridge and the eastern slope of the Čemšeniška Planina and from two sections on the Mt. Mrzlica (Fig. 1c). Where the density of the outcrops allowed three detailed geological maps were constructed. The maps were compiled at the eastern side of Čemšeniška Planina, including the Flinskovo ridge (Fig. 1c/log 11, Fig. 2c), while two maps were compiled about the north-western and north-eastern flanks of Mt. Mrzlica (map Fig. 2a, b and Fig. 1c/log 12) and about the north-eastern ridge. Generally, at each area, the bedding is dipping to the north. Previous maps (Premru, 1983; Buser, 1978, 2010) already showed the presence of the Bača Dolomite Formation and the Biancone Formation; however, other members of the SB were unknown.

The observations from the Tuhinj area did not yield a continuous succession (Fig. 1c/log 10). The composite stratigraphic column incorporates outcrops in several north-south directed side valleys and roads near the villages Vaseno and Buč across the Tuhinj Valley. Scarce outcrops were insufficient to create a detailed map. The Bača Dolomite Formation crops out in several road cuts between Vaseno and Velika Lašna (outcrop 057: 46°12’40.0444” N; 14°41’56.3451” E), and observations were also made at a large quarry west of Špitalič (outcrop 055: 46°12’50.7312” N; 14°48’25.4728” E). The Ponikve Breccia can be seen in a road cut on the way from Buč to Vaseno (outcrop 674: 46°13’01.3121” N; 14°42’45.4706” E). The Biancone Limestone was observed at a small agricultural road near Buč twigging to north from the main road (site 672: 46°13’02.7672” N; 14°43’08.3765” E). Finally, the Lower Flyschoid Formation is exposed at the southern boundary of the Hruševka village: (site 673: 46°13’24.8869” N; 14°43’13.8492” E).

The succession Flinskovo is composed from observations along the eastern slope of the Čemšeniška Planina and from the Flinskovo ridge west of Mt. Krvavica (Fig. 1c/log 11). The geological cross section and map (Fig. 2c) were first presented by Scherman et al. (2022).

The succession Mrzlica is located on the northern slope of Mt. Mrzlica (Fig. 1c/log 12). It is compiled from the observations made on the north-western (Fig. 2a) and the north-eastern ridge of Mt. Mrzlica (Fig. 2b).

Lithostratigraphic units oldest than latest Triassic

Although this study is about the Upper Triassic to Lower Cretaceous formations partially newly discovered from the area three other formations were also mapped and are worth briefly mentioning. These are the Werfen Formation, The Schlern Formation and the Pseudozilian Formation.

Werfen Formation

The uppermost Permian – Lower Triassic Werfen Formation consist of limestone or dolomite beds with marl and marly or oolitic limestone intercalations. Based on its relatively rich fossil content it was deposited in a shallow (subtidal – supratidal) marine environment. It is known from the Southern Alps in Italy, the Karavanke Mountains in Austria, the Julian Alps, Kamnik Alps and the Sava Folds in Slovenia (e.g., Broglio Loriga et al., 1983; Ramovš et al., 2001; Krainer & Vachard, 2011; Celarc et al., 2012).

Schlern Formation

The Schlern formation is a Ladinian platform carbonate described from the Southern Alps in Italy. Carbonate platform progradation is characteristic of this formation (Fois, 1982). It is described from the Julian and Kamnik Alps in Slovenia (e.g., Celarc et al., 2012).

Pseudozilian Formation

The Pseudozilian Formation is a Ladinian sedimentary formation. It consists of shale, greywackes, sandstones and resedimented volcanilastics, first described by Teller (1898) from the central Slovenia. According to Dozet and Buser (2009), it marks the opening of the Slovenian Basin during the Ladinian.

Studied lithostratigraphic units of the Slovenian Basin successions

Based on our research, field observation and review of the literature four formations of the SB have been identified with certainty. These are the following the Bača Dolomite Formation, the Krikov Formation, the Ponikve Breccia Member of the Tolmin Formation and the Biancone Formation. In addition to these two other formations are possibly present, namely the Upper Member of the Tolmin Formation and the Lower Flischoid Formation. However, further elaborative research is needed to confirm them for sure.

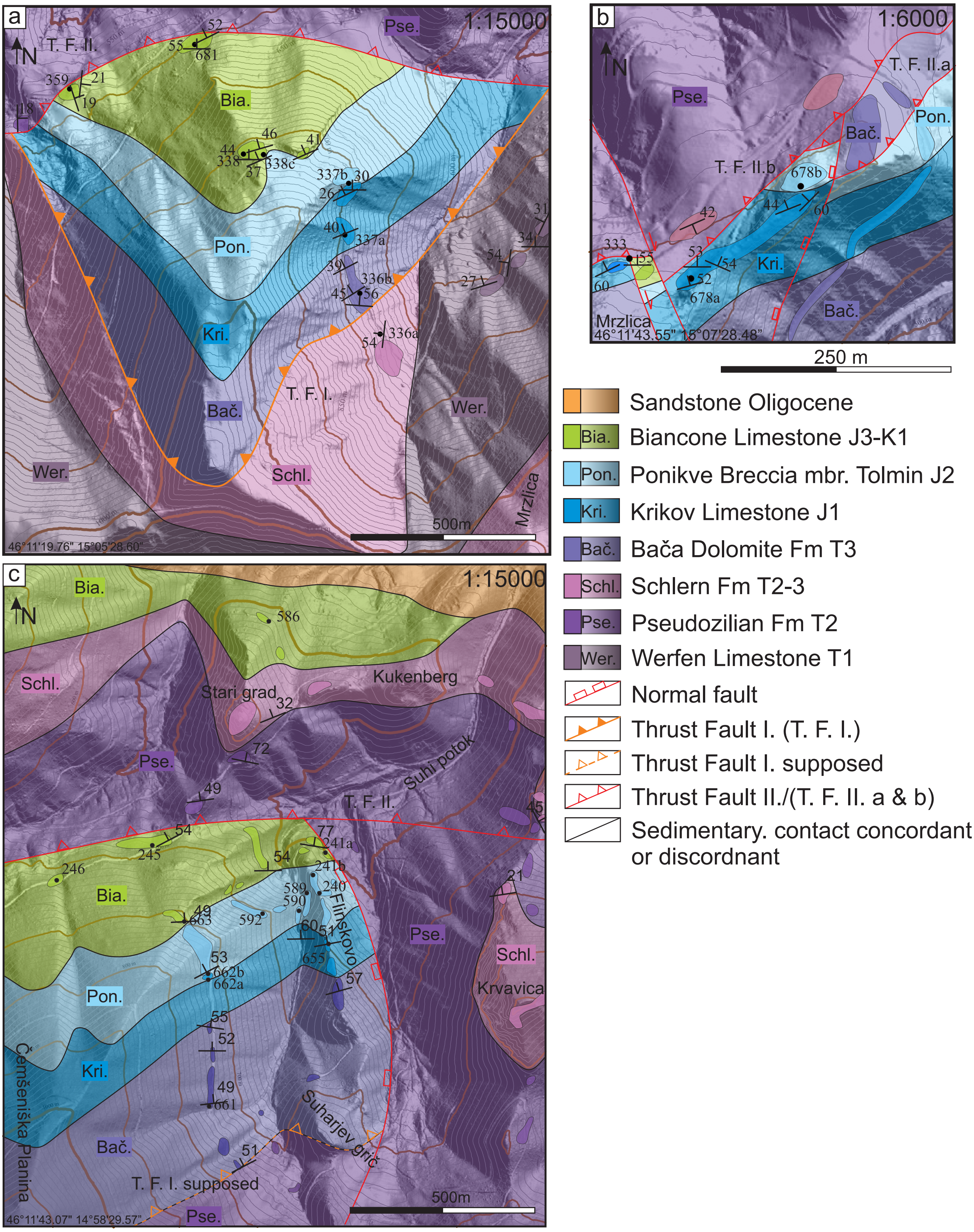

Fig. 2. Detailed new geological maps of the studied sections: a – Mt. Mrzlica NW, b – Mt. Mrzlica NE, c – eastern slope of the Čemšeniška Planina, Flinskovo ridge and Krvavica Mt. Note outcrop numbers that also appear in the stratigraphic logs (Fig. 1c) and on photographs (Figs. 3–7). DEM was produced using the dataset of Ministry of the Environment and Spatial Planning, Slovenian Environment Agency. Outcrops are indicated with opaque colours while postulated extension of formation are marked with transparent colour, note abbreviations for the formations. Thrust Fault I. orange, dashed orange. Thrust Fault II. red continuous line.

Bača Dolomite Formation

Similarly to the classical western development of the SB (e.g., Buser, 1986; Rožič, 2006; Gale, 2010; Goričan et al., 2012b), the Bača Dolomite Formation in the study area mainly consists of black or dark grey dolomite in 20–50 cm thick beds, with chert nodules and even layers. The formation has an estimated thickness of 150–250 m in the Tuhinj Valley area and at the Čemšeniška Planina area (Fig. 1c/log 10; 11) and is approximately 50–150 m thick in the Mrzlica area (Fig. 1c/log 12) but the lower contact is not exposed or truncated. In cases where the bedding is hard to see, chert nodules or layers indicate the bedding as seen in the Tuhinj valley (outcrop 55, Fig. 1c/log 10, Fig. 3d). However, the bedding is mostly clear, for example on the eastern slope of Čemšeniška Planina (outcrop 661, Fig. 4e), where the thick beds alternate with much thinner ones. In some places, such as on the northwest flank of Mt. Mrzlica (outcrop 336b on Fig. 1c/log 12; Fig. 2a, Fig. 3h), the formation contains up to 3–4 m thick breccia layers with a massive appearance. In these, dolomite and chert clasts alternate chaotically. These breccia megabeds were interpreted by Gale (2010) and Oprčkal et al. (2012) as large-scale debris flow deposits related to the middle Norian tectonically-induced subsidence. Since the Bača Dolomite Formation has a distinctive appearance and is therefore easily recognizable in the field, microfacies analysis was not carried out but focused on the overlying limestone layers.

Krikov Formation

The Krikov Formation starts as cherty limestone with a bed thickness of ca. 35 cm. The thickness of the formation is approximately 30 m at the Čemšeniška Planina area (Fig. 1c/log 11) and 70 m at the Mrzlica area (Fig. 1c/log 12). A major part of the formation is composed of a grey to dark grey limestone with chert layers or nodules (e.g., at outcrop 662a on Fig. 2a, Fig. 4d). The limestone is well-bedded (10–30 cm), micritic, with sporadic calcarenite beds. In the Čemšeniška Planina section, calcarenite layers are more common near the top (outcrop 662a, Fig. 1c/log 11; Fig. 2c). However, in the Mt. Mrzlica West sections, calcarenites are more common in the lower and the middle part of the formation (outcrop 337, Fig. 1c/log 12, Fig. 2a). The thin marl interlayers are visible at some places, mostly highlighting the base of a successive layer (Fig. 3g, Fig. 4d). At the top of the formation, the thickness of the layers changes to approximately 15–20 cm; the chert content is much lower, but the marl component increases to almost 20 % (Fig. 3f, Fig. 4c). Different microfacies types, similar to those previously described from the SB (e.g., Rožič, 2006, 2009; Goričan et al., 2012b), were recognised from samples taken from the upper part of the formation in the Čemšeniška Planina section (Fig. 1c/log 11). In the thin section collected from the outcrop (sample 333) on the ridge of Mt. Mrzlica NE (Fig. 2b), the microfacies show dolomitized carbonate mudstone-wackestone texture with "ghosts" of benthic foraminifera (nodosarids, involutinids and textulariids) (Fig. 5a). Scattered rhomboid dolomite crystals could also be observed. The rock was subsequently silicified and the silicification front is clearly visible. In the outcrop on the NW flank of the Mt. Mrzlica section (sample 337; Fig. 1/log 12; Fig. 2a) the formation is represented by bioturbated bioclastic packstone-wackestone limestone that was later silicified and partly dolomitized. Among fossils, it contains mainly fragments of thin-shelled bivalves and sponge spicules. Additionally, a few ostracods, foraminifera and Characeae gyrogonite (Fig. 5b) also occur. The poor foraminiferal fauna consists of textulariids (Fig. 5c), spirillinids (Fig. 5b) and the involutinid *Licispirella* sp. (Fig. 5d). Similar agglutinated forms and spirillinids were figured by Rožič et al. (2022, fig. 14e) from this Lower Jurassic unit of the SB. The genus *Licispirella* appeared in the Norian, but it was common only in the Lower Jurassic (Rigaud et al., 2013). The microfacies and microfossils indicate a distal hemipelagic zone where remnants of Characeae were transported from a freshwater environment.

On the eastern slope of Čemšeniška Planina (sample 662a, Fig. 1c/log 11; Fig. 2c) the characteristic calciturbidite layer of the Krikov Formation could be studied. The original texture of the rock was peloid-ooid-bioclastic wackestone-packstone, with a matrix of micrite and microsparite. Both radial and concentric ooids (sensu Flügel, 2010) occur. Due to the strong silicification, this texture has only been preserved in randomly arranged small fragments (Fig. 5e). In this sample, the majority of the fossils were also silicified and preserved as ghosts. Skeletons of echinoderms are the most frequent, but foraminifers are also common, especially the nodosarianids (*Lenticulina, Marginulina* (Fig. 5f)*, Nodosaria, Dentalina*). The agglutinated forms are represented by textulariids, trochamminids, and ?*Siphovavulina* sp. (Fig. 5e). Specimens of the Lower Jurassic involutinids, namely *Involutina farinacciae* (Fig. 5g) and ?*Trocholina* sp. also occur. Among the miliolinids, the evolute *Ophthalmidium* morphogroup (mg.) *kaptarenkoae* (Fig. 5h) and the semiinvolute

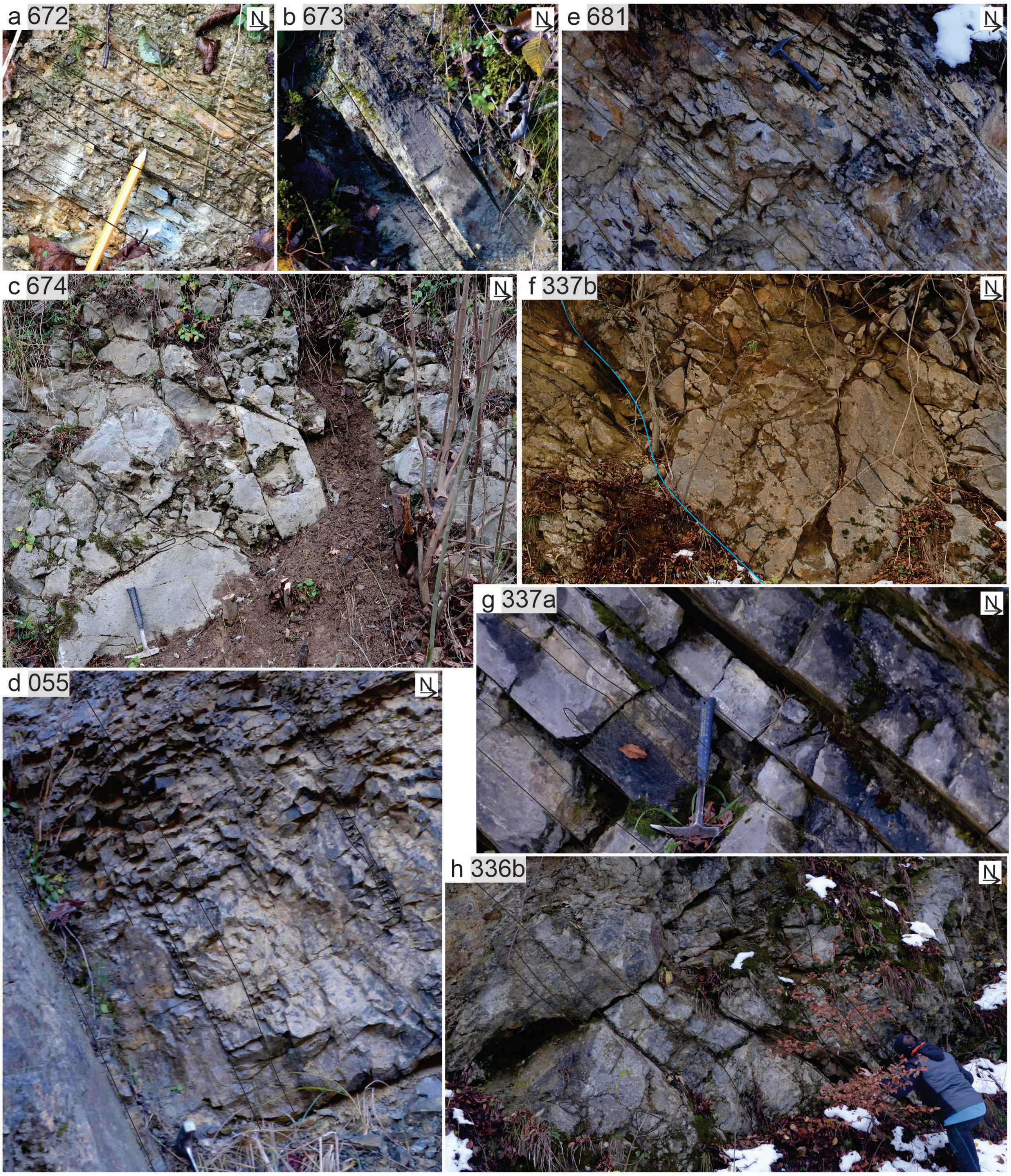

Fig. 3. Interpreted images of the outcrops. The outcrop number is in the top left corner; the north is indicated in the top right corner; a-d) succession of Tuhinj valley area near the villages Vaseno and Buč; e-f) succession on Mt. Mrzlica. Formations: a, e) Biancone Limestone Formation; b) Lower Flyschoid Formation; c, f) Tolmin Formation/Ponikve Breccia Member; f, g) Krikov Formation (the blue line highlights the top of the Krikov Formation and the bottom of the Tolmin Formation/Ponikve Breccia Member); d) Bača Dolomite. Black line highlights the bedding and the contour of the chert.

O. mg. *terquemi* (Fig. 5i) could be tentatively determined. Additionally, a section of an aperture with a bifid tooth could be recognized (Fig. 5j). To our knowledge, this type of aperture is only known from the Lower Cretaceous onwards (e.g., Neagu, 1984; Clerc, 2005), and from the Jurassic only *Sigmoilina moldaviense* has teeth (Danitch, 1971). However, we must note that knowledge about the Jurassic miliolinids, especially the Lower Jurassic ones, is incomplete.

Based on the appearance of *Involutina farinacciae,* the age of the rock can be late Sinemurian – early Toarcian (Fig. 8). This coincides well with the previously determined Early Jurassic, more precisely Hettangian–Pliensbachian age of the Krikov Formation (e.g., Cousin, 1973, 1981; Buser, 1986; Rožič, 2006, 2009; Goričan et al., 2012b).

Tolmin Formation, Ponikve Breccia Member

The Ponikve Breccia member is a massive breccia. It consists of different limestone clasts originating from the erosion of older platform, slope and basinal formations, but in the matrix, contemporaneous grains, such as peloids, ooids, oncoids, intraclasts, and bioclasts are present (Rožič et al., 2022). Based on the occurrence of radiolarians and foraminifera, determined in previous studies (Rožič et al., 2019, 2022) at other localities, the age of the breccia is Middle Jurassic (probably Bajocian – Bathonian), while the age of the clasts ranges from the Late Triassic to Early Jurassic (Rožič et al., 2019, 2022).

Based on the macroscopic and microscopic studies, the Ponikve Breccia appears in each of the investigated areas (Fig. 1c, Fig. 2). The thickness of the formation is approximately 20 m at the Tuhinj area (Fig. 1c/log 10), 25 m at the Čemšeniška Planina area (Fig. 1c/log 11) and 35 m thick at the Mrzlica area (Fig. 1c/log 12). The contact with the Krikov Formation is erosional while the large clasts of the massive Ponikve Breccia truncate the underlying well-bedded Krikov Limestone as seen at outcrops 337b and 662 (Figs. 3f and 4c).

We studied the thin sections of the following samples: sample 338c from Mt. Mrzlica NW, sample 678 from Mt. Mrzlica NE, and samples 240, 241, 589, 590, 592, and 674 from Čemšeniška Planina (Fig. 3c, f; Fig. 4b, c). Macroscopically, many clasts are angular and their size ranges from a few mm to several meters. The clasts are densely packed, thus there is only a minor matrix even further reduced by pressure solution resulting in stylolitic seams. The matrix of the breccia is an ooid-peloid grainstone or packstone. The proportion of peloids, oncoids, and ooids varies greatly, but usually, the latter are the most common. All three major structural types of the ooids (sensu Flügel, 2010) appear. The most frequent are the concentric or tangential ooids, the less frequent are the radial-fibrous ones, and the micritic ones are rare. Fossils occur in the matrix as well as the core of the concentric ooids. In descending order of frequency, the following fossil groups appear: echinoderm fragments, benthic foraminifera, dasycladacean algae, *Rivularia*-type Cyanophyceae, gastropods and incertae sedis (Fig. 5k).

The foraminiferal fauna is relatively poor and shows very low diversity. The characteristic

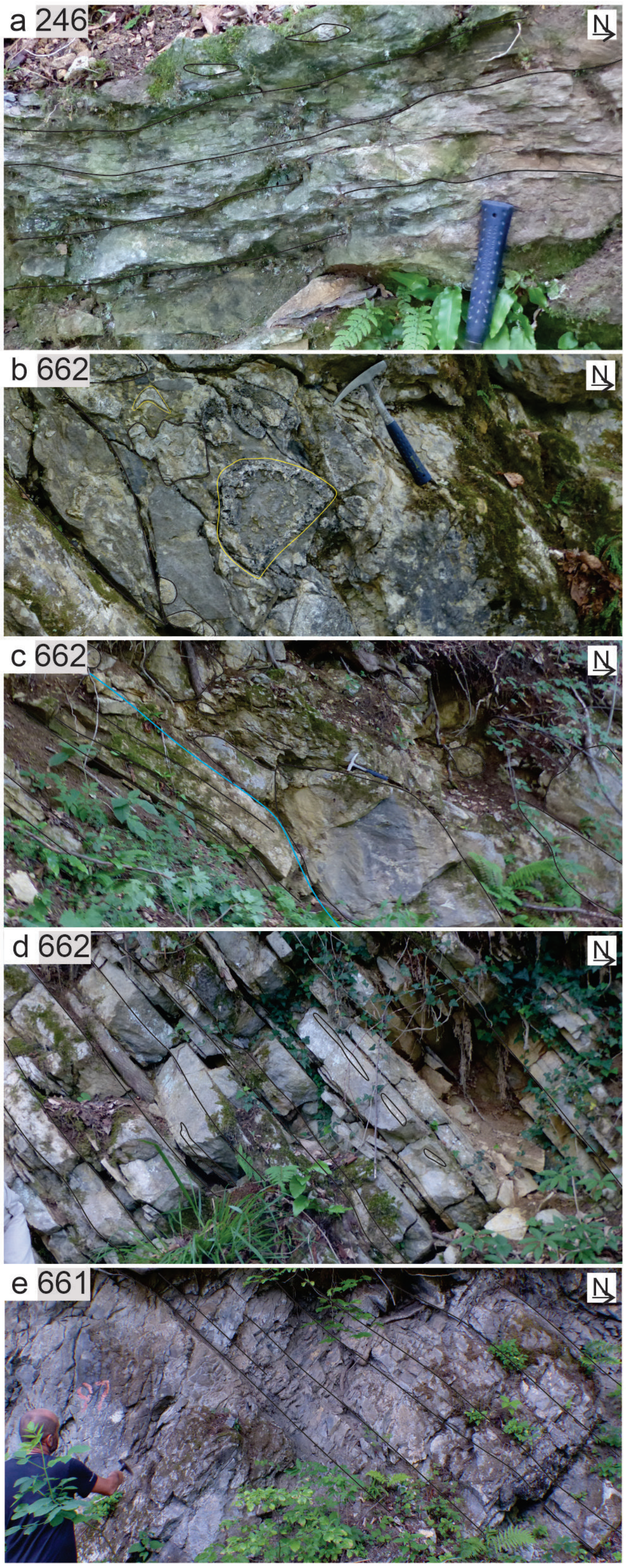

Fig. 4. Images of the outcrops of the succession at Čemšeniška Planina. The number of outcrops is in the top left corner; the North is indicated in the top right corner. Formations: a) Biancone Limestone Formation; b, c) Tolmin Formation/Ponikve Breccia Member (yellow line highlights block with silicified corals); c, d) Krikov Formation (blue line highlights the contact between the Krikov Formation and the Tolmin Formation/Ponikve Breccia Member); e) Bača Dolomite. Black line highlights the bedding and the contour of the cherts.

double-walled *Protopeneroplis striata* and low- and high-spired forms of *Coscinoconus palastiniensis* regularly occur as a core of the ooids or oncoids within clasts, but rarely in the matrix (Fig. 5l, m, n, o). Besides these taxa, agglutinated foraminifera, such as *Glomospira* sp. (Fig. 5q), ?*Siphovalvulina* sp. (Fig. 5p), *Trochammina* sp. (Fig. 5r), several textulariids (Fig. 5s) and a few miliolids, such as *Ophthalmidium* mg. *concentricum* could be recognized (Fig. 5q, t). Nodosarids, mainly *Nodosaria* sp. and Lenticulina sp. (Fig. 6a) are relatively frequent and large, up to 1 mm. The fragile Chlorophyta algae and algal-like bacteria are represented by dasycladales and cyanophytes, such as *Selliporella* mg. *donzellii* (Fig. 6b), *Salpingoporella* sp. (Fig. 6c-d), ?*Megaporella* (Fig. 6e), and algae indet. (Fig. 6g), *Rivularia lissaviensis* (Fig. 6f) and "Cayeuxia" spp. (Fig. 6h). A few specimens of the incertae sedis *Crescentiella morronensis* (Fig. 5u), and other microproblematicum (Fig. 5v) also occur.

The co-occurrence of the early Bajocian – late Bathonian *Selliporella* mg. *donzellii,* Bajocian-Callovian *Coscinoconus palastiniensis,* Aalenian-Tithonian *Protopeneroplis striata* and indicates an early Bajocian – late Bathonian age (Fig. 8).

The effects of the subsequent diagenetic processes on the matrix, such as tectonic deformation and recrystallization could be traced. Due to the pressure solution, peloids and concentric ooids are often deformed, thus becoming elliptic in shape, while the radial fibrous ooids broke (Fig. 5l, Fig. 6a). In most cases, the matrix was dolomitized to varying degrees (e.g., Fig. 5k, o, t, u). Because the micrite or microsparite 'groundmass' of the matrix was affected to a greater extent by late diagenetic dolomitization than for example the ooids or clasts, a rim of dolomite crystals surrounds these grains (Fig. 6h).

Most lithoclasts originate from a carbonate platform. The oldest, the Upper Triassic limestone blocks were the largest and the easiest to recognize macroscopically in the field. Their appearance usually was massive limestone, in some cases, corals, megalodon bivalves or stromatolite layers could be identified in the field (Fig. 4b).

A typical grey, finely laminated platform carbonate clast, showing the features of facies B of the Lofer cycles was found at northern Fliskovo Ridge (outcrop 589, Fig. 1/log 11; Fig. 2c). The laminae consist of packstone, grainstone, dark stromatolites, mudstone with spar-filled shrinkage pores, and spar-filled sheet cracks. The bioclasts occurred only in the pelmicritic packstone and grainstone laminae (Fig. 6i). The foraminifers are the most frequent and diverse, besides them dasycladacean and codiaceaen (Bryopsidales) algae, and *Rivularia*-type calcimicrobes could be recognized. In the foraminiferal fauna, the involutinids dominated. The following taxa could be classified as *Aulotortus communis* (Fig. 6j), *A. sinuosus* (Fig. 6k), *A. tenuis* (Fig. 6l), *A. tumidus* (Fig. 6l), *Parvalamella friedli* (Fig. 6m), *Frentzenella crassa* (Fig. 6i) and *T. ultraspirata* (Fig. 6n). The agglutinated forms are represented mainly by *Gandinella falsofriedli* (Fig. 6o) and "*Trochammina*" *almtalensis* (Fig. 6p, q), additionally a few specimens of ?*Trochammina alpina* (Fig. 6r), *Textularia* sp., and *Valvulina* sp. occur. The taxa of lagenids (*Austrocolomia* sp., *Nodosaria* sp. and *Lenticulina* sp.) and miliolinids (cf. *Paraophthalmidium* spp.) were represented by one specimen (Fig. 6s, t).

Among the algae the most common were the fragments of ?*Petrascula* sp. (Fig. 6s, u) and *Rivularia lissaviensis* (Fig. 6f). In addition, a few specimens of Norian *Bystrickyella ottii* (Fig. 6w) and *Salpingoporella austriaca* (Fig. 6x), *Arabicodium* sp. (Fig. 6l, y) and dasycladaceaen organs of ?*Acicularia* (Fig. 6i), *Patruliuspora* (Fig. 6z), and dasycladaceans (Fig. 6v) could be identified.

Based on the foraminiferal and algal association the age of this clast is Norian (Fig. 8). These forms indicate a shallow well-lighted low-energy environment.

In the Triassic clast of the previously mentioned sample 241, at Flinskovo Ridge east from Čemšeniška Planina, stromatoporoids, sponges, involutinids as *Aulotortus sinuosus, Semiinvoluta* sp. and *Triasina hantkeni* with an encrusting *Tolypammina gregaria* could be recognized (Fig. 6aa). These fossils indicate the Rhaetian age (Fig. 8) and shallow marine platform environment.

On the east side of the Čemšeniška Planina, close to Flinskovo (outcrop 592, Fig. 1/log 11, Fig. 2c), in the breccia coral-bearing limestone clasts were found. The rock is a framestone, in the cavities between the cylindrical corallites of a phaceloid colony is mudstone. The tiny (up to 6 mm in diameter) corallites have an overall stylophyllid morphology, their septa are composed of isolated or sclerenchyma-embedded spines (Fig. 6bb), which is unique among the Triassic–Jurassic scleractinians (e. g., Stolarski and Russo, 2002). These forms could be classified into the Norian-Lower Jurassic genus *Styllophyllopsis,* which has been found in Slovenia only in the lower Norian of the Julian Carbonate Platform (Turnšek, 1997). In the matrix, there was an ammonite embryo, a fragment of stromatoporoids and only a few specimens of foraminifera, like the

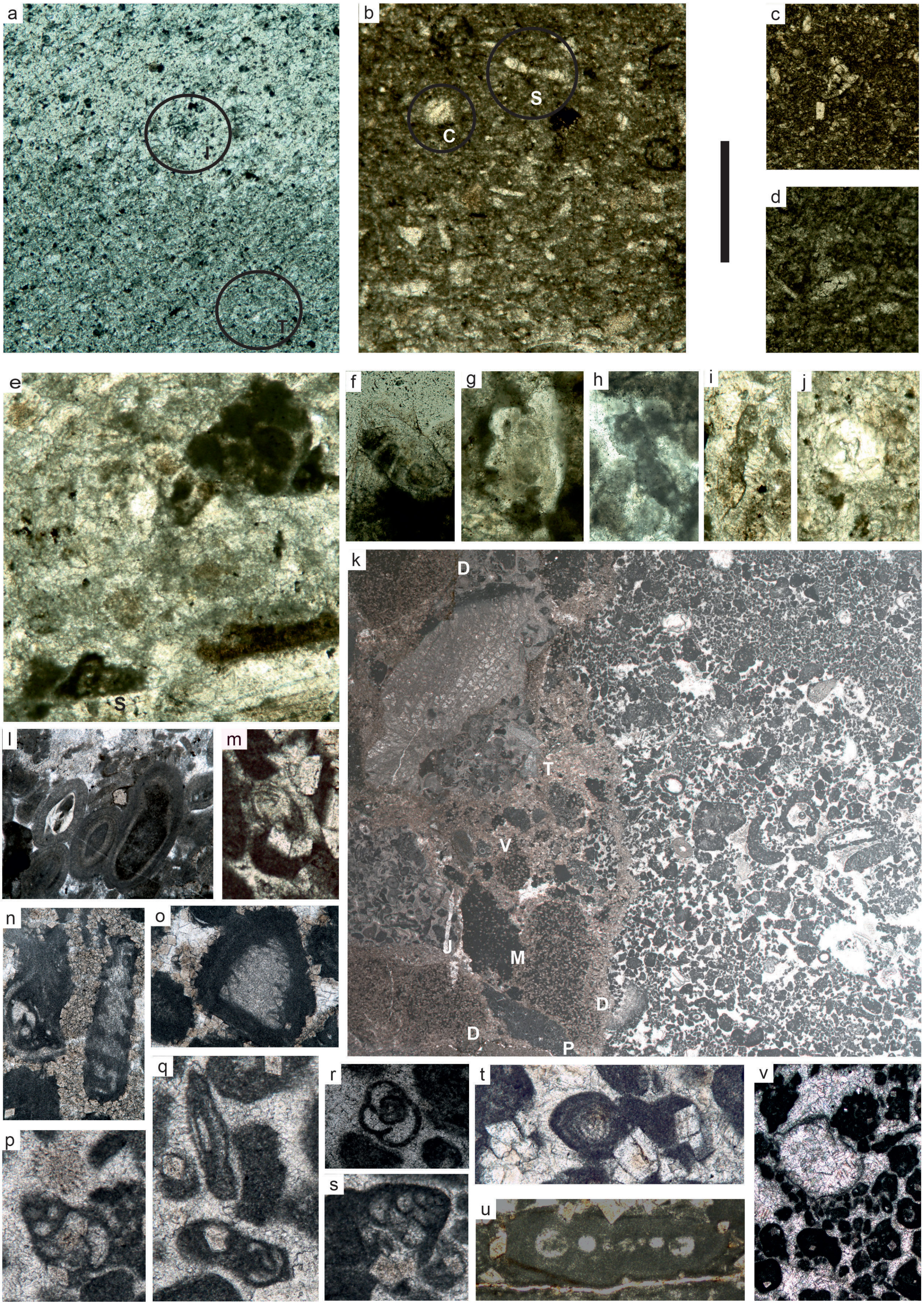

Fig. 5.

involutinid *Coronipora etrusca* (Fig. 6cc) and *Semiinvoluta* sp. (Fig. 6dd) additionally a few agglutinated forms. These foraminifers prefer the oxic and low-energy environment. The *C. etrusca* has an upper Norian—Liassic range, while the genus *Semiinvoluta* is known only from the Rhaetian up to the end of the Pliensbachian (Rigaud et al., 2013). Based on these fossils and the facies, the age of the rock is Rhaetian, but the Early Jurassic (until the end of the Pliensbachian) has not been ruled out (Fig. 8).

A silicified clast with recrystallised radiolarians and sponge spicules occurred in the breccia at the northern Flinskovo Ridge, Čemšeniška Planina (sample 590c). A few specimens of textulariid, involutinid? and nodosariid? foraminifera also could be recognized (Fig. 7a) This rock most probably originated from the Lower Jurassic Krikov Formation.

Close to the previous outcrops (sample 241, Fig. 1/11, Fig. 2c) as clasts of the breccia microfacies types of basinal facies, peloid mudstone-wackestone with thin-shelled bivalves, echinoderm fragments and foraminifers (e.g., *Lenticulina* sp.) occur (Fig. 7b, c). Based on the microfacies (e.g., see Goričan et al., 2012a, fig. 22a) it could be identified as the Lower Jurassic Krikov Formation. In the same breccia sample, in another strongly dolomitized lithoclast (Fig. 7b) a larger agglutinated foraminifera *Everticyclammina praevirguliana* is preserved as a "tiny island" (Fig. 7d). The stratigraphic range of this form is upper Sinemurian—lower Bajocian. The microfacies and the fossils indicate a shallow marine, inner platform environment. Thus, this lithoclast may come also from the calcarenite layers of the Krikov Formation as rip-up clast. Based on the occurrence of the Hettangian-Sinemurian index fossil, *Palaeodasycladus mediterraneaus* a definitely Lower Jurassic clast was found in sample 240, Flinskovo Ridge, Čemšeniška Planina (Fig. 5k, Fig. 7e).

At the NE ridge of Mt. Mrzlica (sample 338c, Fig. 1c/log 12, Fig. 2a), few types of clasts of the breccia appear that previously were neither described in the literature nor in the Ponikve Breccia Member in the western SB. The silicified rock is ocher in color with dark-purple chert nodules. Its microfacies is bioclastic mudstone-wackestone. The bioclasts are almost exclusively fragments of echinoderms, most probably crinoids. Very few ostracods, filled with sparry calcite also occur (Fig. 7f). The appearance of this strange assemblage can be explained by the fact that the skeleton of echinoderms and ostracods is more resistant to dissolution than that of other shells. Since no age-diagnostic fossils were found, the stratigraphic position of this rock type is uncertain. In some clasts (thin sections) one or more parallel or slightly undulating sets of surfaces or very thin veinlets occur (Fig. 7/g-i). The surfaces surround the fragments and give a nodular-bounding appearance (Fig. 7g). They can represent sedimentary lamination, stylolitic seams or incipient layer-parallel foliation planes, partly filled with late calcite. Dolomite crystals are scattered or arranged along the fissures. Cherty nodules of uncertain origin with few dolomite crystals are also present. This microfacies also occurs in the NW flank of Mt. Mrzlica (sample 678a Fig. 2b). Here other microfacies could be identified in thin sections, like mudstone with dissolved radiolarian skeletons; ooid packstone with strongly elongated (deformed) micritic ooids (Fig. 7i); mudstone with bird's-eye structures of irregularly formed and distributed fenestrae, crosscutting calcite veins and stylolites and a few deformed echinoderma fragments and packstone-grainstone with distorted ooids (Fig. 7j). All of these microfacies reflect the late diagenetic selective recrystallization, mechanical distortion and pressure solution processes. There were no age-diagnostic fossils, thus the stratigraphic position of these lithoclasts is uncertain.

Fig. 5. a-j) Krikov Formation, k-v) Ponikve Breccia Member of Tolmin Formation. The scale bar is 400 µm, except k) where 6 mm. a) sample 333 of the outcrop on the ridge of Mt Mrzlica NE, dolomitized carbonate mudstone-wackestone texture with "ghosts" of benthic foraminifera as involutinid (I) and textulariid (T); b-d) sample 337, Mrzlica NW, b) silicified bioclastic (sponge spicules, thin-shelled bivalves) packstone limestone, with Characeae gyrogonite (C) and spirillinid (S); c) textulariid foraminifera; d) involutinid foraminifera *Licispirella* sp.; e-j) sample 662a, Čemšeniška Planina; e) remnants of the peloid-ooid-bioclastic wackestone/packstone texture after the silicification, with agglutinated foraminifera, ?*Siphovalvulina* (S); f) *Marginulina* sp.; g) *Involutina farinacciae* Brönnimann & Koehn-Zaninetti; h) *Ophthalmidium* mg. *kaptarenkoae* Danitch; i) *Ophthalmidium* mg. *terquemi* Pazdrowa; j) miliolid aperture with tooth; k) photomicrograph of the thin section of sample 240, Čemšeniška Planina, on the right: the peloidal grainstone with gastropods, Dasycladacean algae, Echinodermata fragments and foraminifers, on the left: partly dolomitized matrix and different lithoclasts: Triassic (T) intraclastic packstone-grainstone clast with stromatoporoid, sponges, gastropods and foraminifers (see Fig. 6z for enlarged image), Lower Jurassic clast (J) with bioclastic grainstone fabric and algae (see Fig. 7e for enlarged image), dolomite clast (D), vermetus tubes (V), strongly dolomitized mudstone clast (M), peloidal mudstone clast (P); l) deformed ooids of the breccia matrix with *Protopeneroplis striata* Weynschenk, sample 674, Čemšeniška Planina; m) *Protopeneroplis striata* Weynschenk, sample 590, Čemšeniška Planina; n-o) *Coscinoconus palastiniensis* Henson, high (n) and low (o) spired forms, sample 240, Čemšeniška Planina; p) ?*Siphovalvulina* sp., sample 240, Čemšeniška Planina; q) *Glomospira* sp. and miliolids, sample 240, Čemšeniška Planina; r) *Trochammina* sp.; s) textulariid (?*Valvulina* sp.), sample 240, Čemšeniška Planina; t) *Ophthalmidium* mg. *concentricum* (Terquem & Berthelin), sample 674, Čemšeniška Planina; u) *Crescentiella morronensis* (Crescenti), sample 241, Čemšeniška Planina; v) microproblematicum, sample 240, Čemšeniška Planina.

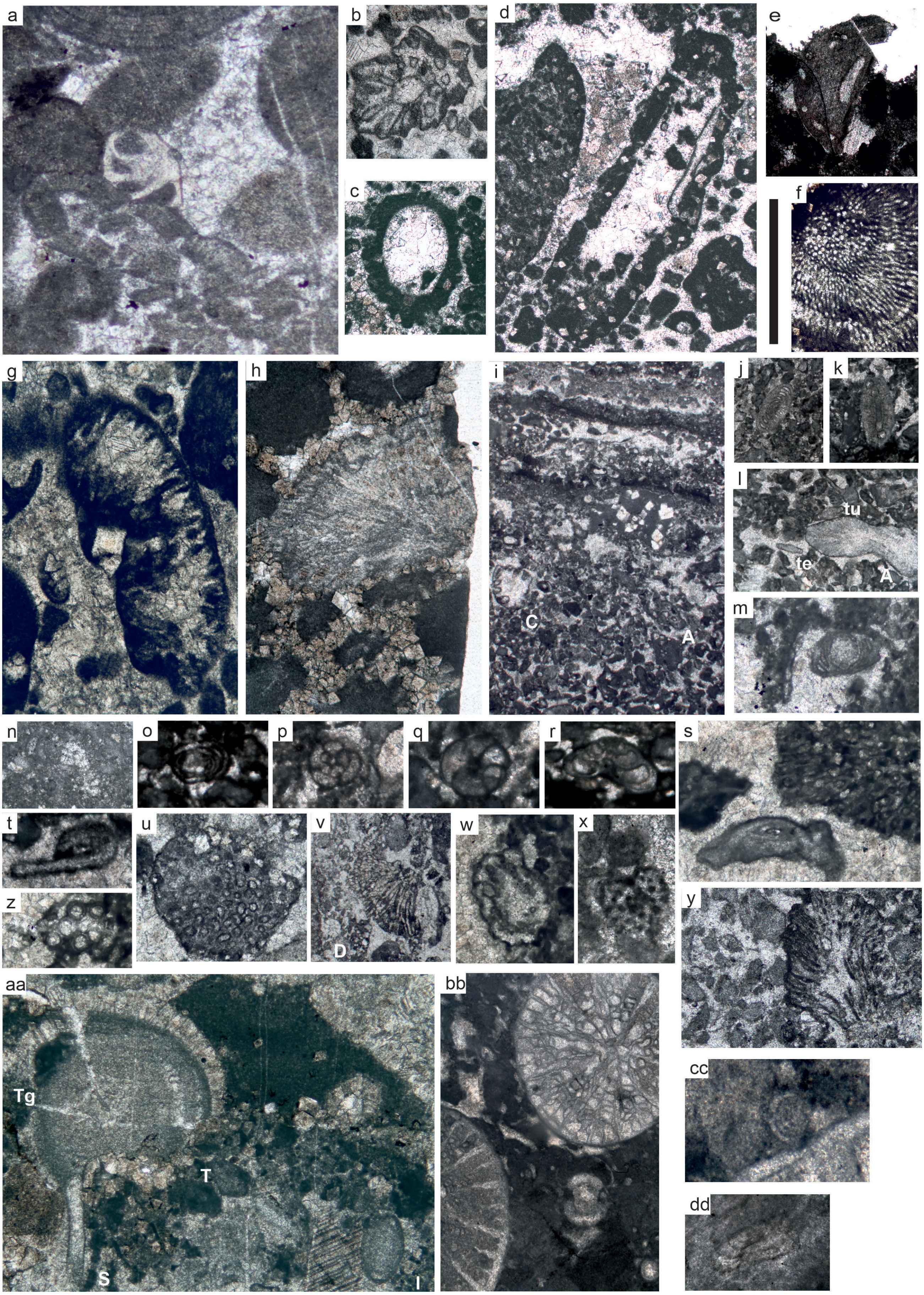

Fig. 6.

Based on the field studies, microfacies and microfossils analyses the provenance of the matrix was threshold lines in the photic zone. The breccia formed on the upper slope environment and is characterized by the bimodal grain size, larger clasts, and well-sorted, sand-sized grains amidst them. It means that the Ponikve Breccia is a typical mass-flow breccia (e.g., sensu Flügel, 2010).

Tolmin Formation Upper Member(?)

It is worth mentioning that we could not find the contact of the Ponikve Breccia Member and Biancone Limestone on the field thus further observation is needed. On the topography, however, a linear depression marks the transitional interval of the two formations, the thickness of which was estimated to be approximately 10 m (Fig. 1c/log 11, 12; Fig. 2a, c). Although we did not find any outcrop of chert, shale or marl, this soil-covered depression may suggest a softer sedimentary rock between the formations. We postulate that this can correspond either to the Upper Member of the Tolmin Formation, which is in the topmost part often characterized by alternating radiolarite and marl/shale beds (Rožič, 2009). Alternatively, this covered part may correspond to the marly basal part of the Biancone Limestone.

Biancone Limestone Formation

The Biancone Formation is composed of white, yellow, light pink or grey thin-bedded limestone and the colours are often varying within the same bed. The macroscopic texture is fine-grained micritic (porcelain). The thinly bedded (or foliated?) limestones could be identified at the Tuhinj area (outcrop 672, Fig. 3a), the northern slope of the Flinskovo ridge and the Čemšeniška Planina (outcrops 241-246, Fig. 2c, and outcrop 246 Fig. 4a) and on the NW slope of Mt. Mrzlica (outcrop 681 Fig. 3e). On the eastern slope of the Flinskovo Ridge (outcrop 241a, Fig. 2c), a dm-scale closed fold was measured, which could be considered a slump fold. Here we include the description of the rocks near the Stari Grad (Fig. 2c) although they do not belong to the SB succession.

Near the base of the sequence two different stratigraphic sequences with similar facies could be studied. In the Flinskovo ridge in outcrop 241a, the rock is light red to yellow micritic limestone, wackestone, and slightly dolomitized. In the thin section, fine lamination could be recognized due to the parallel orientation of the elongated calcite particles ("filaments"). The stylolites and the microcracks with offsets indicate slight layer-perpendicular shortening. The veins differ in width and their voids are filled with coarse crystalline calcite. A few calcified radiolarians, ostracods, and scattered opaque grains could be identified (Fig. 7k). From the second type of stratigraphic sequence north from Stari grad at outcrop 586 (Fig. 2c) pink-yellow variegated, silicified mudstone (wackestone) appears. In thin-section, this showed irregular crosscutting calcite veins often associated with irregular clay seams (Fig. 7m). A few stylolites and scattered pyrite crystals also occur. It did not contain identifiable fossils. Based on the microscopic features these rocks could be the hemipelagic uppermost part of the Tolmin or the base of the Biancone Limestone Formations although macroscopic characters support the latter option.

Due to the diagenetic process, at each studied area (Fig. 2a–c), the Biancone Limestone is often chertified to varying degrees and often dolomitized (Fig. 3a, e; Fig. 4a). In some outcrops, chert nodules could be recognized (e.g., Čemšeniška Planina section, outcrop 246, Fig. 4a). The calcareous character becomes slightly more marly upward while in site 245 yellow silicified calcareous marlstone is the dominant rock type (Fig. 2c). Based on the microfacies study, its original depositional texture was most probably mudstone. Wavy stylolitic seams often filled with dark clay, dispersed opaque minerals, rhomboid dolomite crystals, and few radiolarians were recognized (Fig. 7l). The thickness of the formation is approximately 50–100 m at all three areas (Fig. 1c/log 10-12).

Fig. 6. Ponikve Breccia Member of the Tomin Formation a-h) Middle Jurassic microfossils in clasts and matrix, i-aa) Triassic clasts. The scale bar is 1 mm, except g and bb where it is 3 mm a) broken radial-fibrous, and micritic ooids with *Lenticulina* sp., sample 590, Čemšeniška Planina; b-e) outcrop 240, Čemšeniška Planina; b) *Selliporella* mg. *donzellii* Sartoni & Crestenci; c-d) *Salpingoporella* sp., e) ?*Megaporella* sp.; f) *Rivularia lissaviensis* (Bornemann), sample 241, Čemšeniška Planina; g) algae indet., sample 674, Čemšeniška Planina; h) "*Cayeuxia*" sp., ooids with dolomite crsystal rim, sample 240, Čemšeniška Planina; i-y) sample 674, Čemšeniška Planina: i) laminated pelmicritic packstone-grainstone with stromatolite layers with *Frentzenella crassa* (Kristan) (T) and ?*Acicularia* sp. (A); j) *Aulotortus communis* (Kristan); k) *Aulotortus sinuosus* Weynschenk; l) *Aulotortus tenuis* (Kristan) (te), *A. tumidus* (Kristan-Tollmann) (tu) and *Arabicodium* sp. (A); m) *Parvalamella friedli* (Kristan-Tollmann); n) *Trocholina ultraspirata* Blau; o) *Gandinella falsofriedli* (Salaj, Borza & Samuel); p-q) "*Trochammina*" *almtalensis* Koehn-Zaninetti; r) ?*Trochammina alpina* Kristan-Tollmann; s) cf. *Paraophthalmidium* sp. and ?*Petrascula* sp.; t) cf. *Paraophthalmidium*; u) ?*Petrascula* sp.; v) dasycladacean organ (D) and *Rivularia lissaviensis* (Bornemann); w) *Bystrickyella ottii* Barattolo, Cozzi & Romano; x) *Salpingoporella austriaca* Schlagintweit, Mandl & Ebli; y) *Arabicodium* sp.; z) *Patruliuspora*; aa) Triassic clast with *Aulotortus sinuosus* Weynschenk (I), *Semiinvoluta* sp. (S) and *Triasina hantkeni* Majzon (T) encrusted with *Tolypammina gregaria* Wendt (Tg); bb-dd sample 592, Čemšeniška Planina: bb) *Styllophyllopsis* sp. and ammonite embryo; cc) *Coronipora etrusca* (Pirini); dd) *Semiinvoluta* sp.

It is to note that the rock exhibits a densely packed set of slightly undulating, wavy or planar surfaces. Locally the dark solution residue point to strong pressure solution. The interpretation is twofold: either they represent sedimentary lamination overprinted by pressure solution or the stylolitic surfaces are already the sign the incipient layer-parallel foliation induced by layer-perpendicular (vertical) shortening (Fig. 7k-m). Despite the absence of age-determining fossils, the macroscopic and microscopic characteristics of the rock match well with the development of the Biancone Limestone in the SB. The projected age is late Tithonian to Berriasian (Rožič et al., 2009; Goričan et al., 2012b).

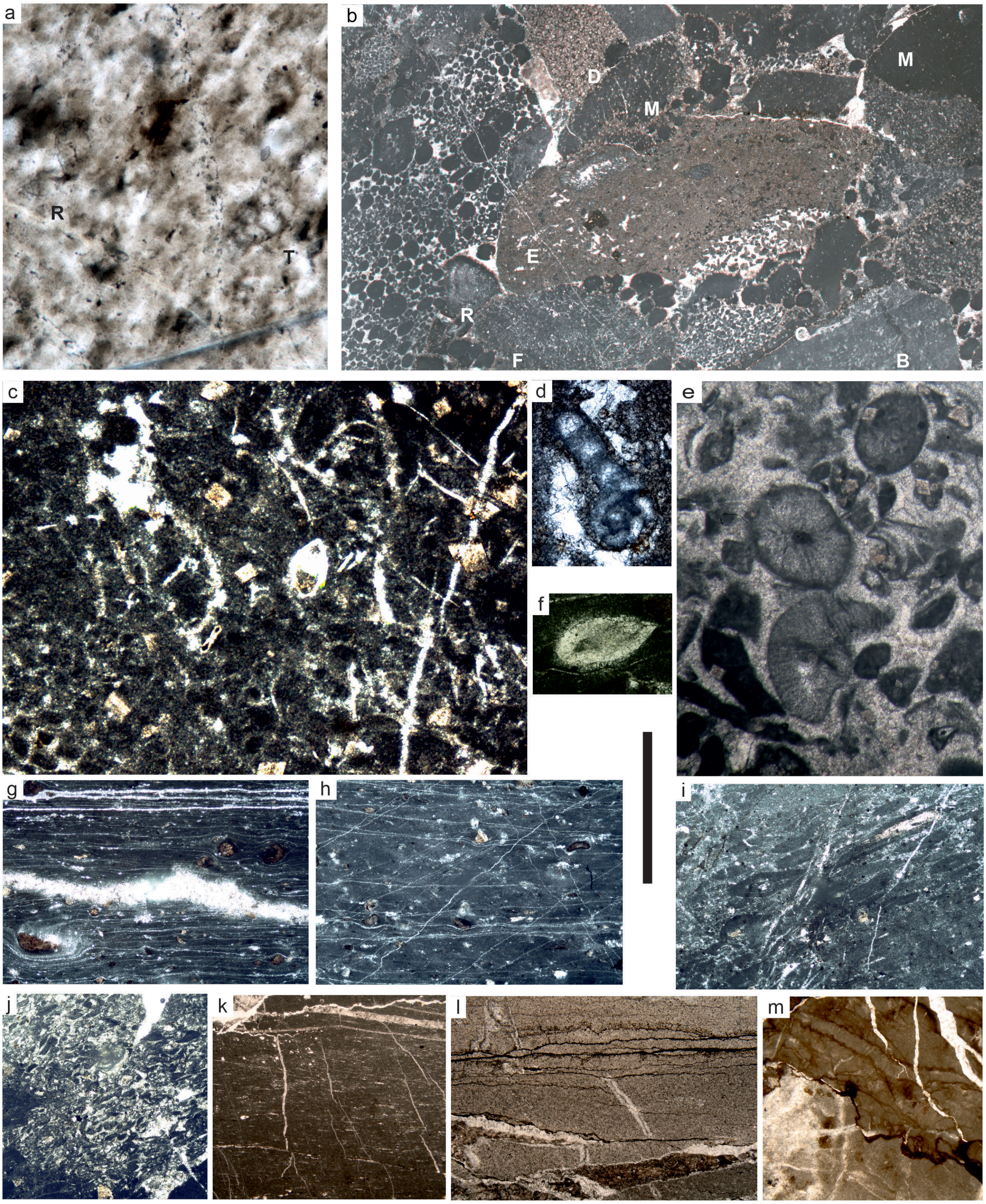

Fig. 7.

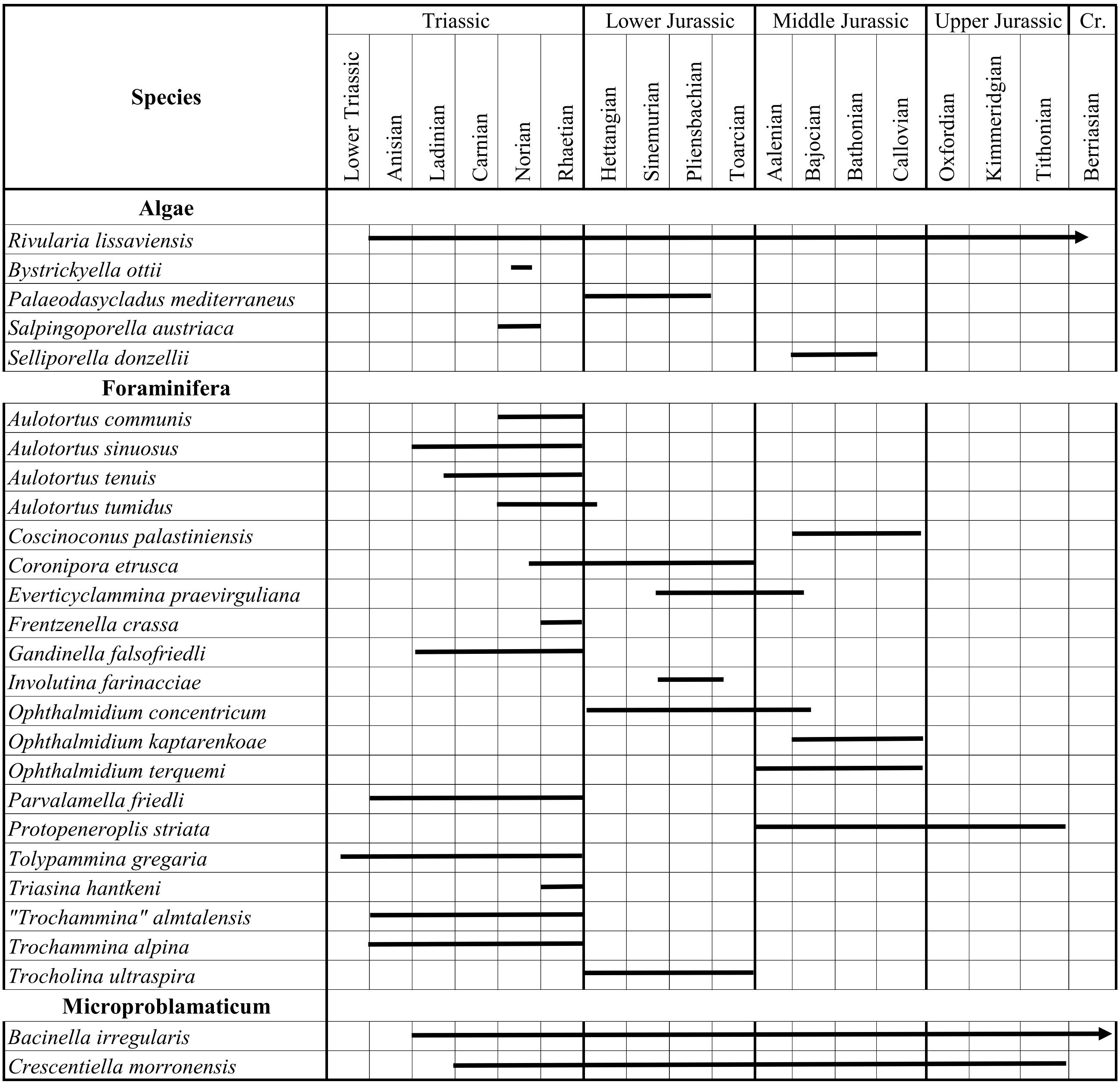

Fig. 8. Stratigraphic range of the most important age-determining fossils based on the literature cited in the appendix.

Fig. 7. a-e) Lower Jurassic clasts, f-j) clast of unknown age of the Ponikve Breccia Member of Tolmin Formation, k) basinal facies of the Tolmin Formation or Biancone Limestone Formation, l-m) Biancone Limestone Formation. The scale bar is 10 mm, except a, c, d and f where it is 1 mm a) Silicified clast, bioclastic (radiolarians and sponge spicules) packstone with nassellarian Radiolaria (R) and textulariid foraminifera (T), sample 590c, Čemšeniška Planina; b) clast with the matrix of the breccia, which is dolomitized ooid–peloid grainstone with microsparite-sparite matrix and different angular lithoclasts. In the matrix, there are *Rivularia lissaviensis* (Bornemann) (R), *Crescentiella* mg. *morronensis* (C = Fig. 5u) and foraminifers. The lithoclasts are the following: dolomite (D), mudstone with *Bacinella irregularis* Radoičić (B, see also Fig. 7c) and stromatolite (Triassic?), dolomitized, basinal peloid mudstone-wackestone facies, with filaments and foraminifers (F, enlarged on Fig. 7d) Lower Jurassic clast from the Krikov Formation, mudstone with dolomite crystals (M), dolomitized lithoclast with a larger agglutinated foraminifera, *Everticyclammina praevirguliana* Fugagnoli, sample 241, Čemšeniška Planina; c) enlarged peloid mudstone-wackestone clast of Fig. 7b) with filaments, Echinodermata fragments and *Lenticulina* sp.; d) enlarged part of b), *Everticyclammina praevirguliana* Fugagnoli; e) *Palaeodasycladus mediterraneaus* (Pia) from the Jurassic lithoclast of sample 240, Čemšeniška Planina; f-h) sample 338a, NE ridge of Mt. Mrzlica: f) ostracod filled with sparry calcite, g) nodular-bounding appearance of stylolites with undulose surfaces and arranged in parallel sets, with Echinodermata fragments; h) calcite veins arranged in different sets; i-j) sample 678, NW flank of Mt Mrzlica, i) ooid packstone with micritic matrix and strongly elongated micritic ooids with crosscutting calcite veins; j) grainstone with distorted ooids; k) slightly dolomitized, micritic hemipelagic limestone, wackestone with elongated calcite particles (most probably calcified radiolarians) giving a fine lamination appearance, sample 241a, Čemšeniška Planina; l) chertified thin-bedded limestone mudstone with wavy foliation, which is filled with dark clay, sample 245, Čemšeniška Planina; m) chertified mudstone, irregular crosscutting quartz veins associated with irregular clay foliations, sample 586, Čemšeniška Planina.

The Lower Flyschoid Formation

This formation is more common in the western SB. The thickness of the formation is approximately 50–100 m at the Tuhinj area (Fig. 1c/log 10). Its age is late Aptian/Albian to middle Cenomanian (Buser, 1986; Demšar, 2016) or Turonian (Cousin, 1981; Rožič et al., 2014).

At the Tuhinj area, we observed a small outcrop composed of very fine-grained material, grey marlstone and shale (outcrop 673, Fig. 1c/log 10, Fig. 3b). This is the uppermost member of the Tuhinj area succession. The sedimentological features, laminated appearance, high clay content with a few cm thick carbonate-rich layers, and stratigraphic position support the identification of this formation as the Lower Flyschoid Formation of the SB.

Short description of the detailed maps (stratigraphy and structures)

Mount Mrzlica

Mt. Mrzlica is located 5 km SW from Žalec with three ridges descending northward from the peak. The SB succession is only present on the north-western flank and the north-eastern ridge while the northern flank in between is composed of Permian to Lower Triassic rocks. The Mrzlica NW map (Fig. 2a) is located on the north-western flank of Mt. Mrzlica, 1 km northwest of the peak. Buser (1978) only indicated a unified Jurassic sequence over Triassic platform limestones and on the eastern part the equivalent of Bača Formation. Buser (2009) indicated the presence of the Bača Dolomite, Biancone Limestone and Triassic platform limestone in this order from north to south on the northern side of Mt. Mrzlica. Our study indicates that the succession is composed of the Bača Dolomite, Krikov Formation, Ponikve Breccia Member of the Tolmin Formation, and the Biancone Limestone. The Perbla Formation and the other three members of the Tolmin Formation, typical for more continuous Slovenian Basin successions (Rožič, 2009), are missing from the succession. There are two thrust faults; the hanging wall of the older thrust comprises the SB succession (Fig. 2a, Thrust Fault I.), and the footwall is the Middle Triassic Schlern Formation and the Lower Triassic Werfen Formation. This thrust was responsible for the displacement of the SB units over the Triassic Units of the Dinarides. The second thrust (Fig. 2, Thrust Fault II.) is interpreted as being younger, with a very steep angle; it is responsible for the overthrusting of the SB succession with the Middle Triassic Pseudozilian Formation and the overlying Triassic to Cretaceous succession.

The map Mrzlica NE (Fig. 2b) is located 1.5 km northeast of the peak of Mt. Mrzlica. Previous maps (Buser, 1978, 2010) indicated the Bača Dolomite in this area. During our mapping, several formations of the SB were observed, partly based on lithological similarities of rocks to the succession of the Mrzlica NW section. At this part of Mt. Mrzlica two thrust faults are interpreted. The older one (Fig. 2b Thrust Fault II. a) is responsible for thrusting the Bača Dolomite over the succession of younger SB members. The younger thrust (Fig. 2b, Thrust Fault II. b) is responsible for the displacement of the Pseudozilian Formation over the SB units, shown also on the Mrzlica NW map (Fig. 2a). This younger thrust is then cut by a NW-SE trending dextral strike-slip fault that was already active before the second thrust. A west-dipping normal fault is cutting through the SB formations surely postdating the first thrust and probably predating the younger thrust.

Flinskovo and Čemšeniška Planina

In this area, the formations of the SB start from Ladinian Pseudozilian resedimented volcaniclastic rocks and sandstone, followed by the Bača Dolomite. We emphasise that this contact could as well be a thrust fault meaning that the lower boundary of the Bača Dolomite can be tectonic (similar to Fig. 2a, Thrust Fault I.). In the latter case, however, the Pseudozilian Formation would structurally belong to the Dinarides. Above the Bača Dolomite, follows the Lower Jurassic Krikov Formation, the Middle Jurassic Ponikve Breccia Member, and finally the Upper Jurassic to Lower Cretaceous Biancone Limestone. The SB succession seems to form a klippe above the Carboniferous to Lower Triassic sequence of the Dinarides, as judged from the map of Placer (2008). The eastern boundary of this klippe, just east of the Flinskovo ridge a north–south striking normal fault is positioned between the footwall Pseudozilian and Schlern Formations of the Dinarides and the hanging wall SB units (Fig. 2c). Later, a younger east-west striking thrust (Fig. 2c, Thrust Fault II.) displaced the Triassic Pseudozilian Formation over the SB succession (in the west) with an analogue role as in the Mt. Mrzlica area. In the eastern part of the map, the younger thrust cut across and repeats a Mesozoic succession composed of the Pseudozilian, Schlern and the Biancone Limestone Formations without the presence of the Jurassic rocks of the SB succession; this part does not belong to the SB. Near the Stari Grad we postulate stratigraphic contact between the Schlern and Biancone Formations because such stratigraphic order was followed between the Mt. Krvavica and Mt. Mrzlica (Scherman et al. 2022).

Discussion and Conclusions

Our observations and paleontological studies corroborate previous suggestions (Buser, 1996; Placer, 2008; Rožič, 2016), that the SB units extend eastward of the Ljubljana Quaternary basin, i.e., along the northern flank of the Sava Folds. The studied locations represent the important connection between the eastern and western sequences of SB units studied so far. SB successions are characterized by prominent stratigraphic gaps and are similarly developed in all three research areas. The successions start with the rather thick Bača Dolomite Formation, but its base seems to be a thrust plane near the Tuhinj Valley and on the Mrzlica Mts. An exception is the Čemšeniška Planina where it is not excluded that the succession starts with the Pseudozilian Formation and the basal thrust is just below it. In fact, all the map disposition suggests the dual position of the Pseudozilian Formation; north of the young steep E-W striking thrust the Pseudozilian Formation does not seem to be part of the SB succession, because the Jurassic formations are missing (Stari Grad Fig. 2c, and north of the Mt. Mrzlica, Fig. 2a, b). On the other hand, on the south-eastern corner of the Čemšeniška Planina the Pseudozilian Fm. can be the lower preserved unit of the overlying SB succession, like in many cases in the western SB (Rožič 2006; Gale 2010).

The Bača Formation is followed by the Krikov Formation, documented in two of our sections at Čemšeniška Planina and Mrzlica areas (Fig. 1c/logs 11, 12). No observations of the Krikov Formation were made in the Tuhinj area; however, a 300 m gap in observation could also suggest its possible presence (Fig. 1c/log 10). The Krikov Formation from the study area is dominated by hemipelagic limestone, with the subordinate occurrence of resedimented limestones. Similar successions are found in the Mrzli vrh and Mirna sections (Rožič, 2006; Rožič et al., 2017, 2022), whereas similar developments are found along the entire SB southern margin (Rožič, 2006; Rožič et al., 2019, 2022).

The Perbla Formation and the Lower Member of the Tolmin Formation are missing from the studied sections. The Ponikve Breccia Member was observed and proven by paleontological data from all three areas (Fig. 1c/logs 10, 11, 12). This lithostratigraphic unit was described recently from the entire SB southern margin. The most similar thickness is reported from the Mrzli Vrh, the Ponikve Plateau and Podpurflca sections (Fig.1c/logs 1, 3, 6) (Rožič et al., 2022). The Ponikve breccia passes towards the basin gradually into the lower resedimented limestones that at the type locality (Fig. 1c/log 3, Rožič et al., 2022) occur as calciturbidite interbeds within siliceous limestone and radiolarite. In some transitional sections (Mrzli Vrh, Ponikve Plateau, Trnje, sites 1, 3, 7 on Fig. 1c), the Ponikve Breccia is overlain by these siliceous pelagic sediments (Rožič et al., 2013, 2019, 2022). Our observations at the Čemšeniška Planina area could be similar to the Ponikve Plateau (Rožič et al., 2019), where the fully covered, several meters thick stripe occurs between the Ponikve Breccia and Biancone Limestone. In other studied locations, the Biancone Limestone could lie directly over the Ponikve Breccia, which is observed also in the Mirna Valley sections (Rožič et al., 2019; 2022, see detailed discussion therein). The contact with the overlying Lower Flyschoid Formation is generally erosional in the SB, and the stratigraphic gap encompasses a large part of the Lower Cretaceous and is found practically in all SB successions. The formation is shale-dominated, which is characteristic for some other comparable sections, such as Zapoškar, Škofja Loka (Podpurflca, Dešna, Trnje) and Mirna River sections (Rožič et al., 2022). Our observation near Tuhinj corroborates this general knowledge although the lower contact was not observed.

We conclude that within the northern flank of the Sava Folds, the outcrops of the SB can be traced. The three investigated successions (Fig. 1c/log 10, 11, 12) show close similarities to almost all previously studied Jurassic sections at the southernmost margin sequences of the SB (Rožič et al., 2019, 2022). Therefore, the newly studied successions establish the connection between the western and eastern Slovenian Basin successions. If the studied successions would represent the eastward continuation of the Podmelec Nappe (lowermost imbricate unit of the Tolmin Nappe) needs further consideration.

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Appendix: Microfossils species and their stratigraphic range and palaeoenvironment

The species of each fossil group are listed in alphabetical order.

Cyanophyta

Rivularia lissaviensis (Bornemann, 1887)
Stratigraphic range: Middle Triassic – Aptian.
Environment: this species appears in the silent water of the back reef or lagoon (Haas et al., 2019).

Chlorophyta

Dasycladales
Bystrickyella ottii Barattolo, Rozzi & Romano, 2008
Stratigraphic range: this species was established from the middle Norian.
Environment: shallow marine, platform facies (Barottolo et al., 2008).

Palaeodasycladus mediterraneus (Pia, 1920):
Stratigraphic range: Hettangian – Pliensbachian.
Environment: low-energy inner platform (Rychliński et al., 2018).

Salpingoporella austriaca Schlagintweit, Mandl & Ebli, 2001
Stratigraphic range: Norian.
Environment: inner platform, near the reef (Carras et al., 2006).

Selliporella mg. *donzellii* Sartoni & Crestenci, 1962
Stratigraphic range: lower Bajocian – upper Bathonian.
Environment: low-energy inner platform (Sokač & Grgasović, 2017).

Foraminifera

Aulotortus communis (Kristan, 1957)
Stratigraphic range: Norian – Rhaetian.
Environment: shallow marine platform (Gale et al., 2012).

Aulotortus sinuosus Weynschenk, 1956
Stratigraphic range: Ladinian – Rhaetian.
Environment: shallow marine platform (Gale et al., 2012).

Aulotortus tenuis (Kristan, 1957)
Stratigraphic range: Ladinian? Carnian – Rhaetian.
Environment: shallow marine platform (Haas et al., 2010).

Aulotortus tumidus (Kristan-Tollmann, l964)
Stratigraphic range: Norian – Liassic?
Environment: shallow marine platform (Haas et al., 2010).

Coscinoconus palastiniensis Henson, 1847
Stratigraphic range: Bajocian – Callovian (Haas et al. 2006).
Environment: it is common in the mud facies of the inner platform (Haas et al., 2012).

Coronipora etrusca (Pirini, 1966)
Stratigraphic range: upper Norian – Liassic.
Environment: well-oxygenated low-energy environment (Blau & Haas, 1991).

Everticyclammina praevirguliana Fugagnoli, 2000
Stratigraphic range: upper Sinemurian – lower Bajocian.
Environment: shallow marine low-energy environments in the inner platform (Haas et al., 2019).

Frentzenella crassa (Kristan, 1957)
Stratigraphic range: Rhaetian.
Environment: shallow marine, platform and reef (Rigaud et al., 2013).

Gandinella falsofriedli (Salaj, Borza & Samuel, 1983)
Stratigraphic range: Ladinian – Rhaetian.
Environment: Different shallow marine environments, such as lagoons or upper slopes (Gale, 2012).

Involutina farinacciae Brönnimann & Koehn-Zaninetti, 1969
Stratigraphic range: upper Sinemurian – lower Toarcian.
Environment: ooidal-peloidal facies of the outer platform (Haas et al., 2019).

Ophthalmidium c*oncentricum* (Terquem & Berthelin, 1875)
Stratigraphic range: Hettangian – lower Bajocian.
Environment: outer platform environment (Clerc, 2005).

Ophthalmidium kaptarenkoae Danitch, 1971
Stratigraphic range: Bajocian – Callovian.
Environment: inner and middle shelf environment (Clerc, 2005).

Ophthalmidium terquemi Pazdrowa, 1958
Stratigraphic range: Aalenian – Callovian.
Environment: inner and middle shelf environment (Clerc, 2005).

Parvalamella friedli (Kristan-Tollmann, 1962)
Stratigraphic range: Anisian – Rhaetian.
Environment: Low-energy shallow water environment, such as lagoonal, back-reefal environment or shoal facies (Haas et al. 2019).

Protopeneroplis striata Weynschenk, 1950
Stratigraphic range: Aaleni – end of the Tithonian.
Environment: outer platform ooid shoal environment (Haas et al., 2006).

Tolypammina gregaria Wendt, 1969
Stratigraphic range: Lower Triassic – Rhaetian
Environment: It is an attached epifaunal foraminifera related to low sedimentation rate and mesotrophic conditions (Rodríguez-Martínez et al., 2011).

Triasina hantkeni Majzon, 1954
Stratigraphic range: Rhaetian.
Environment: shallow platform environment (Gale et al., 2012).

"*Trochammina" almtalensis* Koehn-Zaninetti, 1969
Stratigraphic range: Anisian – Rhaetian.
Environment: shallow marine, platform (Gale et al., 2012).

Trochammina alpina Kristan-Tollmann, 1964
Stratigraphic range: Anisian – Rhaetian (Salaj et al., 1983).
Environment: shallow marine, platform and reef (Bernecker, 2005).

Trocholina ultraspirata Blau, 1987
Stratigraphic range: Lower Jurassic.
Environment: shallow marine, platform and reef (Rigaud et al., 2013).

Microproblematicum

Bacinella irregularis Radoičić, 1959 emend. Schlagintweit and Bover Arnal, 2013
Stratigraphic range: Genus Bacinella described from the Ladinian – Albian of the Tethys (Schlagintweit and Bover Arnal, 2012).
Environment: This species is a typical biostrome builder of backreefal or peritidal depositional settings environment (Granier, 2021).

Crescentiella mg. *morronensis* (Crescenti, 1969)
Stratigraphic range: Upper Triassic-Upper Jurassic.
Environment: Shallow marine, mainly in a reef environment (Senowbari-Daryan et al., 2008, Senowbari-Daryan, 2013).

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Pisma Johanna Jacoba Ferberja Geološki opisi Slovenije iz druge polovice 18. stoletja

Letters of Johann Jacob Ferber Geological descriptions of Slovenia from second half of 18th century

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Izvleček

Obravnavana sta prevoda pisem Johanna Jacoba Ferberja (1743–1790), švedskega geologa in mineraloga, ki je septembra 1771 potoval preko Slovenije. Prvo pismo, naslovljeno na Ignaza von Borna, je bilo objavljeno v knjigi »Pisma iz Italije o naravnih čudesih te dežele, ki so bila poslana naslovniku Ignacu plemenitemu Bornu«, ki je izšla leta 1773 v Pragi, drugo pismo, poslano Giovanniju Arduinu, pa najdemo v knjigi »Zbirka razprav s področja kemije, mineralogije, metalurgije in oriktografije«, ki je izšla leta 1775 v Benetkah. Obe pismi vsebujeta razsvetljenski znanstveni opis geologije dela območja današnje Slovenije, ki temelji na takrat veljavnih geoloških teorijah. V članku smo podali kratke življenjepise akterjev, prevoda obeh pisem ter njun komentar in interpretacijo.

Abstract

The two translations of letters by Johann Jacob Ferber (1743–1790), a Swedish geologist and mineralogist, who travelled through Slovenia in September 1771, are discussed. The first letter addressed to Ignaz von Born was published in the book »Briefe aus Wälschland über natürliche Merkwürdigkeiten dieses Landes an den Herausgeber derselben Ignatz Edlen von Born« published in Prague in 1773, and the second letter to Giovanni Arduino was published in the book »Raccolta di memorie chimico-mineralogiche, metallurgiche, e orittografiche« published in Venice in 1775. Both letters represent an Enlightenment scientific description of the geology of part of what is now Slovenia, based on the geological theories valid at the time. In the article, we provide brief biographies of the actors, translations of the two letters, their commentary and interpretation.

Uvod

V človeški zgodovini se je geološko védenje pričelo razvijati hkrati z drugim naravoslovnim znanjem. Človek je bil vedno odvisen od naravnih virov, med katere sodijo tudi mineralne surovine, teh pa ni mogoče najti in izkoriščati brez izkušenj in teoretičnih izhodišč. Tako lahko zametke geološke teorije najdemo že v najzgodnejših spisih, kasneje pa še mnogo več v spisih grških in rimskih filozofov. Ne glede na to, da so začetki geološkega znanja zelo stari, se prava geološka znanost prične razvijati mnogo kasneje, in sicer v razsvetljenskem 18. stoletju, ko se je geologija pričela razvijati v smeri sodobne znanosti. Iz tega razloga pogosto govorimo o razsvetljenski geologiji. Razsvetljensko stoletje je zelo pomembno tudi za razvoj geologije na območju današnje Slovenije in sosednjih pokrajin. Čeprav tudi v Sloveniji najdemo nekatera starejša dela, ki vsebujejo elemente geološkega znanja, na primer pri Janezu Vajkardu Valvasorju (1641–1693), je razsvetljensko 18. stoletje tisto obdobje, ko geologija zaživi v celoti, celo več, doživi svojevrsten vrhunec. Zlasti v drugi polovici 18. stoletja je na območju današnje Slovenije nastala vrsta pomembnih del. Na tem mestu omenimo le nekatere pomembne osebnosti, kot so Giovanni Antonio Scopoli (1723–1788), Baltazar Hacquet (1739/1740–1815) in Žiga Zois (1747–1819), ki so se v večji ali manjši meri ukvarjali s področjem geologije. V tistem času je ponoven zagon doživel rudnik živega srebra v Idriji. Svojevrsten pojav živega srebra pa ni pritegoval le izobražencev, ki so delovali v Idriji ali na tedanjem Kranjskem, temveč tudi znanstvenike in intelektualce iz širšega evropskega prostora. Ti so rudnik v Idriji pogosto obiskovali in o tem ohranili pomembna pričevanja.

Med pomembne obiskovalce rudnika v Idriji sodi tudi Johann Jacob Ferber (1743–1790), švedski naravoslovec, geolog in mineralog. Formalno gledano Ferber velja za avtorja prvega znanstvenega opisa rudnika v Idriji z naslovom *Beschreibung des Quecksilber-Bergwerks zu Idria in Mittel-Crain* (Opis živosrebrnega rudnika v Idriji na srednjem Kranjskem), ki je kot samostojna publikacija izšel leta 1774 (Čar, 1991; Ferber, 1991; Čar & Režun, 2002). Vendar so podrobne raziskave pokazale, da je Ferber za to delo le posodil svoje ime, pravi avtor pa je najverjetneje Ignaz von Born (1742–1791), pomembna osebnost avstrijskega razsvetljenstva (Brenčič, 2014a). Drugo Ferberjevo delo, ki je prav tako pomembno za razumevanje geološke znanosti v Sloveniji, je knjiga *Briefe aus Wälschland über natürliche Merkwürdigkeiten dieses Landes an den Herausgeber derselben Ignatz Edlen von Born* (Pisma iz Italije o naravnih čudesih te dežele, ki so bila poslana naslovniku Ignacu plemenitemu Bornu – skrajšano Pisma iz Italije). Delo se prične s pismom, v katerem Ferber opisuje svojo pot preko Slovenije in razpravlja o geoloških danostih območja, ki ga je obiskal. Čeprav gre pri tem z današnjega vidika za nekoliko nenavaden zapis, je to eden prvih znanstvenih in teoretičnih opisov geoloških razmer na ozemlju Slovenije, ki je napisan na podlagi takrat aktualnih geoloških znanstvenih teorij. To je eno prvih znanih besedil o geologiji Slovenije, ki izhaja iz začetka razvoja sodobnih geoloških doktrin.

Prvo Ferberjevo pismo iz dela Pisma iz Italije na svojevrsten način dopolnjuje drobna publikacija *Lettera Orittografica del Celebre Signor Gian-Giacomo Ferber del Collegio Metallico di Svezia, scritta dalla Boemia al chiarissimo signor Giovanni Arduino Pubblico Soprantendente all Agricultura, etc. in Venezia* (Oriktografsko pismo slavnega gospoda Johanna Jacoba Ferberja, člana švedskega montanističnega kolegija, napisano iz Češke dragemu gospodu Giovanniju Arduinu, javnemu kmetijskemu uradniku v Benetkah – skrajšano Pismo Arduinu). V njej je objavljeno Ferberjevo pismo naravoslovcu in geologu Giovanniju Arduinu, ki je postavil eno prvih teoretično konsistentnih stratigrafskih teorij. Tudi to delo je pomembno za poznavanje razvoja geologije na območju Slovenije.

Sl. 1. Johann Jacob Ferber (1743–1790).
Fig. 1. Johann Jacob Ferber (1743–1790).

V nadaljevanju podajamo prevod prvega Ferberjevega pisma, ki je objavljeno v Pismih iz Italije, ter nekatere odlomke njegovega pisma Giovanniju Arduinu. Čeprav prvo pismo deloma opisuje tudi območje izven meja današnje Slovenije, ga zaradi pomena podajamo v celoti. Pismo Arduinu pa navajamo le v tistih delih, ki omogočajo dodatne vpoglede v Ferberjevo razumevanje geoloških razmer na tem območju, saj se vsebinsko v veliki meri prekriva s prvim pismom in je v nekaterih opisih bolj površno kot prvo pismo. V nadaljevanju na kratko povzemamo življenjepise Johanna Jacoba Ferberja, Ignaza von Borna in Giovannija Arduina, predvsem z vidikov, ki so pomembni za razumevanje in takratno tolmačenje geoloških razmer na območju današnje Slovenije. Sledijo pregled dejstev o nastanku obeh pisem, njun prevod in znanstvenokritična analiza. V okviru slednje podajamo opombe s komentarji in interpretacijo v kontekstu sodobnega razumevanja razvoja razsvetljenske geologije.

Biografska izhodišča

Johann Jacob Ferber (1743–1790) je bil švedsko-nemški geolog in mineralog, čigar študijski mentor je bil Carl von Linné (1707–1778). Rodil se je septembra 1743 v Karlskroni na južnem Švedskem. Študiral je na Univerzi v Uppsali na Švedskem, kjer je leta 1763 doktoriral. Disertacija je bila posvečena botaniki, vendar se je že v tem času navduševal predvsem za mineralogijo. Leta 1765 je odpotoval na svojo prvo pot v tujino. Najprej se je ustavil v Berlinu, kjer se je iz kemije in mineralogije izpopolnjeval na Pruski kraljevi akademiji znanosti. Nato je obiskal Češko, Nemčijo, Nizozemsko, Francijo in Anglijo. V tem času se je verjetno začelo veliko prijateljstvo z Ignazem von Bornom, ki je bil prav tako pomemben mineralog, poleg tega pa je bil izredno pomembna in vplivna razsvetljenska osebnost. S te poti se je Ferber vrnil leta 1770, vendar je kmalu ponovno odpotoval, tokrat najprej na Češko. Iz Prage je leta 1771 odšel na Dunaj in nato na pot po Italiji, ki jo je zaključil avgusta 1772. To je obdobje, ki ga je obravnaval v delu Pisma iz Italije. V letih 1774–1783 je deloval kot profesor fizike na visoki šoli v Mitauu v današnji Jelgavi v Latviji. Leta 1783 so ga zvabili v St. Petersburg, kjer je postal član akademije znanosti in profesor mineralogije, vendar je od tod leta 1786 na hitro odšel, skorajda pobegnil, ker mu je cesarica Katarina Velika namenila vodenje državnih rudnikov v Sibiriji. Po prihodu iz Rusije se je naselil v Berlinu, vendar je od tod kmalu ponovno odpotoval na Češko. Ob vrnitvi v Berlin se je zaposlil pri pruski vladi. Zanjo je po vsej Evropi zbiral pomembne informacije o montanistiki, zlasti tam, kjer so imeli Prusi neposredne gospodarske ali politične interese. Med svojimi številnimi potovanji se je leta 1789 znašel v Švici, kjer ga je v Bernu zadelo nekaj zaporednih kapi, po katerih si ni več opomogel. Številna potovanja so terjala svoj davek, aprila 1790 je umrl (Zenzén, 1956; Hoppe, 1990; 1995; Beretta, 2007; Brenčič, 2014a).

Ferber je bil zelo plodovit pisec. Napisal je številne knjige in članke, veliko se je ukvarjal z recenziranjem, zlasti geoloških del. Pisal je tudi potopise in izdajal zbirke svojih dopisovanj z drugimi pomembnimi raziskovalci. Vsebina teh del je danes znana le še specialistom za zgodovino razsvetljenske geologije.

V času svoje kariere je Ferber veljal za pomembnega mineraloga, čigar slava je segala v širši mednarodni prostor. Še dve desetletji po njegovi smrti je bilo objavljenih nekaj njegovih del. Vendar je kmalu nato utonil v pozabo, njegovega imena, tudi v delih, ki obravnavajo zgodovinski razvoj mineralogije, skorajda ni več mogoče zaslediti. Morda je to posledica dejstva, da je večina njegovih del napisana v nemščini, večina sodobne zgodovine geologije pa je interpretirana in objavljena v angleškem jeziku.

Poznavanje in analiza Ferberjevega dela sta za razumevanje razvoja geološke znanosti na območju današnje Slovenije, zlasti Idrije, izredno pomembna. Kot znanstvenik, ki je prihajal iz širšega evropskega prostora in ki je v svojem času veljal za enega najpomembnejših mineralogov in geologov, je z osebnimi in verjetno tudi pisnimi stiki na območje nekdanje Kranjske prinašal aktualna znanstvena spoznanja. Iz teh informacij so se oplajali intelektualci, ki so delovali na tem območju, hkrati pa so do njih vzpostavljali kritično distanco. Na njihovo delo je Ferber vplival tudi s svojimi kasnejšimi deli in zapisi. Po izidu prve in druge knjige Oriktografija Kranjske, ki ju je Baltazar Hacquet objavil v letih 1778 in 1781, je Ferber v nemškem referatnem časopisu *Allgemeine deutsche Bibliothek* v letih 1780 in 1782 objavil oceni obeh knjig, ki sta bili za Hacqueta porazni. Negativna je bila zlasti kritika druge Hacquetove knjige, v kateri se avtor podrobno posveča rudniku v Idriji. Ferberjevi oceni sta v veliki meri vplivali na nadaljnje znanstveno sprejemanje Hacquetovega dela, pa tudi neposredno na Hacqueta samega. Kritiki nista le oceni njegovega dela, temveč v veliki meri tudi analiza geoloških razmer na območju Slovenije, zlasti Idrije, saj Ferber polemizira z avtorjevimi geološkimi opisi in razlagami, pri tem pa podaja tudi lastne geološke interpretacije. Podrobna analiza Ferberjevih ocen prvih dveh knjig Hacquetove Oriktografije Kranjske nas še čaka.

Naslovnik Ferberjevih Pisem iz Italije je bil Ignaz von Born (1742–1791). Rojen je bil v današnji Albi Iuliji, nekdanjem Karlsburgu, v Romuniji. Študiral je na dunajskem jezuitskem kolegiju, iz katerega je izstopil in leta 1763 v Pragi zaključil študij prava. Zatem se je preusmeril v študij montanistike, ki jo je obiskoval v Schemnitzu, današnji Banski Štiavnici. Leta 1769 je v Pragi postal rudarski uradnik (Bergrat). Leta 1770 pa se je odpravil na znamenito popotovanje po Madžarski in Transilvaniji. S potovanja je Ferberju pošiljal pisma, ki jih je ta leta 1774 objavil v knjigi *Briefe über mineralogische Gegenstände, auf seiner Reise durch das Temeswarer Bannat, Siebenbürgen,*

Sl. 2. Ignaz von Born (1742–1791).
Fig. 2. Ignaz von Born (1742–1791).

Ober- und Nieder- Hungarn an den Herausgeber derselben, Joh. Jacob Ferber, geschrieben (Mineraloška pisma Joh. Jacobu Ferberju s potovanja po Temišvarskem Banatu, Sedmograškem, Zgornji in Osrednji Madžarski). V letih 1772–1776 Born ni opravljal državnih služb, vendar je bil v tem času zelo aktiven. Leta 1776 je na Dunaju prevzel Naturalienkabinet predhodnika današnjega Naturhistorisches Museum. Born velja za enega najpomembnejših mineralogov svoje dobe. Sodeloval je pri nastanku in urejanju še danes pomembnih mineraloških zbirk. Od tod izvira njegov velik vpliv na mineraloško sistematiko druge polovice 18. stoletja. Sedemdeseta leta 18. stoletja so čas, ko se je njegov družbeni vpliv zelo povečal. Bil je mojster najpomembnejše dunajske in s tem avstrijske prostozidarske lože »Zur wahren Eintracht« (slv. K pravi slogi). V svojih delih je segal na številna področja, od prostozidarstva do mineraloških in montanističnih objav, pravnih in filozofskih del ter književnosti in številnih pamfletov. Intenzivno se je ukvarjal z eksperimentiranjem. Leta 1784 je razvil nov amalgamacijski postopek. Za posledicami bolezni je leta 1791 globoko zadolžen umrl na Dunaju (Lindner, 1986; Brenčič, 2014a).

Born se je zelo zanimal za rudnik živega srebra v Idriji, najverjetneje je tudi pravi avtor prvega znanstvenega dela o njem (Brenčič, 2014a). Nekatera dela, ki so pripisana Ferberju, so verjetno njegova, saj kot rudarski uradnik ni smel objavljati. Iz njegovih in Ferberjevih del izhaja, da sta se intenzivno zanimala tudi za geologijo na širšem območju današnje Slovenije, informacije o tem pa sta posredovala v širši evropski prostor – v kakšni meri in o čem, je treba še raziskati. Izpričano je Bornovo poznanstvo z Žigo Zoisom in drugimi intelektualci iz Kranjske. Od tod naj bi izvirala domneva, da je bil Zois član njegove prostozidarske lože, kar pa je malo verjetno (Košir, 2015). Prav tako obstajajo dokazi o osebnih stikih med Bornom, Ferberjem, Scopolijem in Hacquetom.

Sl. 3. Giovanni Arduino (1714–1795).
Fig. 3. Giovanni Arduino (1714–1795).

Biografija Giovannija Arduina (1714–1795) je mnogo manj razburljiva kot Ferberjeva in Bornova, zato pa so njegova dela veliko pomembnejša za razvoj geoloških znanosti. In čeprav se je v enem od svojih pisem Ferber iz Arduina norčeval, češ da je že nekoliko star, je preživel oba. Rodil se je v Caprinu pri Veroni. Imel je zelo dobro izobrazbo s področja rudarstva in metalurgije, na področju kemije in mineralogije pa je bil samouk. Študiral je v Veroni, pri osemnajstih pa je odšel delat v rudnike na Tirolsko. Nato je delal v Toskani, Modeni in Vicenzi. Do leta 1769 je opravljal delo deželnega geodeta v Livornu, zatem pa je postal višji uradnik za kmetijstvo v Beneški republiki – to funkcijo je opravljal do svoje smrti v Benetkah (Vaccari, 2006). Zaradi rudarske in geodetske prakse v rudnikih v širšem italijanskem in avstrijskem prostoru je imel izreden občutek za prostor, hkrati pa je imel neposredne izkušnje iz rudnikov. Njegovi geološki profili že imajo značaj pravih stratigrafskih profilov z vrisanimi litostratigrafskimi elementi in prvimi zametki strukturnih interpretacij. Postavil je stratigrafsko klasifikacijo sedimentov in kamnin ter jih razdelil v štiri skupine, ki sestavljajo klasifikacijski sistem. Ferber se je z njim srečal ob obisku Padove septembra 1771.


Herrn Johann Jakob Ferbers
Briefe aus Wälschland
über
natürliche Merkwürdigkeiten
dieses Landes
an den Herausgeber derselben
Ignatz Edlen von Born,
des heil. röm. Reichs Rittern, kais. königl.
Bergrath, und Mitglied der kön. Schwedischen
Akademie der Wissenschaften.

Prag 1773.

Sl. 4. Naslovna stran Ferberjevega dela pisma iz Italije.

Fig. 4. First page of Ferber‘s work written in German Travels through Italy.

Prvo pismo iz Italije

Izhodišča

Knjiga Pisma iz Italije o naravnih čudesih te dežele, ki so bila poslana naslovniku Ignacu plemenitemu Bornu, je izšla leta 1773 v Pragi pri založbi Wolfgang Gerle. Izvod izvirnika je ohranjen tudi v NUK in izhaja iz knjižnice Žige Zoisa. Nemško besedo *das Wälschland* v naslovu bi bilo morda smiselneje prevajati kot Laško, vendar smo se zaradi lažjega razlikovanja in geografske opredelitve odločili, da uporabimo današnji geografski označevalec Italija.

Na velik tedanji pomen Ferberjeve knjige kažejo tudi njeni prevodi. Prevedena je bila v angleščino in francoščino. Francoski prevod je izšel leta 1776 v Strasburgu pri založniku Bauer et Treuttel. Delo je prevedel in komentiral član akademije in montanist Philippe-Frédéric de Dietrich (1748–1793). Istega leta je izšel tudi angleški prevod v Holbournu v Londonu pri tiskarju Davisu, ki je tiskal za Royal Society. Angleški prevod pa je zelo površen, saj je prevajalec besedilo krajšal. Knjigo je prevedel in obsežne opombe napisal Rudolf Erich Raspe (1736–1794), ki je v svetovni književnosti najbolj znan kot avtor dela o Lažnivem Kljukcu ali baronu Münchhausenu (Brenčič, 2014b), veliko pa se je ukvarjal tudi z geologijo in mineralogijo.

Prvo pismo, ki je predmet naše analize, je Ferber napisal iz Benetk in je datirano s 25. septembrom 1771. V originalni objavi iz leta 1773 je zapisano v gotici in objavljeno na 14 straneh.

Posamezne krajše dele prevoda pisma, ki so pomembni za razumevanje Ferber/Bornove knjige o rudniku živega srebra v Idriji, smo že objavili (Brenčič, 2014a), na tem mestu pa podajamo integralni prevod celotnega pisma. Pismo je iz nemškega izvirnika prevedeno s pomočjo Raspejevega angleškega prevoda. Zaradi lažjega sklicevanja so odstavki v pismu numerirani z oglatimi oklepaji od [B1] do [B16]. S kratico B smo odstavke označili zaradi tega, ker gre za pismo Bornu, v nadaljevanju kratico A uporabljamo za pismo Arduinu.

Sl. 5. Rudolf Erich Raspe (1736–1794).

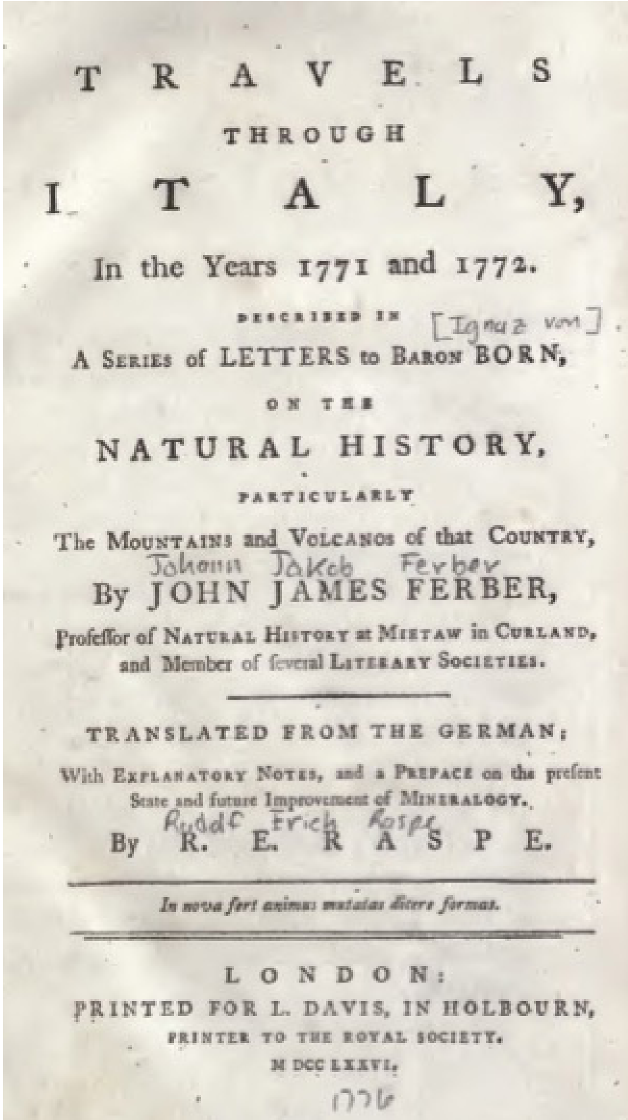
Fig. 5. Rudolf Erich Raspe (1736–1794).

Prevod prvega pisma

Nadvse spoštovani in dragi prijatelj!

[B1] Končno imam čas, da Vam pišem iz te krasne dežele, ki sem si jo tako dolgo želel videti in kjer sem se na majhnem območju, na katero sem vstopil med Benetkami in Gorico, prepričal, da si zasluži pohvale, ki jih opisujejo potopisci; z upoštevanjem mile klime, plodov narave in lepote, po katerih presega skoraj vso preostalo Evropo. V Benetkah sem še tujec in svojo radovednost po znamenitostih, ki me vabijo, sem žrtvoval za nekaj enakega užitka pogovora z Vami. Več kot nagrajen bom, če Vam bodo opisi mojega potovanja z Dunaja do sem, ki bi Vam jih rad posredoval, naredili pol toliko zadovoljstva, kot sem ga občutil jaz, ko sem opazoval naravo. Ko bom nadaljeval svoje potovanje po Italiji, bom, v skladu z Vašo željo, opisoval naravna čudesa, ki jih bom videl, zlasti tista, ki sodijo v oriktografijo in fizikalno geografijo, opise ostalih zanimivosti lahko najdete v drugih knjigah. Tu bom uporabil svobodo, ki ste mi jo dali, in se ne bom veliko posvečal eleganci. Če se bo kaj zgodilo proti Vaši volji, mi morate oprostiti, iz lastne izkušnje veste, da množica objektov zelo pogosto odvrača in šibi pozornost najboljših naravoslovcev in da potovanje ne dopušča ne časa in ne priložnosti za eksperimente in metodološka razlikovanja. Pišem Vam kot prijatelju, o katerega dobri volji imam toliko dokazov in ki sam namerava potovati po Italiji, tako da bo zlahka popravil moje nenamerne napake; ki mu bom opisal, kar bom videl, in tudi to, kar bom verjetno izpustil ter česar sploh ne bom videl ali pa ne bom mogel dovolj natančno preiskati. Sedaj me poslušajte!

[B2] Takoj ko zapustiš Dunaj, opaziš iz smeri Madžarske, kot tudi v smeri proti Avstriji in Štajerski, dolge razpotegnjene verige med seboj povezanih apnenčevih hribov, ki so oblikovani kot valovi in sem jih opazoval na celotni poti od Dunaja do Vipave. Dve poštni postaji pred Gorico sem jih deloma prevozil, deloma pa so me spremljali. Ponekod se vzpenjajo izrazito visoko ali pa se razširijo ter so razdeljeni z globokimi dolinami in široko raztezajočimi se ravninami, po katerih tečejo reke. Preko teh hribov je speljana odlična cesarska deželna cesta. Pri Vipavi, kjer se prične milo italijansko podnebje in trta, se gorovje razdeli. Na levi se razteza skozi Furlanijo in vzdolž Jadranskega morja do Istre, Dalmacije in otočja, toda na desni se razteza do Tirolskih Alp, kjer se te združijo s Tridentskim in Veroneškim gorovjem. Med tem gorovjem je do Benetk ravna pokrajina z vinsko trto, koruzo, ajdo, prosom in sirkom, zasajenih pa je le malo žit. Apnenec, ki tvori prej omenjena go-


TRAVELS
THROUGH
ITALY,
In the Years 1771 and 1772.
DESCRIBED IN [Ignaz von]
A SERIES of LETTERS to BARON BORN,
ON THE
NATURAL HISTORY,
PARTICULARLY
The MOUNTAINS and VOLCANOS of that COUNTRY,
Johann Jakob Ferber
By JOHN JAMES FERBER,
Professor of NATURAL HISTORY at MIETAW in CURLAND,
and Member of several LITERARY SOCIETIES.

TRANSLATED FROM THE GERMAN;
With EXPLANATORY NOTES, and a PREFACE on the present
State and future Improvement of MINERALOGY.
Rudolf Erich Raspe
By R. E. RASPE.

In nova fert animus mutatas dicere formas.

LONDON:
PRINTED FOR L. DAVIS, IN HOLBOURN,
PRINTER TO THE ROYAL SOCIETY.
M DCC LXXVI.
1776

Sl. 6. Naslovna stran angleškega prevoda Ferberjevega dela Pisma iz Italije.

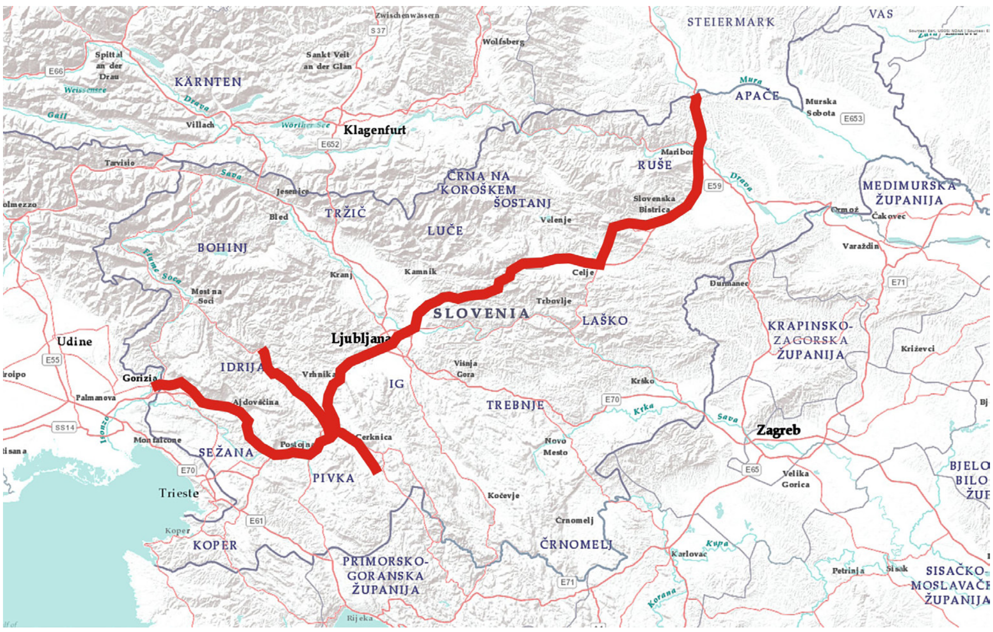
Fig. 6. First page of English translation of Ferber's work Travels through Italy.

rovja, je v večjem delu svetlo siv, vendar je tu in tam njegova barva črna, v celoti ali pa razpršeno, kot črni klini znotraj svetlo sivega apnenca. V nekaterih primerih so apnenčeve gore v celoti črne. Trdota kamnine je povsem drugačna kot v Avstriji, na Štajerskem in Kranjskem je dober marmor, ki ga lomijo v kamnolomih. Njegova zrna so v večji meri drobna, gosta in močna, ne zaznamo jih, redko je luskast in nikoli slan. Znotraj lahko najdemo okamnine iz velikih in manjših morskih školjk, vendar v majhnem številu. Ti hribi so v Avstriji vse do meja Štajerske neporaščeni z gozdom ter v večji meri posajeni z vinsko trto in žiti; toda na Zgornjem Štajerskem se povzpnejo do znatnih višin, poraščeni so z jelovim in smrekovim gozdom ter ločeni z globelmi, ki so poraščene z listavci. Na Spodnjem Štajerskem in vsem Kranjskem sem jih videl poraščene z brezami, bukvami in kostanji, razen nekaterih krajev, kjer rasteta jelka in smreka. V celoti jih sestavljajo bolj ali manj horizontalne in debele plasti ali telesa in so pravo dvignjeno gorovje, ki glede na okoliške pokrajine ležijo na skrilavcih, ki se zvezno razprostirajo v podlagi. Ti skrilavci so pravi glinavci modre ali črne barve ali tudi tako imenovani roženčevi skrilavci, sestavljeni iz kremena in sljude, v katerih najdemo tudi glinasto mešanico.

[B3] Skoraj na vsakem koraku sem imel priložnost prepričati se o tem, kako ta skrilavec neprekinjeno poteka pod apnenčevimi hribi. Včasih izdanja na površino in se tako nadaljuje na določeni razdalji, toda kmalu nato se skrije pod apnenčev pokrov. Svinčevi rudniki na Štajerskem in rudnik živega srebra v Idriji ležijo v tem skrilavcu, pod pridruženim debelim apnencem, ki leži na njih. Na podlagi vzorcev in poročil s Tirolske, o katerih ste mi Vi, dragi prijatelj, pripovedovali, sem opazil, da ima ta sosednja dežela enako zgradbo, in čeprav v štajerskih rudnikih železa v okolici Eisenerza kopljejo rudo v apnencih, ni nobenega dvoma, da je v večjih globinah skrilavec. Želel bi Vam predstaviti vsaj nekaj krajev, v katerih sem imel na svoji poti skozi Avstrijo, Štajersko in Kranjsko priložnost opazovati značilnosti teh hribov in vse ostalo, kar bi si zaslužilo Vašo pozornost.

[B4] V Bistrici na Muri, blizu Pegaua (poštna postaja) na Štajerskem, najdemo rudnik svinca, ki je v lasti barona von Heipela. Rudnik sestavljajo: 1. Paulov glavni vpadnik in zračnik, 2. Martinov glavni šaht, 3. Nepomukova štolna, 4. Marijina in Melhiorjeva štolna, 5. Elizabetina štolna in 6. Novi Barbarin šaht. Tu pridobijo letno od 8.000 do 9.000 centov svinčeve rude, ki vsebuje 3 kvinte do 1 lot srebra. Svinčeva ruda je iz drobnih kristalov ter se nahaja v žilah kremena in apnenca, ki potekajo skozi moder skrilavec, preko katerega se vzpenja štajersko apneno gorovje, poraščeno z jelovim gozdom. Rudnik s šahti in štolnami leži malo nad dnom doline reke Mure, ki teče zelo blizu rudnika, rovi so izkopani v isti ravnini. V njej se konča apnenec in v notranjost nadaljuje skrilavec, v katerem je izkopan Paulov vpadnik, ki vpada do globine 52 klafter. V tem šahtu delajo in izvažajo s konji, celo vodno kolo poganjajo konji. Tako bo vse dotlej, dokler ne bo dokončano novo vodno kolo. Na površju ležeči goli apnenec je brez kakršnih koli žil, iz gostih in trdih zrn, vsebuje pa nekaj malega okamnin. V Votschbergu, 5 do 6 ur od Bistrice, je rudnik premoga, vendar je boljši rudnik v Limu na Zgornjem Štajerskem, 10 milj od tod. Reka Mura me je spremljala na poti od Kriglocha preko Merzhofna, Brugga, Radelsteina, Pegaua in Gradca in še dalje. Kaže, da je dolina, po kateri teče reka, nastala z divjim prebojem skozi apnenčevo hribovje, ki ga sedaj opazujemo ob straneh, ali s počasnim odnašanjem in poglabljanjem z vodo. V Gradcu sem z velikim veseljem pregledal zbirko naravnih zanimivosti v jezuitskem kolegiju, ki z minerali in insekti ni tako revna in po kateri me je vodil učeni pater Biwald, dober botanik. Od Gradca do Gorice sem se moral ozreti za poštno kočijo in poiskati kraje, ki jih bom sedaj poimenoval.

[B5] Med Ehrenhausnom in Mariborom sem se spustil po pobočjih visokega hriba iz sivega apnenca. Kosi apnenca, ki so ležali na cesti, so vsebovali sledove okamenelih polžev. Tu sem našel tudi kose črnega apnenca, ki je vseboval siva zrna. Ko sem prešel ta hrib, se je nadaljevala dolina med Mariborom



Sl. 7. Pregledni prikaz Ferberjeve poti po Sloveniji.

Fig. 7. Schematic representation of Ferber's travel through Slovenia.

in Bistrico (drugo naselje, čeprav se imenuje enako kot Bistrica ob Muri), ki je tu zadnje naselje. V celotni dolini ni bilo več vidnih apnencev, vendar so na površini, ki je bila pokrita z zemljo, kakor tudi kršje, ki je bilo razbito zato, da bi izboljšalo cesto, ležali črnikasti in modrikasti glinavci, deloma roženčevi skrilavci, ki jih tvorita kremen in sljuda.

[B6] Za Bistrico se hribi ponovno dvignejo in na vrhu hriba se ponovno pojavi siv apnenec, ki vsebuje, čeprav malo, nekaj velikih morskih školjk ostrig, pektinid in njim podobnih. Tudi tu je apnenec iz gostih zrn, toda najvišji del je bil porozen in rahel kot kak lehnjak, v katerem so bili zaobljeni prodniki in druge nesprijete kamnine povezani med seboj. Na drugih mestih so te plasti vsebovale deformirane ali podolgovate školjkaste pizolite, ki so bili sprijeti med seboj. Našel sem tudi črn apnenec in v njem sive vključke – v nekaterih delih je bil otrdel in nato tudi črn roženec. Prav tako sem videl črn apnenec z belimi žilami. Pri Bistrici in tudi pred tem med Ehrenhausnom in Mariborom ležijo različne leče iz modro sivega trapa z vključenimi črnimi večstranskimi kristali šorlita, ki so kratki in s povprečnim prečnim presekom.

[B7] Med Bistrico in Konjicami sem našel naslednje leče: 1. velike rdeče granate v zelenem zrnatem šorlitu in med njimi drobne delce bleščeče sljude, 2. velik črn žilnati šorlit v belem kremenu, 3. zelen jaspis. Zavedam se, da prosto ležeči kosi kamnov niso pravi dokaz, ne glede na to pa dajejo občutek o tem, kakšno je sosednje hribovje. Če so kot material za rekonstrukcijo nakopičeni ob cesti, je to vzrok, da lahko upravičeno sklepamo na kamnolome v bližini, zlasti če se ne pojavljajo v zaobljeni obliki, kar bi kazalo na njihov izvor v bližnji reki, temveč so ostri in sveže razbiti.

[B8] Na tem predelu je apnenčevo gorovje pokrito s tanko plastjo breče, ki je sestavljena iz zaobljenih prodnikov, zacementiranih skupaj s kalcitom.

[B9] Med Celjem in Vranskim sem na poti našel rožencu podobno, otrdelo rdečo zrnato glino ali bolus z vključenimi kremenovimi žilicami.

[B10] Med Vranskim in Šentožboltom je takoj pod prvim krajem zgrajena piramida, ki označuje mejo med Štajersko in Kranjsko, povsem poleg nje pa je iz kamna zgrajen slavolok. Tu stoji precej visok mizasti hrib iz skrilavca, ki se razteza v bližino Ljubljane. Vendar v daljavi vidimo apnenec, s katerim so pokrite vzpetine skrilavca.

[B11] Nad podobne skrilave hribe se med Ljubljano in Vrhniko vzpenja apnenčev pokrov. V gozdu pred Ljubljano sem na površini hriba našel majhno plast rdečkastega morskega peska, ki izvira s površja hribovja in ki ga kopljejo za potrebe vzdrževanja ceste.

[B12] Med Vrhniko in Idrijo so skrilavi hribi prekriti z običajnimi apnenci, ki so na veliki dolžini svetlo sivi, nato pa se spremenijo v črno obarvane.

[B13] Idrija je majhno neurejeno rudarsko mesto v zelo globoki dolini, na obeh straneh reke z enakim imenom, z visokimi gorami iz črnega apnenca, ki se vzpenjajo na obeh straneh. V tej dolini se iz globine na plano vzpenja črn skrilavec, ki vpada poševno ter ima v talnini in krovnini apnenec. Znameniti rudnik živega srebra se nahaja v njem, skrilavec pa je bolj ali manj prežet z živim srebrom in cinabaritom. Razteza se do 20 idrijskih rudarskih klafter globoko in v širino od 200 do 300 klafter. Vpad in površina te plemenite skrilave žile sta zelo spremenljiva in nepredvidljiva. Pravokotna globina glavnega jaška je 111 klafter. Izognil se bom opisovanju tukajšnjih rud, ker jih imaš v svoji zbirki, poleg tega pa jih je opisal že gospod rudarski uradnik Scopoli v svoji razpravi *de Hydrargio Idriensi*. Kljub temu pa imam manjšo opombo: na stenah rudnika sem videl halotrictum gospoda Scopolija, ki je bil zaradi cinabarita znatno pordečen. Tu je taljenje in žganje rude skrivnost, zaradi česar nobenemu tujcu ne dovolijo, da bi obiskal žgalnico, čeprav njena zunanjost že na prvi pogled priča o tem, da je njihova metoda zelo podobna tisti, ki jo uporabljajo v Almadenu v Španiji in ki jo je zelo natančno opisal gospod Jussieuj v razpravah kraljeve družbe v Parizu. Daleč od tega, da bi bila ta metoda dobra in brez potrebe po izboljšavah. Vendar verjetno ne razmišljajo tako, ker v nasprotnem primeru ne bi bilo nobenega razloga za takšno skrivanje. Nič ni bolj nasprotnega napredku znanosti in celo napredku držav kot takšno ustvarjanje skrivnostnosti.

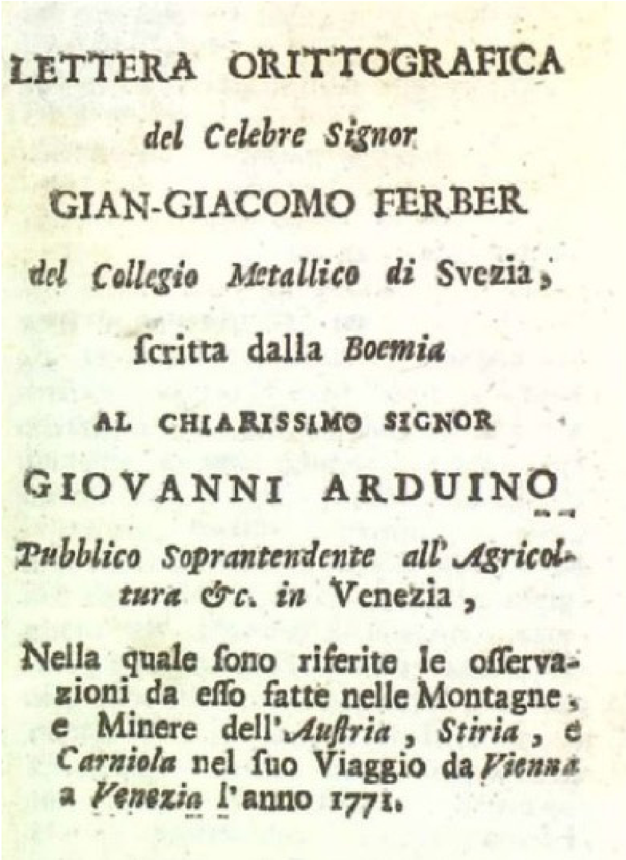
[B14][1] Primer Francoske akademije, ki objavlja do sedaj neznane podatke, bi lahko bil za druge narode spodbuda za javno posnemanje; in še več kot to, ker Akademija deluje po darežljivih principih, ki so razloženi v Preface v Spectacles des Arts. Tako bi se posnemanje prav gotovo izkazalo kot uspešno in obvladljivo ter v dobro človeštva. Poleg tega je živega srebra v Idriji v izobilju in, z izjemo Zwybruckna in Palatinata, ga je v Evropi težko najti, zato ne vidim nobenega smisla, zakaj žganje obravnavajo s takšno skrivnostnostjo nasproti tujcem, ki trpijo pomanjkanje te dobrine. Narava je dala Idriji tako izjemno količino, da jo je dovolj za potrebe Evrope in celo Amerike. Če želijo zadržati določeno ceno, jim njihove surovine in cene ni treba podvreči reguliranim omejitvam. Če želijo, lahko z nizkimi cenami premagajo katerega koli tekmeca. Dolgo je že tega, kar smo na Švedskem

[1] Na tem mestu smo zaradi preglednosti besedila namerno vrinili odstavek, tako kot je storil prevajalec v angleščino Raspe.

razpisali nagrado za izboljšanje pridobivanja našega bakra; na podlagi tega smo povabili vse švedske in tuje kemike. Tako je, za to smo podelili plemstvo in druge velike ugodnosti proslavljenemu Kuncklu, čeprav njegov predlog novega procesa ni v celoti zadovoljil naših pričakovanj. Kljub temu je naš baker najboljši v Evropi, pri čemer se sploh ne branimo, da bi se njegovega taljenja in predelovanja naučili na Madžarskem ali v drugih deželah. Kakršno koli izboljšanje takšne vrste lahko pričakujemo od kemije in metalurgije, toda kako naj ga dosežemo, če je še tistim, ki posedujejo nekaj znanja, prepovedan vpogled v osnovne postopke. Obiskal sem rudnike živega srebra v Palatinatu in Zweybrucknu, opazoval sem taljenje, seznanjen sem s tem, kakšen proces uporabljajo v Almadenu, in kar je na vsem tem, kemija in metalurgija sta me naučili principov teh postopkov. Le želim si lahko, da bi v moji deželi odkrili tako bogat rudnik živega srebra, kot je v Idriji. Povsem prepričan sem, da naši teoretični plavžarji ne bodo imeli težav s tem, kako obvladati rudo.

[B15] Med Planino in Postojno sem srečno prečkal dobro znani gozd, ki se razteza vse do Turčije in od koder vdirajo tolpe turških roparjev, ki ne napadajo le popotnikov, temveč vpadajo tudi v vasi, kakor se je zgodilo pred nekaj leti v Planini, kjer so ubili gospodarja v hiši, v kateri sem imel skromno kosilo. Helebarde cesarjevih vojakov, ki so nameščeni po vaseh, so zelo prispevale k izboljšani varnosti. Hribi iz apnenca pri Planini in Postojni ponujajo mnogo podzemnih jam, ki so obložene z različno oblikovanimi stalaktiti, v katerih lahko prepoznamo različne figure. Te potekajo tudi do 2 milji daleč pod zemljo in sprejemajo vodo iz različnih rek, kot na primer Postojnska jama reko Pivko. Znamenito Cerkniško jezero, dve uri oddaljeno od Planine, je nekaj časa plovno, nato ribarijo, sejejo in žanjejo; še več, pravijo, da se voda iz njega izprazni v takšne jame.

[B16] Med Vipavo in Meštrami, kjer sem se vkrcal za Benetke, sem šel skozi plodno ravnino, ki je bila bogato zasajena z vinsko trto, figami, murvami, koruzo in mnogimi drugimi rastlinami, značilnimi za toplo klimo. To me je v razmerju, ki je zelo nenavadno, zelo očaralo. Enoličnost razmerij, ki je tako značilna za druge ravninske pokrajine, ni bila utrudljiva, ker je bil vsak korak tal preoran za trojno žetev, zasajen s pšenico ali koruzo, z murvami in lombardskimi topoli, v enakomernih vrstah, da podpirajo grozdje in slikovite brajde, povezujoče se od drevesa do drevesa. Italija bo prav gotovo prikazala več možnosti te vrste. O, ko bi bili z menoj. V bodoče Vam bom opisal več. Imejte se lepo in imejte me radi. Vaš ...


LETTERA ORITTOGRAFICA
del Celebre Signor
GIAN-GIACOMO FERBER
del Collegio Metallico di Svezia,
ſcritta dalla Boemia
AL CHIARISSIMO SIGNOR
GIOVANNI ARDUINO
Pubblico Soprantendente all' Agricoltura &c. in Venezia,
Nella quale ſono riferite le oſſervazioni da eſſo fatte nelle Montagne, e Minere dell' Auſtria, Stiria, e Carniola nel ſuo Viaggio da Vienna a Venezia l'anno 1771.

Sl. 8. Naslovnica Ferberjevega pisma italijanskemu geologu Giovanniju Arduinu.

Fig. 8. First page of Ferber's letter to Italian geologist Giovanni Arduino.

Pismo Giovanniju Arduinu

Nastanek pisma

V zbirki knjig Žige Zoisa, ki jo hrani NUK v Ljubljani, je ohranjeno Ferberjevo natisnjeno oriktografsko pismo italijanskemu geologu Giovanniju Arduinu, ki ni identično prvemu Ferberjevemu pismu iz njegove knjige Pisma iz Italije. Poleg tega pisma so v knjigi še druga besedila, ki vsa izvirajo iz tiskarne beneškega založnika Benedetta Milocca. Najstarejše besedilo je iz leta 1779. V Zoisovi knjižnici prevladujejo geološko-mineraloška dela, v njej sta med drugim Arduinovo delo Osservazioni chimicae sopra alcuni fossili (O kemijskih opazovanjih in nekaterih fosilih) iz leta 1779 in italijanski prevod Bornovega dela o potovanjih po Banatu iz leta 1778. Po kataložnem zapisu NUK naj bi bilo Ferberjevo pismo natisnjeno med letoma 1771 in 1780 v Benetkah, vendar je razpon te datacije preširok. Kot bomo pokazali v nadaljevanju, je bilo pismo natisnjeno leta 1775. Kot ločeno tiskano delo je, po za sedaj znanih podatkih, natisnjeno Ferberjevo pismo Arduinu le v NUK v okviru Zoisove zbirke, v katalogih drugih svetovnih knjižnic ga kot samostojne publikacije nismo našli.

Izkaže se, da je Ferberjevo pismo Arduinu sestavni del dela Raccolta di memorie chimico-mineralogiche, metallurgiche, e orittografiche (Zbirka razprav s področja kemije, mineralogije, metalurgije in oriktografije), ki je leta 1775 izšlo v Benetkah pri založniku Benedettu Miloccu. Gre za zbirko različnih esejev, ki obravnavajo kemijska, mineraloška, metalurška in geološka vprašanja. Knjiga je brez tekoče paginacije, vsak prispevek ima lastno številčenje strani. Po vsebini sodeč ne gre za Arduinova dela, temveč za dela ali zapise, ki so mu jih posredovali drugi avtorji ali njegovi dopisniki. Nekateri prispevki so anonimni, na primer tisti o rudniku železa v Eizenerzu na Štajerskem. Arduino je dela le uredil in nekatera komentiral. V knjigi so objavljena tri Ferberjeva pisma Arduinu. Prvo med njimi je naše pismo, med prispevki je objavljeno pod zaporedno številko 7. Poleg tega sta natisnjeni še dve kasnejši pismi, prvo je bilo 15. decembra 1772 poslano iz Altzedlitza, drugo pa 1. marca 1773 iz Prage. Obe se ukvarjata s stratigrafijo in kamninami na območju Alp ter Apeninov.

Pismo, ki ga obravnavamo, je Ferber Arduinu napisal 25. septembra 1772 iz Altzedlitza na Češkem, potem ko se je avgusta 1772 že vrnil s potovanja po Italiji. Pismo je izvirno, saj Ferber zapiše: »Odločen sem, da Vam poročam o tem, kar sem opazoval na poti od Dunaja do Benetk. To, kar bom zabeležil, je veren povzetek zapiskov, ki sem jih naredil od kraja do kraja, seveda preveden v italijanščino na najboljši način, kot ga poznam, ne glede na švedsko skladnjo, ki jo uporabljam.« Zelo pomenljiv je kraj, v katerem je pismo nastalo. Altzedlitz ali v kasnejši pisavi Alt Zedlitz je današnji češki kraj Staré Sedliště na zahodu Češke blizu meje z današnjo Avstrijo, v katerem je imel sedež svojega posestva Ignaz von Born. Čas in kraj nastanka ter vsebina pisma Arduinu, ki je v marsičem identično prvemu pismu iz Italije, nakazujejo, da sta bila potovanje in celotna knjiga Pisma iz Italije Bornov in Ferberjev skupni projekt.

Tako po datumu nastanka kot po natisu je Ferberjevo pismo Arduinu mlajše. Zato je razumljivo, da Ferber samo povzema nekatera dejstva, ki jih je napisal v prvem pismu, ali pa jih v celoti izpušča. V tem pismu se podrobneje ukvarja z nekaterimi teoretičnimi izhodišči, zlasti s splošnimi vprašanji o primarnih kamninah, medtem ko nekatere podrobnosti in komentarje iz prvega pisma izpušča.

V natisu ima pismo 22 v izvirniku numeriranih strani. Vsebuje 34 odstavkov, ki smo jih zaradi lažjega sklicevanja označili od [A1] do [A34], kratica A označuje, da je pismo namenjeno Arduinu. Zaradi prekrivanja vsebine s pismom Bornu iz pisma Arduinu prevajamo le posamezne odstavke.

Odlomki in povzetki iz pisma

V uvodnem delu pisma, v odstavkih od [A1] do [A3], Ferber zapiše svoje prepričanje, da lahko sklepe o naravi izpeljemo le iz usklajenih opazovanj pojavov, ki jih opazuje več različnih ljudi. Z Dunaja preko Gradca, Gorice in Benetk do Neaplja se je v Italijo odpravil z namenom, da spozna naravne znamenitosti, o katerih na severni strani Alp ni poročil, tako kot v Italiji ni mogoče dobiti knjig, ki izidejo na severu Evrope, zato izmenjava informacij ni mogoča. Tako ni poznal številnih del, zlasti o oriktografiji, ki so jih napisali italijanski učenjaki, med njimi Arduino. Vse to je spoznal med svojim potovanjem, zahvaljujoč italijanščini, ki se je je naučil med potjo. Vse to ga izredno veseli in sedaj, ko se je vrnil, bo Arduinu sporočil svoja opažanja ter premisleke o poti med Dunajem in Benetkami.

Po teh uvodnih stavkih v odstavkih od [A4] do [A7] sledijo opisi, ki so zelo podobni opisom v odstavku [B2] prvega pisma iz Italije. V nadaljevanju pisma sledi splošno teoretična razprava o naravi kamnin na obravnavanem območju. Ferber zapiše:

[A8] Vsa ta apnenčeva gorovja tvorijo različno debele plasti, ki so zdaj bolj, zdaj manj nagnjene proti obzorju. Kamnine so tiste vrste, ki jih v soglasju z vašo ekscelenco prepoznavam kot sekundarne. Očitno je, da jih sestavljajo morski sedimenti, ki so stratigrafsko odloženi nad drugačno vrsto kamnin, to je primarnih, ki so starejše in drugačne narave.

[A9] Te primarne kamnine, ki v vseh prej omenjenih deželah ležijo pod apnenčevim gorovjem sekundarnega reda in tvorijo njegovo podlago, so iz skrilavca, ki je bodisi glinen, turkizno obarvan, bodisi črn in pogosto popolnoma čist, včasih pa tudi pomešan s sljudo; ali pa je sestavljen iz sljude in kremena, kot to poimenujejo Nemci, ali iz roženčevega skrilavca, kot to poimenujemo Švedi.

[A10] To je popolnoma enak pojav, spoštovani gospod Arduino, kot ste ga opazili v gorah Belluna in Feltre, na Tirolskem, v Trentu, Vicenzi, Brescii in Bergamu ter na različnih mestih v Velikem toskanskem vojvodstvu, Republiki Lucca in podobno. Čeprav je vaš skrilavec, ki ste ga opazili v prej omenjenih krajih in zelo dobro opisali ter z utemeljenimi razlogi dokazali, da je v primerjavi z drugimi vrstami kamnin, ki imajo očitne znake kasnejšega nastanka, ena od po vrsti resnično prvotnih kamnin, je sestavljen iz lojevca ali sljude in kremena, zato menim, da ni drugačne vrste, temveč je varianta skrilavcev, ki sem jih opazoval v prej omenjenih avstrijskih pokrajinah. Raznovrstnost je prvotno odvisna od naključnih mešanic ter načinov združevanja in zgoščevanja.

[A11] Na zgoraj omenjenem potovanju sem se lahko na vsakem koraku prepričal o obstoju tega pojava. Rudniki svinca na Štajerskem in živega srebra v Idriji na Kranjskem ležijo v omenjenem skrilavcu, ki leži pod stratificiranim apnencem, ki je vsepovsod brez mineralov. Znamenite železove rude na Štajerskem, v okolici kraja Eisenertz, ki je tako poimenovan zaradi obilja te kovine, res pridobivajo iz apnenca; vendar ni dvoma, da bodo izkopi, če se lahko nadaljujejo zelo globoko in z dobičkom, dosegli zgoraj omenjeni skrilavec. Moja zgoraj navedena opažanja in tista, ki sem jih izvedel v rudnikih svinca, ki jih je mogoče najti v isti državi, me v to zelo prepričajo.

[A12] V teh rudnikih železa najdemo zanimive stalaktite bizarnih in elegantnih oblik, ki so zelo znani pod neprimernim in zavajajočim imenom železne rože, saj so popolnoma brez kovine. Niso nič drugega kot kalcitne ali selenitne konkrecije, saj gre za kalcinacijsko snov, nasičeno z vitriolno kislino.

V nadaljevanju Ferber omeni (odstavek [A13] skupaj z obsežno opombo), da je o teh pojavih pisal jezuit Nikolaus Poda von Neuhaus (1723–1798). Na kratko poda njegovo biografijo profesorja rudarstva v Banski Štiavnici in v jezuitskem kolegiju v Traunkirchnu na Salzburškem. Nato nadaljuje z razpravo o naravi apnenca in gorovij, ki jih tvori.

[A14] Tudi na Tirolskem so skrilavce pridobivali skozi apnenec. Verjetno je večina apnenčastih gora nastala z odlaganjem na drugih primarnih kamninah, skrilavih, granitnih in drugih; torej so to sekundarne kamnine, ki so nastale kasneje.

Zatem (odstavka [A15] in [A16]) Ferber izraža svoje mnenje o tem, da so apnenci sekundarne kamnine, odložene nad skrilavci. Pri tem navaja, v katerih primerih po Evropi to drži (na primer na Madžarskem, v Franciji, Angliji), tudi v primerih, ko pod njimi ležijo marmorji, kot na primer v Servezzi in Carrari. Podoben prostorski odnos med kamninami je opazoval tudi na območju Neaplja, v Apeninih ter drugod po Italiji.

V odstavkih od [A17] do [A34] so opisi podobni opisom od [B4] do [B16], tako da je pismo vsebinsko zelo podobno prvemu pismu iz Italije. Rudnik svinca v Bistrici na Muri, ki je natančno opisan v [B4], le na kratko opiše v odstavku [A19], Idrije, opisane v [B13], se le dotakne, diskusijo o skrivanju podatkov in znanja v Idriji iz [B14] pa povsem izpusti.

Tudi Cerkniškega jezera se v primerjavi z [B15] v [A33] le dotakne, vendar pa na koncu pisma poda zelo zanimivo nepaginirano pripombo. Ferber nakaže, da se kraške jame pojavljajo tudi v Nemčiji, Angliji, Franciji in drugod, ter zapiše: »Takšne jame v velikem številu obstajajo v apnenčevih gorovjih, ki obkrožajo rudogorje v okolici Harza, Hanovra in drugod. V njih pogosto najdemo številne okamnine, sestavljene iz kosti, zob in rogov živali, za katere verjamemo, da so morskega izvora. Takšna je tudi Baumannova jama, ki jo je proslavil Leibnitz v svojem delu Protogea.«

Ferber pismo Arduinu zaključi s prijaznimi in vdanostnimi pozdravi.

Opombe in komentarji

Rekonstrukcija Ferberjeve poti preko Slovenije nam povzroča nekaj težav, saj je pot površno in neuravnoteženo opisana. V nekaterih primerih avtor uporablja popačena imena krajev, ki jih lahko rekonstruiramo le s pomočjo primerjave z imeni na starejših topografskih kartah. Ta imena smo v prevodu pisma Bornu zapisali v današnji obliki. Domnevamo, da je ta površnost posledica Ferberjevega neznanja jezika krajev, skozi katere je potoval, hkrati pa nas njegovo zapisovanje imen sili v domnevo, da je kraje po spominu opisoval nekaj dni kasneje, ne da bi si sproti delal natančnejše terenske zapiske. Nenatančnost njegovih opisov je verjetno tudi posledica pomanjkanja natančnejših topografskih kart, ki takrat še niso bile na razpolago. Kljub temu lahko njegovo pot rekonstruiramo in opišemo s sodobnimi, danes veljavnimi geografskimi imeni.

Z Dunaja je potoval proti jugozahodu do Gloggnitza in Mürzzuschlaga ter nato do Bruck and der Murr, od tod dalje je potoval po dolini reke Mure do Peggaua in Gradca. Pot je nadaljeval ob Muri do današnjega Leibnitza – Lipnice, pri Ehrenhausnu – Ernovžu je prečkal reko Muro in nadaljeval pot do Maribora, Slovenske Bistrice, Slovenskih Konjic, Celja, Vranskega, Trojan in Ljubljane. Od tod je šel do Vrhnike, obiskal je Idrijo in verjetno tudi Cerkniško jezero. Pot je nadaljeval od Planine skozi Postojno, Razdrto in nato v Vipavsko dolino do Vipave, od tod pa do Gorice. Nato je odšel do Mešter, kjer se je vkrcal na ladjo za Benetke. Tega dela poti ni posebej opisoval. Na poti se je ves čas držal cesarske ceste, saj poroča o poštnih postajah, na katerih je prenočeval. To je običajna pot, ki so jo v tistem času ubirali popotniki z Dunaja proti Benetkam. Na tej poti je verjetno obiskal tudi Eisenerz, na kar posredno namiguje v obeh pismih. V pismih ne poroča, koliko dni je potovanje trajalo, opravil pa ga je septembra 1771.

Zapisi krajevnih imen, tako v izvirnikih kot v prevodih prvega pisma, bi si zaslužili posebno pozornost, vendar to ni namen našega zapisa. Na tem mestu se na kratko dotaknimo le dveh toponimov. V nemškem izvirniku je Ljubljana poimenovana

Lanbach, Vrhnika pa Oberlaubach. Verjetno gre v prvem primeru za tipkarsko napako. V angleškem in francoskem prevodu prevajalca uporabljata toponim Laubach. V italijanskem pismu Arduinu je Ljubljana zapisana kot Lubiana. V nemškem besedilu je Idrija zapisana kot Hydria, prav tako tudi v angleškem prevodu, medtem ko je v francoskem prevodu in v pismu Arduinu zapisana kot Idria.

Posebno poglavje pri razumevanju in prevajanju starejših geoloških tekstov je znanstvena terminologija. Ta se je v času dveh stoletij in več povsem spremenila. Izrazi, ki jih uporabljamo danes, imajo povsem drugačen pomen, kot so ga imeli nekoč. Ugotovimo lahko, da so označevalci, to je besede same, danes enaki ali zelo podobni, označenci, to je njihov pomen, pa povsem drugačni.

Ferber izraza geologija ne pozna, namesto njega uporablja izraz oriktografija, ponekod pa bi lahko sklepali tudi na uporabo sinonima fizikalna geografija. Izraz oriktografija se je uporabljal zlasti v srednjeevropskem prostoru, lep primer je delo Baltazarja Hacqueta Oriktografija Kranjske. Odsotnost uporabe termina geologija in iz nje izhajajočih izvedenk je razumljiva, saj je de Luc izraz v sodobnem pomenu uvedel šele leta 1778, v polni rabi pa je šele od leta 1779, ko je de Sassure objavil prvi del Potovanj po Alpah (Brenčič, 2011).

Dotaknimo se še nekaterih litološko-stratigrafskih terminov. Sodobnega geologa najbolj zbode uporaba pojma skrilavec. Termina skrilavec v starejših geoloških besedilih pred začetkom 19. stoletja ne smemo enačiti s terminom skrilavec, kot so ga uporabljali geologi sredi 19. stoletja ali kasneje. Termin skrilavec je lep primer razvoja besede, kjer označevalec ostaja skozi stoletja nespremenjen, spreminja pa se označenec, to je pomen besede. Pri Ferberju in njegovih sodobnikih je skrilavec tako litološki kot stratigrafski pojem. Z litološkega vidika kot skrilavce imenujejo vse sedimentne klastične kamnine, predvsem drobnozrnate, hkrati pa mednje uvrščajo vse metamorfne kamnine, predvsem tiste, za katere danes vemo, da so rezultat nizkotemperaturne in nizkotlačne metamorfoze. S stratigrafskega vidika pa so pri starejših geologih skrilavci najstarejše kamnine, v nekaterih primerih jih imenujejo tudi primitivne kamnine, ki naj bi nastale takoj za magmatskimi kamninami. Opredelitve skrilavcev se bomo nekoliko dotaknili še v nadaljevanju.

Podobno je s terminom marmor. Kot marmor geologi 18. stoletja opredelijo vse tiste kamnine, ki jih je mogoče uporabljati kot masivne bloke za gradnjo ali oblikovanje, tudi za skulpture, ne glede na njihovo petrologijo, kot jo razumemo danes. Čeprav se zdi, da Ferber v pismu Arduinu pozna metamorfni marmor ([A16]) kot posebno petrološko kategorijo, ta termin istočasno uporablja za kamnine, ki jih je mogoče oblikovati ([B2]).

Tudi pri terminu apnenec (Ferber uporablja nemško besedo »das Kalchstein«) se je treba zavedati, da ga je Ferber uporabljal mnogo širše kot danes. Iz opisov izhaja, da med apnence vključuje tudi dolomite in verjetno nekatere plastnate klastične kamnine, na kar lahko sklepamo bolj iz njegovih drugih del kot iz obravnavanih pisem. Očitno ne loči med mineralom kalcitom in kamnino apnencem.

Pri Ferberjevem nemškem terminu »das Hornschifer« ([B2], [B5], [A9]) je pri prevajanju nastala dilema. Ker smo Ferberjev izraz »Horn« prevajali kot roženec [B6], smo se odločili, da uporabimo izraz roženčev skrilavec, česar v sodobni petrološki terminologiji ne poznamo več. Za takšno rešitev smo se odločili tudi zaradi tega, ker v pismu Arduinu Ferber nakaže, da to kamnino Nemci poimenujejo drugače [A9] ter da sta v njej minerala kremen in sljuda. Alternativa temu prevodu ostaja rogovačni skrilavec, kar bi bilo morda v primerjavi s sodobno mineraloško in petrološko terminologijo bolj sprejemljivo. Pri tem je bolj verjetno, da se v »skrilavcih«, ki jih je opazoval Ferber, pojavljajo minerali, podobni rogovači.

Ferber pogosto navaja imena mineralov. Za nekatere je nesporno, da jih lahko imenujemo tudi v skladu z današnjo nomenklaturo, na primer kremen ([B2], [B4], [B5], [B7], [A9], [A10]) in sljuda ([B7], [A9], [A10]). Verjetno je pravilno poimenoval tudi različek kremena jaspis ([B7]). Nekoliko bolj problematično je poimenovanje granatov ([B7]) in šorlitov ([B6], [B7]), ki po današnji mineraloški terminologiji sodijo med črne različke turmalinov. V rudniku Idrija omenja mineral halotrictum ([B13]). To poimenovanje je vpeljal Scopoli in ga danes ne poznamo več, po vsej verjetnosti pa naj bi šlo za epsomit.

V Ferberjevi terminologiji zasledimo tudi termin trap ([B6]). Tudi to je izraz, ki ga danes v večini geoloških terminologij ne poznamo več. Gre za temne drobnozrnate bazalte. Tam, kjer je to kamnino videl Ferber, med Mariborom in Slovensko Bistrico, je ne bomo našli.

V diskusiji z Arduinom Ferber zapiše: »Niso nič drugega kot kalcitne ali selenitne konkrecije, saj gre za kalcinacijsko snov, nasičeno z vitriolno kislino ([A12])«. Selenit je sinonim za sadro, vitriolna kislina pa je običajno žveplova (VI) kislina. Ta stavek bi potemtakem razumeli, kot da gre za mešanico mineralov kalcita in sadre.

Dotaknimo se še opombe o Cerkniškem jezeru, ki je dodana pismu Arduinu. V njej Ferber citira delo Protogea, katerega avtor je nemški filozof Gottfried Wilhelm Leibniz (1646–1716). Leibniz je delo napisal v letih 1691–1693, ko je delal na območju Češko-saškega rudogorja, vendar za časa njegovega življenja ni izšlo. Natisnili so ga šele leta 1749 na podlagi rokopisov, ki so jih našli v Kraljevi knjižnici v Hanovru (Cohen & Wakefield, 2008). V tem delu se Leibniz posveča tudi najdbam v Baumannovi jami. Gre za Baumannshöhle na območju Harza v Nemčiji, ki velja za eno najstarejših turističnih jam na svetu.

Interpretacija in diskusija

Prevod

Svojevrsten izziv pri študiju starejših geoloških besedil, pa tudi drugih starejših naravoslovnih besedil, je terminologija. Na ta problem smo opozorili že pri prevajanju Hacquetovih del (Brenčič, 2020). Znanstvena terminologija se neprestano razvija, dopolnjuje in spreminja. Pri tem se pojavljajo takšne težave, da si lahko upravičeno zastavimo vprašanje, ali so takšni prevodi smiselni in ali je prevode brez obsežnih spremnih študij sploh mogoče izvesti. Pri prevajanju starejših geoloških tekstov moramo biti zelo previdni, saj zlahka zdrsnemo v popravljanje geoloških napak. Prevajalec je soočen z dilemo, ali naj opis nekega izdanka ali območja prevede tako, kakor to območje geologi vidimo in razumemo danes, ali tako, kot je zapisano v izvirniku. Odgovor je na videz kot na dlani; prevajati je treba tako, kot je zapisano v izvirniku. Vendar pri takšnem izhodišču naletimo na veliko težavo. Terminologija, ne glede na željo po objektivizaciji znanosti, je vedno zaznamovana s trenutnim stanjem znanosti, iz katere izhaja. Ker se znanstveno védenje neprestano spreminja, se spreminja tudi terminologija.

Pri razvoju znanstvene terminologije se dogajajo neprestane pomenske spremembe ali preskoki, ki jih razdelimo v tri skupine. Pri razlagi tega si lahko pomagamo s terminološkim aparatom, ki izhaja iz lingvistike. V ta namen uporabimo pojem *označenca* ali signifikata, ki predstavlja pomenski ali vsebinski del jezikovnega znaka, ter pojem *označevalca* ali signifikanta, ki predstavlja jezikovni znak. Oglejmo si to na primeru besede sediment. Če to besedo obravnavamo kot označevalec, je to sklop črk ali glasov *sediment*, ki jo tvorijo, če pa jo obravnavamo kot označenec, je to konkreten predmetni ali materialni sediment v naravi, ki ga na primer najdemo na bregu reke Save. Z razvojem geološke terminologije se razmerja med označenci in označevalci neprestano spreminjajo.

Prvo skupino pomenskih terminoloških sprememb predstavlja preskok označenca; ohrani se označevalec, spremeni pa se označenec. Lep primer tega sta pojma bazalt in marmor. Gre za označevalca, ki ju uporabljamo že stoletja, vendar pa so danes njuni označenci, torej njuni pomeni, povsem drugačni kot nekoč. Tako je danes marmor metamorfna kamnina, nekoč je bil katera koli kamnina, ki jo je bilo mogoče klesati in obdelovati. Nekoč je bil bazalt katera koli temnejša kamnina, praviloma magmatskega izvora. Danes je bazalt petrološko le še mafična predornina. Te pomenske razlike opazimo tudi v Ferberjevih pismih.

Drugo skupino predstavlja preskok označevalca; ohrani se označenec, spremeni pa se označevalec. Sem sodijo vsi tisti geološki pojavi, ki so jih nekoč poimenovali drugače kot danes. Takšnih primerov v analiziranih Ferberjevih pismih ne zasledimo. Iz starejše slovenske geološke terminologije pa bi lahko navedli pojem labora, kar danes opredeljujemo kot konglomerat ali groh oziroma tuf.

Tretjo skupino pomenskih sprememb predstavlja izginotje termina, pri čemer iz znanstvene teorije izgineta tako označenec kot označevalec. Do tega pride takrat, ko za določen pojav ugotovimo, da je bil sestavljen iz več drugih, prav tako pomembnih pojavov ali da je bil plod povsem napačnih teoretičnih predpostavk. Primer tega sta pojma eter in flogiston. V to skupino bi lahko uvrstili tudi pojem skrilavec, kot ga uporablja Ferber. Ta pojem je v današnji geološki terminologiji že zelo omejen in iz specializiranega petrološkega izrazja postopoma izginja. Uporabljamo ga le še v laičnem ali polstrokovnem diskurzu.

Pri prevajanju starejših geoloških znanstvenih besedil je treba opozoriti še na dva problema. Prvi je opis pojavov, ki znanstveno v času izida besedila še niso bili znani, avtor pa jih je na neki način opisal. Pri geoloških besedilih, ki opisujejo območje današnje Slovenije, sta taka primera dolomitna kamnina in mineral dolomit. Tak primer je pri Ferberju omenjanje apnenca, ki je podoben lehnjaku ([B6]), Hacquet pa v Oriktografiji Kranjske dolomit opisuje na zelo različne načine (Brenčič, 2020). Starejša besedila je treba terminološko prevajati tako, da uporabljamo istočasno terminologijo. Če bi prevajali besedilo iz starejše angleščine v nemščino, bi morali uporabljati takratno nemško terminologijo. To je mogoče le v tistih jezikih, v katerih je bila takšna terminologija razvita, težje pa je tam, kjer istočasna terminologija še ni obstajala. In takšen primer je prav slovenščina. Slovenska geološka terminologija se prične razvijati šele v drugi polovici 19. stoletja.

Zaradi vsega naštetega so prevodi starejših geoloških besedil še v večji meri interpretacije kot prevodi literarnih besedil.

Geološke metode

Še danes, po večstoletnem razvoju geološke znanosti, je terensko delo temeljni kamen, na katerem geologi gradimo svoja spoznanja. Brez terenskega dela ni geologije. Podobno vlogo je imelo terensko delo tudi v preteklosti, pri tem pa se je njegova narava spreminjala, spreminjali so se inštrumenti, ki so jih geologi uporabljali pri delu in v laboratoriju, predvsem pa je prišlo do velikih sprememb v teoretičnih spoznanjih. Če bi analizirali terensko delo predhodnikov sodobnih geologov, bi opazili, da je bilo v primerjavi z današnjim mnogo bolj površno, da so geologi pogosto skušali v kratkem času zajeti večja območja, na podrobnosti pa se niso ozirali. Zlasti na začetku geoloških raziskav, ko je bilo na voljo le malo podatkov o geoloških razmerah izven vplivnih območij posameznih univerz in administrativnih središč, so bile dobrodošle že osnovne informacije o nekem območju. Takšnemu geološkemu pristopu pravimo potovalna geologija (Klemun, 2007), najbolj znan predstavnik takšnega pristopa na območju današnje Slovenije je bil Baltazar Hacquet (Brenčič, 2020). Tudi celotno Ferberjevo raziskovalno delo na področju geologije ni nič drugega kot potovalna geologija, njega samega pa lahko opredelimo kot potujočega geologa.

Ferberjeva geološka pisma so nastala v času, ko so se v mineralogiji kemijske analizne metode šele pričele uveljavljati. Te metode so bile z današnjega vidika zelo enostavne, temeljile pa so predvsem na kvalitativnih izhodiščih, osnovne kvantitativne analize so se šele vzpostavljale. Pomembna Lavoisierjeva (1743–1794) dela so bila objavljena in postala dostopna šele po nastanku Ferberjevih pisem. Zaradi tega Ferberjeva prepoznava kamnin in mineralov temelji predvsem na uporabi človeških čutov, vida, tipa, vonja in okusa, kar bi lahko poimenovali senzorična metoda določanja mineralov. Za določanje mineralov so uporabljali tudi osnovne fizikalne preizkuse, na ta način so določali predvsem njihovo trdoto. Veliko pozornost so namenjali barvi mineralov. Tako je Abraham Gottlob Werner (1747–1817) v svoji Lepiziški sistematiki, ki je izšla leta 1774, opredelil 50 barv mineralov, ki so bili osnova za njihovo klasifikacijo. V istem delu je opredelil tudi druge vizualne značilnosti mineralov, kot sta hrapavost in razkolnost. Opredelil je tudi slanost kot okus na jeziku (Carozzi, 1962). Čeprav Ferberjeva pisma segajo v čas pred nastankom Wernerjeve sistematike, je mogoče njene zametke opaziti tudi v obravnavanih pismih. Zato tudi zapiše, ali je določen mineral slan ali ne. Veliko pozornost posveča tudi barvi in strukturi kamnin. Kljub vsemu izhaja tudi iz rezultatov kemijskih analiz, ko na primer govori o mineralih konkrecij in kapnikov v Eisenerzu ([A12]). Pri takšnem določanju mineralov je z današnjega vidika prihajalo do velikih napak. Osnovne minerale, kot sta kremen in sljuda, so določili pravilno, težave pa so se pojavile že pri karbonatnih in silikatnih mineralih, ki jih je senzorično težko ločiti med seboj. Nekaterih, kot so gline, pa niso niti prepoznavali kot minerale. Podobno kot pri nekaterih drugih geoloških terminih je tudi pri poimenovanju mineralov prihajalo do velikih sprememb. Prav zaradi tega je ob analizi starejših geoloških besedil pogosto težko določiti, katere minerale so takratni geologi zares opazili in opisali.

Na tem mestu velja omeniti, da je Ferber fosile razumel že v povsem sodobnem pomenu, kar je za tisti čas zelo pomemben preskok, saj je to še obdobje, ko so kot fosili pogosto opredeljeni vsi predmeti, ki so pod zemljo (Brenčič, 2021).

Ferber v obeh pismih sledi stratigrafski teoriji, ki jo je vpeljal Arduino. Vpogled v to teorijo je ključen za razumevanje njegovih pisem. Arduino je sedimente in kamnine razdelil v štiri skupine, ki sestavljajo osnovno ogrodje njegovega klasifikacijskega sistema kamnin (Vaccari, 2006). Prva skupina je sestavljena iz dveh velikih podskupin, *roccia primigenia* in *montes primarii*. Prva podskupina, *roccia primigenia*, je nastala kot posledica ohlajanja prvotnega Zemljinega površja. V to skupino je Arduino uvrščal skrilavce. Drugo podskupino, *montes primarii,* je razdelil na dve dodatni podskupini. V prvi so graniti, porfirji in kristalinske kamnine, ki so posledica delovanja »ognja«, v drugi pa peščenjaki in konglomerati brez fosilov, ki so nastali kot posledica delovanja »vode«. V drugo veliko skupino, imenovano *montes secundarii,* so bili uvrščeni marmorji in plastnati apnenci s fosili. Tretjo veliko skupino sestavljajo *montes tertiarii*, vanjo sodijo prodovi, peščenjaki in gline. V zadnjo skupino sodijo predvsem plastnati rečni sedimenti. Arduinova stratigrafska klasifikacija je apriorna, starost kamnine je določena ne glede na njeno prostorsko lego. Tako so skrilavci apriori najstarejše kamnine in niso nastali hkrati z drugimi kamninami ali celo kasneje. Ohranjeni so tudi nekateri Arduinovi geološki profili, ki nakazujejo zametke razumevanja strukture. Dosedanje raziskave kažejo, da je na Arduinovo klasifikacijo kamnin svoje geološke opise naslonil tudi Baltazar Hacquet v svoji Oriktografiji Kranjske (Brenčič, 2020).

Ferber v skladu z Arduinovo stratigrafsko doktrino prepoznava skrilavce kot primarne kamnine, vendar ostalih kamnin ne razdeljuje tako natančno kot on, uvršča jih med sekundarne, zdi pa se, da terciarnih kamnin ne prepoznava kot ločene skupine. Ferberjeva delovna klasifikacija kamnin je sestavljena le iz dveh skupin, znotraj katerih opisuje različne litološke različke. Čeprav se v celoti ne opredeli do Arduinove klasifikacije, se zdi, da mu pri opisovanju litoloških razmer na poti skozi Slovenijo posredno oporeka, saj stratigrafsko med kamninami, ki jih opredeli kot skrilavce in apnence, ne opazi nobenih drugih kamnin.

Sklep

Ferberjevi geološki pismi, prvo pismo Ignazu von Bornu, ki je bilo objavljeno v knjigi Pisma iz Italije iz leta 1771, in drugo pismo Giovanniju Arduinu iz leta 1772, sta pomemben dokument iz obdobja prvih znanstveno utemeljenih geoloških raziskav ozemlja na območju današnje Slovenije. Zavest o začetkih geoloških raziskav pomikata v starejše obdobje, kot je veljalo do sedaj. Druga polovica razsvetljenskega 18. stoletja se tako ponovno kaže kot pomemben mejnik na področju geoloških raziskav današnje Slovenije.

Po Sloveniji je Ferber potoval na začetku obdobja, v katerem se oblikujejo prve konsistentne geološke teorije, ki jih današnja zgodovina znanosti uvršča v skupino neptunističnih in plutonističnih teorij. Prav tako je to obdobje, ko se v mineralogiji šele pričenjajo uveljavljati metode kvantitativnih kemijskih analiz. Začetki tega se odražajo v Ferberjevih zapisih, vendar pa se, vsaj v obravnavanih pismih, naslanja bolj na takratno italijansko geološko šolo z Giovannijem Arduinom kot njenim glavnim predstavnikom kot na nemško geološko šolo.

Dosedanje raziskave geoloških del iz 18. stoletja kažejo, da je besedil in s tem geoloških analiz ozemlja današnje Slovenije več, kot smo jih poznali do sedaj. Odkritja teh del pomembno dopolnjujejo dosedanja spoznanja o delovanju Giovannija Antonija Scopolija, prvega na Kranjskem nastanjenega naravoslovca, ki se je aktivno ukvarjal tudi z geološkimi raziskavami v modernem pomenu, v okviru teh prizadevanj pa je sodeloval tudi s Ferberjem in Bornom. Nekatera od starejših geoloških besedil, ki obravnavajo območje današnje Slovenije, so ohranjena v Zoisovi zbirki knjig, ki jih hrani Narodna in univerzitetna knjižnica v Ljubljani. Analiza teh del nas še čaka v prihodnje. Objava in obdelava Ferberjevih pisem je eden prvih korakov v tej smeri.

Summary

In the second half of the 18th century, geology, alongside other natural sciences, starts to develop more intensively. In the area of present-day Slovenia, there was a great interest in the Idrija mercury mine at this time. The most famous figures involved in its exploration were Giovanni Antonio Scopoli (1723–1788) and Baltazar Hacquet (1739/1740–1815), but it also attracted other explorers. The first scientific work on the mercury mine was written by the Swedish-German mineralogist and geologist Johan Jacob Ferber (1743–1790), entitled "Beschreibung des Quecksilber-Bergwerks zu Idria in Mittel-Crain", published in 1774. Detailed research into other documents from the period has shown that Ignaz von Born (1742–1791) is probably the real author of this work.

Ferber was a prolific writer, with numerous works on geology. Two other published letters are important for his view of the geology of the area. The first letter was published in his book of letters from his travels in Italy, "Briefe aus Wälschland über natürliche Merkwürdigkeiten dieses Landes an den Herausgeber derselben Ignatz Edlen von Born" published in Prague in 1773. This work was also translated into English in 1776 under the abridged title "Mr Ferber's Travels through Italy" and translated by Rudolph Erich Raspe (1736–1794). A second letter about a visit to the area was written by Ferber to the Italian geologist Giovanni Arduino and was published in two editions. The first is a separate edition of the letter entiteld "Lettera Orittografica del Celebre Signor Gian-Giacomo Ferber del Collegio Metallico di Svezia, scritta dalla Boemia al chiarissimo signor Giovanni Arduin Pubblico Soprantendente all Agricultura, etc. in Venezia", which, according to the information known so far, is preserved as such only in the library of Sigismund Zois (1747–1819), which is held by the National and University Library in Ljubljana. The second available edition of this letter is part of the monograph "Raccolta di memorie chimico-mineralogiche, metallurgiche, e orittografiche", published in Venice in 1775, in which Govanni Arduino collected and published the letters and works of his correspondents.

In both letters Ferber describes his journey from Vienna to Mestre in what is now the Republic of Italy. He travelled along the then imperial road in a mail coach from Vienna to Bruck an der Mur, and from Mura valley past Graz to Ehrenhausen in what is now the Republic of Austria. In the present-day Republic of Slovenia he travelled from Maribor to Slovenska Bistrica, Slovenske Konjice, Celje, Trojane, Ljubljana, Vrhnika, to

Idrija and Cerkniza Lake, then via Planina, Postojna and Vipava to Gorizia. Along the way, he described the geological conditions. The letter to von Bron is more detailed in terms of the description of the lithological conditions on the route. He describes in detail the lead mine at Feistriz an der Mur and the mercury mine in Idrija. In the context of this description, he also discusses the futility of concealing information about the processing of mercury ore, as he witnessed during his visit to Idrija. He describes Lake Cerknica very briefly. In his letter to Arduio, he summarises the geological situation to a large extent, as he does in his letter to von Born. However, in it he discusses much more thoroughly the nature of the sedimentary rocks he had observed on his journey. He disputes with Arduin his interpretation of the rocks, which he divides into primary and secondary rocks. Ferber describes the relationships between the shists sensu Arduino and the carbonates as they were understood before the discovery of dolomitic rock.

The paper provides a translation of both letters into Slovene. The letter to von Born has been translated in its entirety, while the letter to Arduino has been translated only in the part that complements the first letter. On the basis of the translation, we provide a commentary on Ferber‘s individual geological terms and compare them with those that are valid today. In the final part of the paper we give an interpretation of Ferber‘s letters. In it, we address the problem of understanding and translating older geological texts from the point of view that the terminology has changed considerably. We also touched upon the issue of geological and mineralogical descriptions, which at the time of the Ferber letters were based almost entirely on sensory abilities. Finally, we touched on Ferber‘s understanding of Arduino‘s stratigraphic theory and the descriptions of stratigraphy on his journey through Slovenia.

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Prospalax priscus jaw from the site of Wężе 2 (southern Poland, Pliocene)

Čeljust vrste *Prospalax priscus* iz najdišča Węże 2 (južna Poljska, pliocen)

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Abstract

The ecology and adaptations of the Anomalomyidae (Muroidea) have been long debated in the scientific literature. A jaw belonging to *Prospalax priscus* (Anomalomyidae) was found at the Late Pliocene site of Węże 2 in southern Poland. The presence of this species at the site agrees with the interpretation of *P. priscus* and the Anomalomyidae in general as adapted to forest environments.

Izvleček

V znanstveni literaturi se že dolgo razpravlja o ekologiji in prilagoditvah družine Anomalomyidae (Muroidea). Čeljust, ki pripada vrsti *Prospalax priscus* (Anomalomyidae), je bila najdena na najdišču Węże 2 iz zgornjega pliocena na južnem Poljskem. Prisotnost te vrste na tem najdišču se ujema z interpretacijo, da sta bili vrsta *P. priscus* in družina Anomalomyidae na splošno kot prilagojeni gozdnemu okolju.

Introduction

The Muroidea (mouse-like rodents) is a highly diverse superfamily of rodents (Rodentia) encompassing around 1750 species, which amounts to circa 75 % of all rodent species. Six main extant clades may be distinguished among the Muroidea, namely the Muridae, the Cricetidae, the Spalacidae, the Platacanthomyidae, the Calomyscidae and the Nesomyidae (Michaux et al., 2001; D'Elía et al., 2003; Jansa & Weksler, 2004; Steppan et al., 2004; Musser & Carleton, 2005; Jansa et al., 2009; Schenk et al., 2013). Moreover, the extinct family Anomalomyidae has been recognized, which cladistically should be supposedly included in the Cricetidae (Bolliger, 1999; López-Guerrero et al., 2017; Nesin & Kovalchuk, 2020). The Muroidea, having probably originated in Eurasia during the Eocene, now inhabit every continent except Antarctica, thriving in a wide range of habitats and occupying many different ecological niches (Lindsay, 1977; Flynn et al, 1985; D'Elía et al., 2003; Musser & Carleton, 2005; Jansa et al., 2009; Schenk et al., 2013; Li et al., 2016). The Anomalomyidae is an example of a muroid clade of which ecology has been long debated and apparently not well understood (Kalthoff, 2000; Hordijk & de Bruijn, 2009; Nesin & Kovalchuk, 2020). Thus, each newly described discovery may bring about important information clarifying the mode of life of this enigmatic family. The purpose of this paper is to present part of the anomalomyid fossil material (a fragmentary left lower jawbone of *Prospalax priscus*) collected at the Late Pliocene site of Węże 2, and subsequently to argue that the presence of this species in the Węże 2 assemblage further supports the interpretation of the Anomalomyidae as adapted to forest environments.

Geological and stratigraphical settings

The Węże 2 site is situated on the NW slope of the Zelce Hill (51°05′52″N 18°47′30″E; 228 m a.s.l.), near the village of Węże, in the vicinity of the town of Działoszyn (Pajęczno County), in the Wieluń Upland, southern Poland. The site comprises a vertical crevice etched in the Upper Jurassic (Oxfordian) limestone by karst processes, originally infilled with late Pliocene fossiliferous sediment of the terra rossa type. The crevice itself is a part of a larger karst cave system of the hill and is located about 150–200 m north from the better known Węże 1 site, which has been dated at MN 15 (Sulimski, 1962; Stefaniak et al., 2020; Szynkiewicz, 2015 A and B).

The locality of Węże 2 was discovered and preliminary explored between 1958 and 1961 by Sulimski. The terra rossa deposits (~3.5 t in total) were collected during field work organized by the Department of Paleozoology of the Polish Academy of Sciences in Warsaw (currently the Institute of Paleobiology PAS) and the Department of Paleozoology of the Wrocław University. Three to four clayey fossiliferous strata of slightly differing lithology were distinguished. These were initially named D1, D2 and D3 by Sulimski (1962) and then renamed D (= upper D1), E (= lower D1), F, and G. Additionaly, there was a stratum of quartz sand at the bottom in which some specimens were also found (this stratum was initially named D4 and then renamed as H). However, only part of the fossil material collected has been attributed to a particular stratum and the faunal lists are generally given for the site as a whole, which is also the case for the nearby and better known site of Węże 1. The faunal composition of the Węże 2 fossil assemblage is currently dated at the late Pliocene (Early Villafranchian) and is considered to belong to the MN 16b zone in the European Land Mammal Age chronology, i.e. 2.9–2.6 mya (Sulimski, 1962; Nadachowski et al., 2015; Szynkiewicz, 2015 A and B; Stefaniak et al., 2020; Marciszak et al., 2023).

The rodents thus far described from Węże 2 include the previously unknown species of a flying squirrel, *Pliopetaurista dehneli* (originally named *Pliosciuropterus dehneli*) (Sulimski, 1964; Hordijk & de Bruijn, 2009), the dormice *Glis minor* and *G. sackdillingensis* (Czernielewski, 2021), the beavers *Trogontherium minus* and *Dipoides* ex gr. *problematicus*-*sigmodus* (Czernielewski, 2022) and the porcupine *Hystrix refossa* (Czernielewski, 2023), see Table 1. Several non-rodent mammalian taxa have also been recognized. These include the lagomorph *Hypolagus beremendensis* (Fostowicz-Frelik, 2007), the cervids *Croizetoceros ramosus* and *Metacervocerus pardinensis*, (Stefaniak, 1995; Stefaniak et al., 2020), the talpid *Rzebikia skoczeni*, defined based on material from Węże 2 (Rzebik-Kowalska, 1990, 2014; Skoczeń, 1976, 1993; Zijlstra, 2010; Sansalone et al., 2016), a proboscidean ?*Anancus* sp. (Stefaniak et al., 2020), as well as the chiropterans *Rhinolopus* sp. and *Myotis* sp. (Kowalski, 1990). Moreover, the presence of several carnivorans was attested, including the canids *Nyctereutes donnezani* and *Canis etruscus* (Marciszak et al., 2023).

In addition to mammals, some other vertebrate remains have been found in Węże 2. Reptiles were represented by the turtle *Emys orbicularis antiqua*, the serpents *Elaphe paralongissima* and *Natrix* cf. *longivertebrata*, as well as the lizards *Ophisaurus pannonicus*, *Anguis* cf. *fragilis*, *Lacerta* cf. *viridis* and *Lacerta* sp. (Młynarski et al., 1984). The amphibian fauna included a new species of salamander named *Mioproteus wezei* and the anurans *Palaeobatrachus* sp., *Pliobatrachus* cf. *langhae*, *Pelobates fuscus*, *Pelobates* sp., *Bufo bufo*, *Rana dalmatina*, *Rana* sp. and *Pelophylax* kl. *esculentus* (Młynarski et al., 1984; Młynarski & Szyndlar, 1989). Moreover, remains of unidentified birds were uncovered (Bocheński et al., 2012) as well as isolated vertebrae of salmonid fishes (Nadachowski et al., 2015). In general, the fauna of Węże 2 is considered to be suggestive of a forest environment, which is supported by the presence of genera strongly associated with woodland habitats, such as *Glis*, *Sciurus*, *Pliopetaurusta*, *Blackia*, *Trogontherium* and *Dipoides* (Sulimski, 1964; Szynkiewicz, 2015 A; Stefaniak et al., 2020; Czernielewski, 2021, 2022).

Material and methods

The *Prospalax* specimen here described (Fig. 1) was discovered and handpicked at the site of Węże 2 in the late 1950's / early 1960's during excavations conducted by Andrzej Sulimski, the Department of Paleozoology of the Polish Academy of Sciences in Warsaw, and the Department of Paleozoology of the Wrocław University. The exact provenance of the mandible (the stratum in which it was found) is not known. In addition, each of the strata contained several dozens of isolated teeth morphologically and morphometrically identical to the *P. priscus* specimens from Węże 1 (Sulimski 1964). This material is part of the collection of the Institute of Paleobiology, Polish Academy of Sciences (abbreviated as ZPAL). The described specimen was examined, measured and photographed with Keyence VHX 900-F Digital Microscope System.

Systematic palaeontology

Superfamily Muroidea Illiger, 1811
Family Anomalomyidae Schaub, 1925
Genus *Prospalax* Méhely, 1908
Prospalax priscus (Nehring, 1897)

Material

A fragmentary left mandible of *Prospalax priscus* with m1-m2 preserved *in situ* (ZPAL M. VIII/b/P1/1), Fig. 1.

Fig. 1. Left mandible of *Prospalax priscus* (ZPAL M. VIII/b/P1/1) in labial (A), occlusal (B) and lingual (C) views.

Table 1. Rodent material from Węże 2 present in the collection of the Institute of Paleobiology PAS according to taxa and stratigraphic units.

Stratigraphic unit	Rodent taxa present
D	*Glis* ex gr. *sackdillingensis-minor* (Gliridae) *Muscardinus pliocaenicus* (Gliridae) *Pliopetaurista dehneli* (Sciuridae) *Blackia miocaenica* (Sciuridae) *Tamias orlovi* (Sciuridae) *Prospalax priscus* (Anomalomyidae) *Baranomys* sp. (Cricetidae) *Mimomys* sp. (Cricetidae) Cricetidae indet.
E	*Glis* ex gr. *sackdillingensis-minor* (Gliridae) *Muscardinus pliocaenicus* (Gliridae) *Pliopetaurista dehneli* (Sciuridae) *Tamias orlovi* (Sciuridae) *Prospalax priscus* (Anomalomyidae) *Trogontherium minus* (Castoridae) *Hystrix refossa* (Hystricidae) *Baranomys* sp. (Cricetidae) *Mimomys* sp. (Cricetidae) Cricetidae indet.
F	*Glis* ex gr. *sackdillingensis-minor* (Gliridae) cf. *Pliopetaurista dehneli* (Sciuridae) *Tamias orlovi* (Sciuridae) *Prospalax priscus* (Anomalomyidae) *Trogontherium minus* (Castoridae) *Hystrix* sp. (Hystricidae) *Baranomys* sp. (Cricetidae) *Mimomys* sp. (Cricetidae) Cricetidae indet.
G	*Glis* ex gr. *sackdillingensis-minor* (Gliridae) *Blackia miocaenica* (Sciuridae) *Tamias orlovi* (Sciuridae) *Prospalax priscus* (Anomalomyidae) *Trogontherium minus* (Castoridae) *Dipoides* ex gr. *problematicus-sigmodus* (Castoridae) *Hystrix* sp. (Hystricidae) *Baranomys* sp. (Cricetidae) *Mimomys* sp. (Cricetidae) Cricetidae indet.

Description

The specimen exhibits the sigmoid pattern of the occlusal dental surfaces typical for the genus *Prospalax*. It is an adult specimen (cf. Sulimski 1964) and corresponds with other mandibles attributed to *P. priscus* and illustrated by Méhely (1908), Sulimski (1964) and Topachevskii (1976) by its relatively robust appearance compared to the *P. petteri* specimens (including the holotype) illustrated by Bachmayer and Wilson (1970). In the Węże 2 specimen the height of the horizontal branch at the level of the posterior edge of the alveolus of m1 is ca. 5.00 mm measured at the labial side. The shape of the angular process is typical for *P. priscus*, while in the holotype of *P. rumanus* it exceeds the length of m1–m2 which is a diagnostic trait for this species (Simionescu 1930; Topachevskii 1976). The dimensions of the preserved teeth in the Węże 2 specimen are 2.07/1.54 mm (m1) and 2.02/1.88 mm (m2). The alveolar m1–m3 length is 6.43 mm which corresponds to the lower end of the range typical for *P. priscus*, i.e. 6.0–9.0 mm (Jánossy 1972; Topachevskii 1976). Topachevskii (1976) points out to the smaller size of *P. rumanus* as defined by the length of the mandibular tooth row which in the described specimens of *P. rumanus* equals 6.0 and 6.2 mm, but as the dimensions of the measured specimens of *P. rumanus* overlap with the measurements of the smaller mandibles of *P. priscus*, it would apparently not be possible to distinguish between the species based on morphometric traits alone. However, the dimensions of m2 (2.02/1.88 mm) and the alveolar length of the Węże 2 specimen are also much smaller than in the holotype specimen of *P. kretzoii* (2.8/2.4 mm, and 10.2 mm), a species that has been diagnosed as being significantly larger than *P. priscus* (Jánossy 1972).

Discussion

Prospalax priscus is now recognized as a representative of the Anomalomyidae. Apparently restricted to the Old World, this family is known to have lasted since the Early Miocene till the beginning of MN 18 (Marković & Milivojević, 2010; López-Guerrero et al. 2017; Nesin and Kovalchuk 2020). The family includes three genera (*Anomalomys*, *Anomalospalax*, *Prospalax*), all of which were previously assigned to the Cricetidae (i.e. the family that comprises hamsters, voles, lemmings, muskrats and the so called New World rats and mice) or the Spalacidae (i.e. the family that includes mole-rats, bamboo rats and zokors) (Bachmayer & Wilson 1978; Kordos 1985; Hugueney & Mein 1993; Bolliger 1999; Jansa & Weksler, 2004; Musser & Carleton, 2005; Nesin & Kovalchuk 2020). It is hypothesized that the Anomalomyidae originated within the Cricetidae, with *Argyromys aralensis* from the Oligocene of Kazakhstan being the immediate ancestor, even though the oldest anomalomyids have been attested in southern Europe (López-Guerrero et al. 2017; Nesin and Kovalchuk 2020). Another hypothesis holds that the origins of the Anomalomyidae are associated with the primitive cricetid *Eumyarion intercentralis* from western Asia (de Bruijn 2009). Among anomalomyids the eponymous genus *Anomalomys* is the most species-rich and is also considered to be the most primitive, while *Prospalax* and *Anomalospalax* are described as being more derived (Kordos 1985, 2005; Nesin & Kovalchuk 2020). The evolutionary lineage *Anomalomys – Prospalax* has been inferred from the fossil record (Bachmayer & Wilson 1970; Nesin & Kovalchuk 2020).

P. priscus is known from several sites in Central Europe and Greece, dated from the Upper Miocene (Daxner-Höck 1970; Temper 2005) till the beginning of MN 18 (Marković & Milivojević, 2010). In Poland it was attested at the MN 15 sites of Draby 1, Mokra 1, Raciszyn 1 (Nadachowski 1989; Nadachowski et al. 1989) and Węże 1 (Sulimski, 1964), as well as the MN 16 site of Rębielice Królewskie 1A (Kowalski, 1960). In Hungary *P. priscus* was reported from the Late Pliocene / Early Pleistocene sites of Csarnóta (Kretzoi 1956; Jánossy 1986; Szentesi et al. 2015) and Beremend (Méhely 1908; Kretzoi 1956; Jánossy 1986; Hordijk & de Bruijn 2009; Pazonyi et al. 2019), the Early/Middle Pleistocene site of Nagyharsány (Nehring 1897; Kretzoi 1956; Jánossy 1986; Pazonyi et al. 2021), the MN 16? sites of Osztramos 7 and Villány 3 (Kretzoi 1956; Jánossy 1986; Kessler 2019), the Late Villanyian site of Dunaalmás IV, as well as from Kisláng, supposedly also of the Late Villanyian age (Jánossy, 1986). Romanian localities of *P. priscus* include the Pliocene sites of Măluşteni and Barault Capeni (= Barót-Köpec) (Simionesciu, 1930; Kormos, 1932). Moreover, the species was attested at the MN 15? site of Notio 1 in Greece (Hordijk & de Bruijn, 2009), MN 16 of Hajnáčka I in Slovakia (Sabol, 2003), and MN 18 of Riđake in Serbia (Marković & Milivojević, 2010). It was also reported from the Upper Miocene of Eichkogel in Austria (Daxner-Höck, 1970; Temper, 2005). The localities are summed up in Table 2.

Supposedly by analogy to the extant Eurasian blind mole rats (the genus *Spalax*), to which it was once considered closely related (Méhely, 1908; Topachevskii, 1976), *Prospalax* has been described as a burrowing animal of the steppe and open grasslands, similar in their behavior and adaptations to the modern spalacids (Kowalski, 1964; Sulimski, 1964; Bachmayer and Wilson, 1970; Sabol, 2003) which was also considered true for the Anomalomyidae in general (Bachmayer & Wilson, 1970; Kowalski, 1994; Bolliger, 1999). However, the interpretation of anomalomyid ecology has been shifting towards understanding them as animals dwelling in forest environments, behaviorally similar to the extant burrowing shrews, and not well adapted to strictly underground lifestyle (Kalthoff, 2000; Hordijk & de Bruijn, 2009; Nesin & Kovalchuk, 2020). Such a shift has been caused by findings of anomalomyid remains within faunal

Table 2. Anomalomyid occurrences unequivocally referred to as *Prospalax priscus*.

No.	Locality	Age	References
1.	Eichkogel (Austria)	Upper Miocene	Daxner-Höck 1970; Temper 2005
2.	Măluşteni (Romania)	Pliocene	Simionesciu 1930; Kormos 1932
3.	Barault Capeni (Romania)	Pliocene	Simionesciu 1930; Kormos 1932
4.	Beremend (Hungary)	Late Pliocene / Early Pleistocene	Méhely 1908; Kretzoi 1956; Jánossy 1986; Pazonyi et al. 2019
5.	Csarnóta (Hungary)	Late Pliocene / Early Pleistocene	Kretzoi 1956; Jánossy 1986; Szentesi et al. 2015
6.	Draby 1 (Poland)	MN 15, Late Ruscinian	Nadachowski 1989; Nadachowski et al. 1989
7.	Mokra 1 (Poland)	MN 15, Late Ruscinian	Nadachowski 1989; Nadachowski et al. 1989
8.	Raciszyn 1 (Poland)	MN 15, Late Ruscinian	Nadachowski 1989; Nadachowski et al. 1989
9.	Węże 1 (Poland)	MN 15, Late Ruscinian	Nadachowski 1989; Nadachowski et al. 1989; Sulimski 1964
10.	Notio 1 (Greece)	MN 15?	Hordijk and de Bruijn 2009
11.	Hajnáčka I (Slovakia)	MN 16	Sabol 2003
12.	Osztramos 7 (Hungary)	MN 16?	Kretzoi 1956; Jánossy 1986; Kessler 2019
13.	Rębielice Królewskie 1A (Poland)	MN 16	Kowalski 1960
14.	Villány 3 (Hungary)	MN 16?	Kretzoi 1956; Jánossy 1986; Kessler 2019
15.	Węże 2 (Poland)	MN 16	Sulimski 1962; Stefaniak 1995; Stefaniak et al. 2020
16.	Dunaalmás IV (Hungary)	Late Villanyian	Jánossy 1986
17.	Kisláng (Hungary)	Late Villanyian?	Jánossy 1986
18.	Nagyharsány (Hungary)	Early/Middle Pleistocene	Nehring 1897; Kretzoi 1956; Jánossy 1986; Pazonyi et al. 2021
19.	Riđake (Serbia)	MN 18	Marković and Milivojević 2010

assemblages otherwise typical for forest habitats (Hordijk & de Bruijn, 2009; Nesin & Kovalchuk, 2020) as well as by the reinterpretation of the anomalomyid incisors as not being proficient digging tools (Kalthoff, 2000; Nesin & Kovalchuk, 2020). Also the relationships between Anomalomyidae and Spalacidae seem to be more distant than previously thought and the presence of burrowing adaptations in these two clades is now described as a result of an evolutionary convergence (Nowakowski et al., 2018; Nesin & Kovalchuk, 2020). It is noteworthy that *P. priscus* itself has not infrequently been found in association with species suggestive for arboreal environments, i.e. flying squirrels (Sciuridae: Petauristini) and dormice (Sulimski, 1964; Daxner-Höck, 1970;

Jánossy, 1986; Nadachowski, 1989; Sabol, 2003; Hordijk & de Bruijn, 2009; Marković & Milivojević, 2010).

Attributing the Węże 2 specimen to *P. priscus* seems well supported due to the robust appearance of the jaw, the shape of the angular process, and the smaller dimensions than the holotype of *P. kretzoii*. Moreover, it can be inferred that the isolated *Prospalax* teeth found at Węże 2 also belong to *P. priscus*, although this cannot be proved by the occlusal morphology as it does not seem to differ significantly between the species and possible interspecific differences were never cited as diagnostic while defining new species within *Prospalax* (Nehring, 1897; Simionescu, 1930; Bachmayer and Wilson, 1970; Jánossy 1972). The presence of *P. priscus* at the site of Węże 2 agrees with the interpretation of this species as adapted to forest rather than steppe environments.

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Ocena količinskega stanja podzemnih voda za Načrt upravljanja voda 2022–2027 (NUV III)

Groundwater quantitative status assessment for River Basin Management Plan 2022–2027 (RBMP III)

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Key words: Groundwater, water body, quantitative status test, water balance, ecosystems, abstractions

Izvleček

Ocena količinskega stanja podzemnih voda je del Načrta upravljanja voda 2022–2027 (NUV III). Z njo po določenih kriterijih ovrednotimo količinsko stanje na 21 vodnih telesih podzemnih voda v Sloveniji kot »dobro« ali »slabo«. Ocena je izvedena s štirimi preizkusi, kjer analiziramo vpliv odvzemov (črpanih količin) podzemne vode na: količine podzemne vode in vodno bilanco, ekološko stanje površinskih vodnih teles, kopenske ekosisteme odvisne od podzemne vode in vdore slane vode ali vode slabše kakovosti v vodonosnik. Končno skupno oceno, na podlagi opravljenih preizkusov, določa kriterij najslabše ocene. Na podlagi rezultatov izvedenih preizkusov imamo 20 vodnih teles ocenjenih s skupno oceno »dobro«. Vodno telo Dravska kotlina pa je ocenjeno kot »slabo«, ker črpanje podzemne vode povzroča vdore vode slabše kakovosti v vodonosnik. Zadnja obdobna ocena količinskega stanja 1991–2020 razkriva, da imamo v plitvih vodonosnikih podzemnih vodnih teles letno na razpolago dobrih 4 milijarde m^3 podzemne vode. Odvzemi podzemne vode (črpane količine) so v obdobju 2014–2019 v plitvih vodonosnikih dosegali povprečno 135 milijonov m^3/leto. Na območju globokega geotermalnega vodonosnika v Murski kotlini so odvzemi v tem obdobju ocenjeni na 2,5 milijona m^3/leto. Numerični modeli simulirajo omejeno napajanje, ki se kaže kot izcejanje iz okoliških kamnin v geotermalni vodonosnik v višini približno 2,3 milijona m^3 termalne vode na leto.

Abstract

The Groundwater quantitative status assessment is part of River Basin Management Plan 2022–2027 (RBMP III) and is used to evaluate, according to certain criteria, the 21 groundwater bodies (GWBs) in Slovenia. GWB can achieve good or poor quantitative status. The assessment is carried out with four tests, where the impact of groundwater abstraction (pumped quantities) on: groundwater quantity and water balance, the ecological status of associated surface water bodies, groundwater dependent terrestrial ecosystems and the intrusion of saline or poor water quality into the aquifer is analyzed. The final overall assessment of each groundwater body, based on the completed tests, is determined by the criterion of the worst test assessment. Based on the results of the tests, within the assessment period, 20 GWBs in Slovenia achieved good quantitative status. GWB Dravska kotlina achieved poor quantitative status, because the pumping of groundwater causes poor quality water intrusions into the deeper aquifer of that groundwater body. Within the last assessment period 1991–2020, approx. 4 billion m^3 of groundwater was available annually in shallow aquifers within groundwater bodies. Groundwater abstraction (pumper quantities) in the period 2014–2019 reached an average of 135 million m^3. In the area of deep geothermal aquifers of the Mura basin, abstractions were estimated to sum up to 2.5 million m^3 per year. Latest numerical simulations point out induced aquifer recharge of approx. 2.3 million m^3 of thermal water.

Uvod

V Sloveniji so količine podzemne vode v prejšnjem stoletju ocenjevali po principih klasifikacije in kategorizacije zalog mineralnih surovin (Andjelov et al., 2016a). Na prehodu v novo tisočletje je okvirna direktiva o vodah, glavni zakon za zaščito voda v evropskem prostoru, postavila nova zakonodajna izhodišča za ocenjevanje količinskega stanja podzemnih voda (Uradni list RS, 2003, 2005, 2009a, 2009b, 2016, 2018). Glavni cilj vodne direktive je trajnostna raba podzemne vode z zahtevo po dolgoročnem ohranjanju vodnih količin brez povzročanja nesprejemljivih okoljskih in drugih posledic. Vodna direktiva od držav članic zahteva, da uporabljajo načrte upravljanja voda in programe ukrepov za zaščito vodnih teles z namenom, da se doseže dobro stanje voda.

Tretji načrt upravljanja voda v Sloveniji (NUV III) je aktualni načrt upravljanja z vodami za obdobje izvajanja med leti 2022 in 2027. Načrt je strateški dokument države za izvajanje okvirne direktive o vodah (Direktiva, 2000). Izdelan je za obdobje šestih let in predstavlja inštrument za doseganje zaščite, izboljšanja in trajnostne rabe vode oz. vodnega okolja v Evropi. V Sloveniji tako za vsako šestletno obdobje na vodnih telesih preučimo in analiziramo vpliv človekovega delovanja na površinske in podzemne vode in zanje določimo cilje. Del NUV III je tudi ocena količinskega stanja podzemnih voda, ki predstavlja kontinuiteto standardiziranega prikaza ocene ter razvoja metodologije ocene količinskega stanja podzemnih voda predhodnih ciklov ocenjevanja količinskega stanja podzemnih voda od leta 2006 dalje (Andjelov et al., 2006, 2016a, 2021a). Količinsko stanje podzemne vode ocenjujemo z vplivi rabe vode na razpoložljive količine podzemne vode. Razpoložljive količine podzemne vode so opredeljene z razliko med obnovljivo količino podzemne vode, ki predstavlja napajanje vodonosnikov iz padavin in količino podzemne vode, ki je potrebna za ohranjanje ekološkega stanja površinskih voda in kopenskih ekosistemov (Uradni list RS, 2009a, 2012, 2016).

Količinsko stanje podzemnih voda je na podlagi opravljenih preizkusov ocenjeno kot »dobro« ali »slabo« (sl. 1). Preizkus vpliva odvzema podzemne vode na spremembo gladine podzemne vode in vodno bilanco izvedemo na vseh 21-tih vodnih telesih podzemnih voda v Sloveniji. Ostale preizkuse izvedemo le tam, kjer ocenjujemo tveganje, da učinki rabe podzemne vode vplivajo na stanje površinskih vodnih teles, na kopenske ekosisteme, ki so odvisni od podzemnih voda, ali na vdore slane vode oz. vode slabše kakovosti.

V članku so predstavljene metode dela in rezultati ocene količinskega stanja podzemnih voda do vključno leta 2020 v Sloveniji, ki so podlaga NUV III. Podana je primerjava z oceno količinskega stanja iz NUV II (Vlada RS, 2016a, 2016b) ter nakazani predlogi nadaljnjih raziskav za povečanje zanesljivosti ocene stanja za prihodnji načrt upravljanja z vodami.

Metodologija izračuna ocene količinskega stanja podzemnih voda

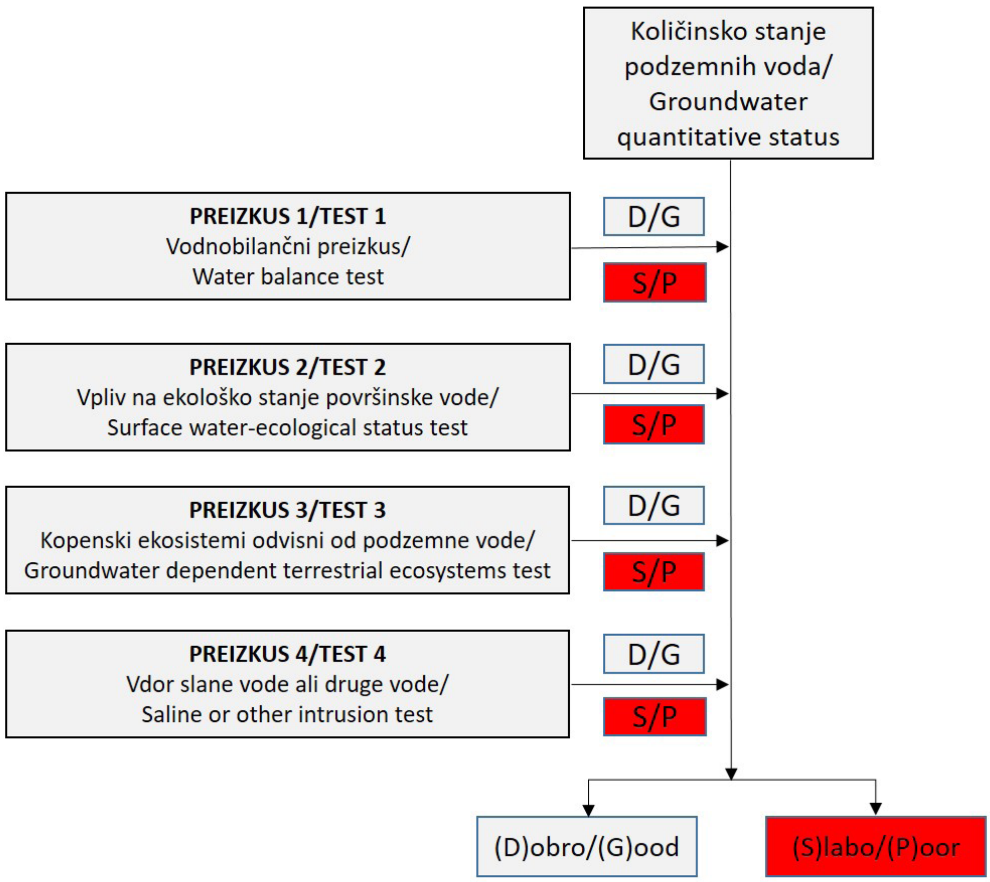
Metode dela

Ocena količinskega stanja podzemnih voda se izvaja za posamezna vodna telesa podzemnih voda (VTpodV) s štirimi preizkusi (Evropska komisija, 2009) (sl. 1). Ugotavlja se vpliv odvzemov podzemne vode, kjer se upoštevajo črpane količine, na:

1. gladine podzemne vode in vodno bilanco (preizkus 1);
2. ekološko stanje površinskih vodnih teles (preizkus 2);
3. kopenske ekosisteme, odvisne od podzemne vode (preizkus 3) in
4. vdore slane vode ali vode slabše kakovosti v vodonosnik (preizkus 4).

Končno skupno oceno, na podlagi opravljenih preizkusov, določa kriterij najslabše ocene (sl. 1).

Ocena vpliva odvzemov podzemne vode na količine podzemne vode (preizkus 1) se je izvedla na vseh enaindvajsetih VTPodV. Prvi del preizkusa 1 je bil ločen za plitve odprte vodonosnike in za globoke zaprte vodonosnike. Za plitve vodonosnike je preizkus temeljil na analizi trenda gladin podzemne vode in malih pretokov izvirov oziroma vodotokov v obdelovalnem in napovedovalnem obdobju na izbranih merilnih mestih državnega monitoringa, za globoke vodonosnike pa na analizi piezometrične gladine v opazovalnih vrtinah. Izračun malih letnih pretokov temelji na povprečju najmanjših dnevnih pretokov po posameznih mesecih (Höller, 2004). Drugi del preizkusa 1 je predstavljal vodnobilančno analizo vseh komponent odtoka, ki smo jo izvedli z regionalnim vodnobilančnim modelom GROWA-SI (Andjelov et al., 2016b). Eden izmed rezultatov vodnobilančnega modela GROWA-SI je tudi količinsko obnavljanje podzemne vode oz. obnovljiva količina podzemne vode, ki predstavlja napajanje vodonosnikov oz. VTPodV iz padavin. Obnovljiva količina podzemne vode je bila izhodišče za oceno razpoložljivih količin podzemne vode. Iz obnovljivih količin podzemne vode se je ob upoštevanju potreb teles površinskih voda in ekosistemov, odvisnih od podzemnih voda, t. i. ekološkega odbitka (Janža et al., 2016), ocenilo razpoložljive količine podzemne vode (Andjelov et al., 2016a, 2021a) in nadalje izračunal delež odvzete črpane podzemne vode. Analiza trenda gladin podzemne vode se je za plitve vodonosnike zaključila z zaporedjem preizkusov z ugotavljanjem deleža merilnih mest z zniževanjem gladin v obdelovalnem in napovedovalnem obdobju, ki naj bi na posameznih VTPodV ne presegal 25 % (Andjelov et al., 2016a, 2021a). Vodnobilančni preizkus se je zaključil s



Sl. 1. Postopek ugotavljanja skupne ocene količinskega stanja vodnega telesa podzemne vode – kriterij »odloča najslabša ocena« (prirejeno po Evropska komisija, 2009).

Fig. 1. Overall procedure of tests for assessing groundwater quantitative status – criterion "the worst-case assessment decides" (modified after Evropska komisija, 2009).

primerjavo odvzetih črpanih količin podzemne vode z razpoložljivimi količinami podzemne vode. Količinsko stanje VTPodV je po vodnobilančnem preizkusu ocenjeno kot »dobro«, kadar dolgoročna povprečna letna količina črpanja podzemne vode ne presega razpoložljive količine podzemne vode (Andjelov et al., 2016a, 2021a). Za plitve vodonosnike se je nadalje po različnih kombinacijah podnebnih in emisijskih scenarijev ocenila še povprečna obnovljiva količina podzemne vode do leta 2100. Analiza vpliva podnebnih sprememb na napajanje podzemne vode je bila izdelana z modelom mGROWA-SI z mesečno časovno resolucijo (Draksler, 2019; Frantar et al., 2019).

Ocena vpliva odvzemov podzemne vode na ekološko stanje površinskih vodnih teles (preizkus 2) se je izvedla na štirinajstih VTPodV, ki so povezana z vodnimi telesi površinskih voda, na katerih je bilo ugotovljeno slabo (ocena slabo in zelo slabo) ekološko stanje. Analizo vplivov odvzemov smo tako izvedli na 20 vodnih telesih (VT) površinskih voda, za katere je bilo za obdobje 2014–2019 ocenjeno slabo ekološko stanje (Andjelov et al., 2021a). Analiziran je bil delež vseh odvzemov podzemne vode glede na količine srednjega pretoka površinske vode (Qs) in glede na povprečno obnavljanje podzemne vode v obdobju 1991–2020, kjer za dobro količinsko stanje delež odvzemov ne sme presegati 10 %, hkrati pa mora biti večina odvzemov iz podzemne vode (Andjelov et al., 2021a).

Ocena vpliva odvzemov podzemne vode na kopenske ekosisteme odvisne od podzemne vode (KEOPV) (preizkus 3) se je izvedla na devetih VTPodV kjer je bilo ocenjeno, da učinki odvzemov podzemne vode lahko vplivajo na kopenske ekosisteme, ki so odvisni od podzemnih voda (Andjelov et al., 2016a, 2021a). Vsi v analizo vključeni kopenski ekosistemi so gozdni habitati in so opredeljeni kot ogroženi oz. poškodovani (Mezga et al., 2015). Analizo količinskega pritiska, oz. primerjavo odvzemov podzemne vode in povprečnega obnavljanja podzemne vode v obdobju 1991–2020 na hidrološkem vplivnem območju habitata, smo izvedli na 13 območjih VTPodV (Andjelov et al., 2021a). Za dobro količinsko stanje VTpodV odvzemi ne smejo presegati mejo 5 % obnovljivih količin podzemne vode na območju ekosistema in njegovega prispevnega zaledja, kar glede na analizo pritiskov predstavlja še zanemarljiv vpliv na KEOPV (WFD Ireland, 2005).

Analiza odvzemov podzemne vode na vdore slane vode ali vode slabše kakovosti v vodonosnik (preizkus 4) se je izvedla za dve vodni telesi podzemne vode: VTPodV 5019 Obala in Kras z

Brkini (slovenski del vodonosnega sistema 50621 Brestovica-Timav) in VTPodV 3012 Dravska kotlina (Andjelov et al., 2021a). Pri preizkusu se je izvedla analiza odvzemov podzemne vode na vdore slane vode ali vode slabše kakovosti, kjer so se povprečne količine odvzema podzemne vode obdobja primerjale s srednjo dolgoletno obnovljivo količino podzemne vode vodonosnika. Nadalje se je primerjalo povprečne dolgoletne vrednosti specifične električne prevodnosti (SEP) z naravnim ozadjem in mejno vrednostjo SEP za pitno vodo. Pri preizkusu se je ugotavljalo tudi trend indikativnih parametrov vdora slane vode (natrij, klorid, SEP) oziroma vode slabše kakovosti (nitrat, SEP) (Andjelov et al., 2016a, 2021a). Za dobro količinsko stanje VTPodV odvzemi ne smejo presegati 10 % obnovljivih količin podzemne vode, ne sme biti presežena meja SEP kakovosti pitne vode in naravnega ozadja ter ne sme biti zaznanega statistično značilnega naraščajočega trenda indikativnih parametrov (Andjelov et al., 2021a).

Ocena količinskega stanja po posameznih VTPodV je podana z določeno stopnjo zaupanja (Evropska komisija, 2016). Visoka stopnja zaupanja pomeni, da so na razpolago kakovostni podatki monitoringa in dober konceptualni model, razumevanje hidrološkega sistema pa temelji na poznavanju naravnih značilnosti in antropogenih pritiskov. Pri srednji stopnji zaupanja imamo na razpolago omejene podatke monitoringa in pomanjkljivo poznavanje hidrološkega sistema. Nizka stopnja zaupanja pa pomeni, da ne razpolagamo s podatki monitoringa oz. ne poznamo hidrološkega sistema.

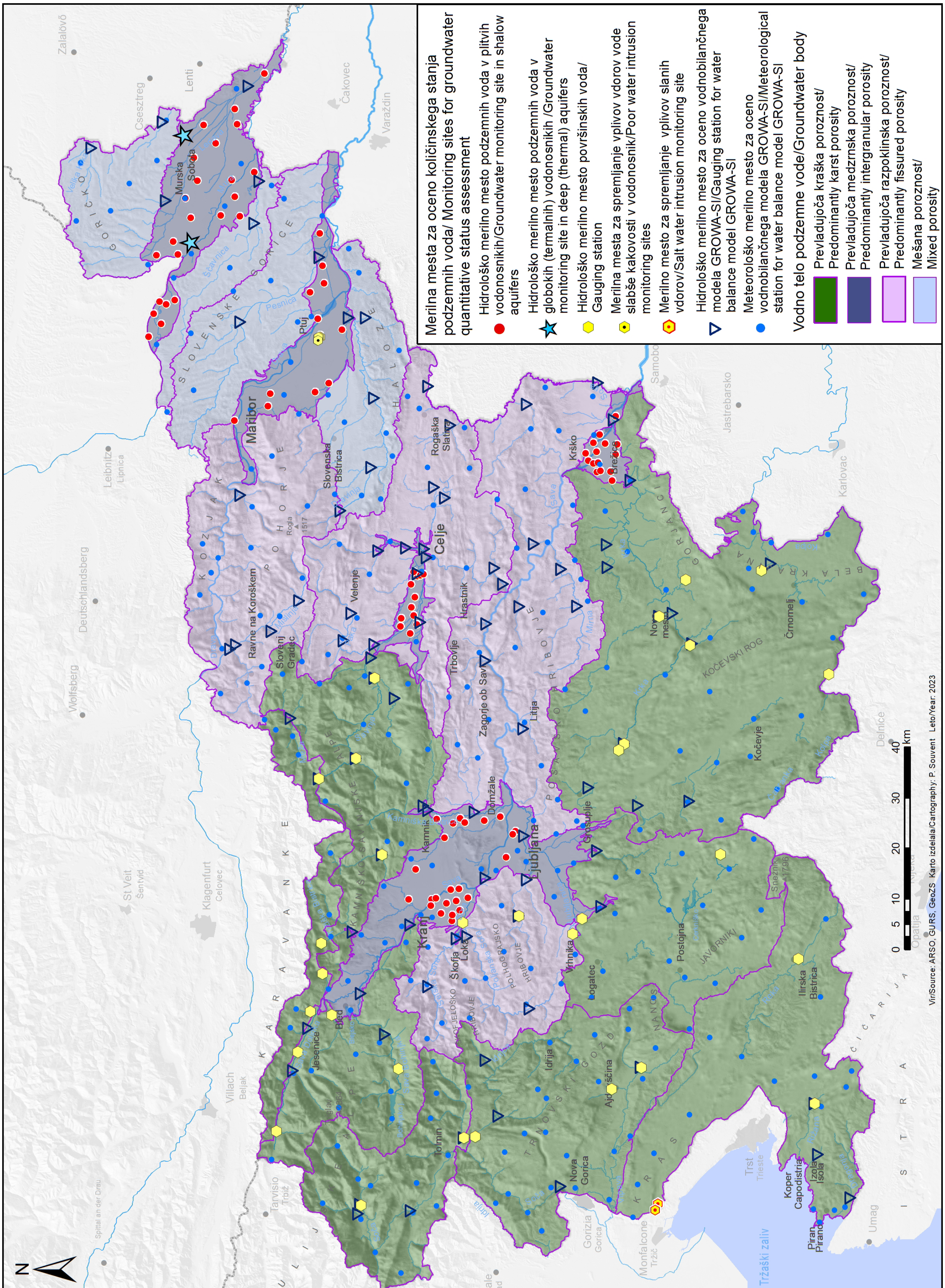
Vhodni podatki

Ocena količinskega stanja podzemnih voda temelji na državnih podatkovnih zbirkah hidrološkega in meteorološkega monitoringa v upravljanju Agencije RS za okolje (Internet 1, Internet 2, Internet 3) ter na podatkih v upravljanju Direkcije RS za vode o odvzetih količinah podzemne vode (Evidenca vodnih povračil). Vodnobilančni model GROWA-SI (Andjelov et al., 2016b) poleg časovnih podatkov upošteva tudi izbrane prostorske podatkovne sloje za ugotavljanje antropogenega vpliva rabe podzemne vode na obnovljive količine podzemne vode.

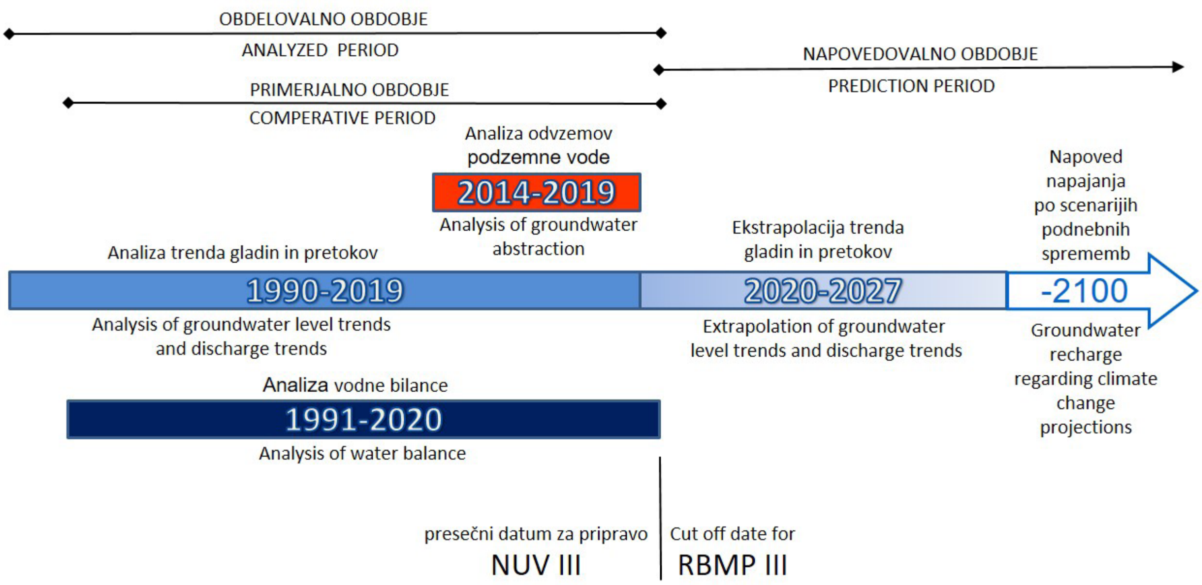
Na vodnih telesih plitvih vodonosnikov s prevladujočo medzrnsko poroznostjo je bil monitoring usmerjen v meritve gladine podzemne vode (86 merilnih mest) in ugotavljanje trendov gladin podzemnih voda. Na vodnih telesih z vodonosniki s kraško, razpoklinsko ali mešano poroznostjo so vhodne podatke predstavljale meritve pretokov (30 merilnih mest), kjer se je ugotavljalo trende malih pretokov izvirov in vodotokov na referenčnih merskih profilih. Za umerjanje regionalnega vodnobilančnega modela napajanja vodonosnikov GROWA-SI, je bil vključen del merilne mreže hidrološkega monitoringa površinskih voda z meritvami pretokov in del mreže meteorološkega monitoringa (sl. 2) s podatki padavin in temperature. Za oceno napajanja globokih geotermalnih vodonosnikov je bil uporabljen hidrogeološki matematični model toka podzemne vode in prenosa toplote (Rman & Šram, 2019). Vodnobilančna ocena temelji na podatkih 199 merilnih mest hidrološkega monitoringa podzemnih in površinskih voda z nizom meritev 30 let in ob predpostavki, da meritve ne odražajo umetnih vplivov na merjeni lokaciji (Internet 1). Za monitoring količinskega stanja podzemnih voda v globokem geotermalnem vodonosniku severovzhodne Slovenije smo v oceno vključili dve merilni mesti z nizom meritev 11 let in v upravljanju Geološkega zavoda Slovenije (Rman et al. 2016; Andjelov et al. 2021a, b). Državni monitoring v obdobju 2014–2019 namreč še vedno ni bil vzpostavljen.

Vhodni podatki za ugotavljanje vpliva črpanih odvzemov podzemnih in površinskih voda na stanje površinskih vodnih teles so ocenjeni pretoki na izhodnem profilu in obnovljive količine podzemne vode (model GROWA-SI) na območju vodozbirnega zaledja vodnega telesa površinske vode s slabim ali zelo slabim ekološkim stanjem (21 površinskih vodnih teles). Obnovljiva količina podzemne vode za preizkus vpliva črpanih odvzemov podzemne vode na KEOPV je pridobljena iz regionalnega vodnobilančnega modela GROWA-SI za območje KEOPV in njihovih prispevnih zaledij. Vhodni podatki za ugotavljanje vdora slane vode (2 merilni mesti) ali druge vrste vdorov (5 merilnih mest) v vodno telo so meritve gladine podzemne vode, SEP vode in meritve indikativnih kemijskih parametrov (kloridni, natrijev in nitratni ion). V oceno so vključeni tudi podatki črpanih količin podzemne vode, odvzetih iz vodnih teles podzemnih voda. Vzorčenje indikativnih parametrov poteka 1 do 2 krat letno, v primeru dveh vzorčenj kot referenčno letno vrednost uporabimo povprečno vrednost.

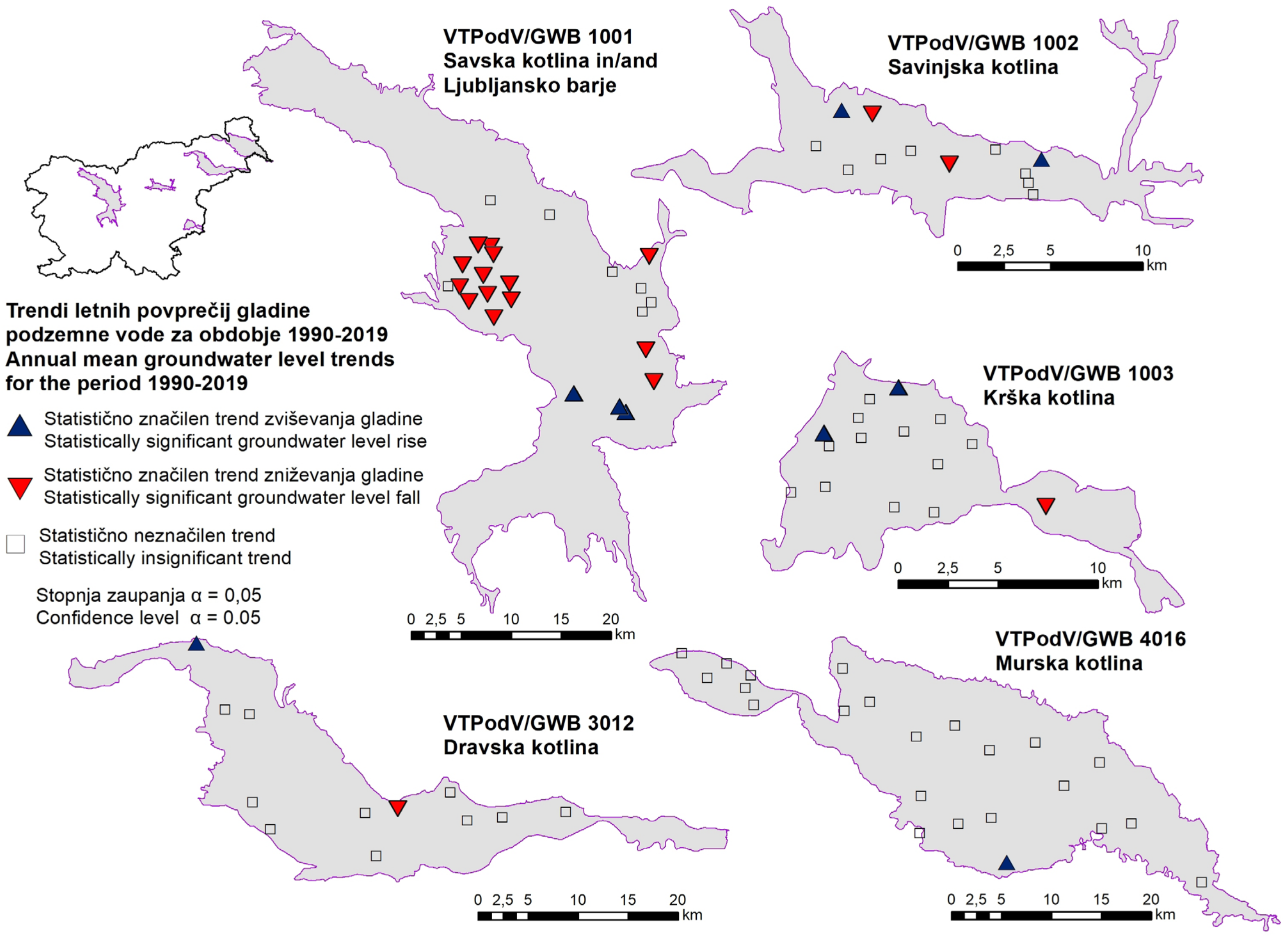
Časovno okno obdelovalnega obdobja je med letom 1990 in 2020 in sicer je bilo za izračune vodne bilance vzeto obdobje 1991–2020, za analize trenda gladin podzemnih voda in pretokov kraških izvirov iz plitvih vodonosnikov obdobje 1990–2019, za povprečne odvzeme podzemne vode pa obdobje 2014–2019, saj pred letom 2014 ni na razpolago ustreznih podatkov oz. urejenih baz. Tridesetletno primerjalno obdobje je 1991–2020. Količinsko



Sl. 2. Merilna mesta vključena v oceno količinskega stanja podzemnih voda v obdobju ocenjevanja za NUV III.
Fig. 2. Monitoring sites for groundwater quantitative status assessment for RBMP III.



Sl. 3. Časovni okvir ocenjevanja količinskega stanja podzemnih voda za pripravo NUV III (2022–2027) Časovna skala ni v merilu.
Fig. 3. Time frame of groundwater quantitative status assessment for RBMP III (2022–2027). Timeline is not in scale.



Sl. 4. Trendi letnih povprečij gladine podzemne vode za obdobje 1990–2019 za VTPodV s prevladujočo medzrnsko poroznostjo (geotermalni vodonosniki tukaj niso presojani).
Fig. 4. Annual mean groundwater level trends for the period 1990–2019 for GWBs with predominant intergranular porosity (geothermal aquifers are not included).

stanje podzemnih voda vključuje tudi napovedovalni obdobji 2020–2027 za oceno ekstrapolacije trenda gladin in pretokov iz plitvih vodonosnikov ter 2021–2100 za oceno sprememb napajanja plitvih vodonosnikov po scenarijih podnebnih sprememb do leta 2100 (sl. 3). Za globok geotermalni vodonosnik severovzhodne Slovenije so zanesljivi podatki o odvzemih in gladinah v aktivnih vrtinah na voljo šele od leta 2017, ko je bil po letu 2015 zaradi podeljenih koncesij po Zakonu o vodah uveden nadzor rabe termalne vode (Andjelov et al., 2019).

Rezultati

Izmed 86 reprezentativnih merilnih mest, ki so bila vključena v *preizkus 1* z namenom določitve trendov gladin podzemnih voda na vodnih telesih plitvih vodonosnikov s pretežno medzrnsko poroznostjo (Andjelov et al., 2016a, 2021a), beležimo statistično značilne upadajoče trende letnih povprečij gladin podzemnih voda (stopnja zaupanja α=0,05) na 18 merilnih mestih, statistično značilne trende zviševanja gladine pa na 9 merilnih mestih (sl. 4). Delež merilnih mest z zniževanjem gladin v napovedovalnem obdobju nikjer ne presega praga 25 % (Uradni list RS, 2009a, 2012, 2016; Andjelov et al., 2021a).

Tudi analiza trenda malih pretokov površinskih voda in izvirov na 30 reprezentativnih merilnih mestih obdelovalnega obdobja 1990–2019 izkazuje nekatere statistično značilne trende zmanjševanja malih letnih pretokov (stopnja zaupanja α=0,05) na 5 merilnih mestih: 3320 Bohinjska Bistrica - Bistrica, 5030 Vrhnika II - Ljubljanica, 8561 Vipava II - Vipava, 6060 Nazarje - Savinja in 8450 Hotešk - Idrijca. Mali letni pretoki po oceni/ekstrapolaciji linearnega trenda do konca napovedovalnega leta 2027 ne bodo dosegli vrednosti praga 95 % pretoka iz krivulje trajanja (Q_{95}) (Andjelov et al., 2021a).

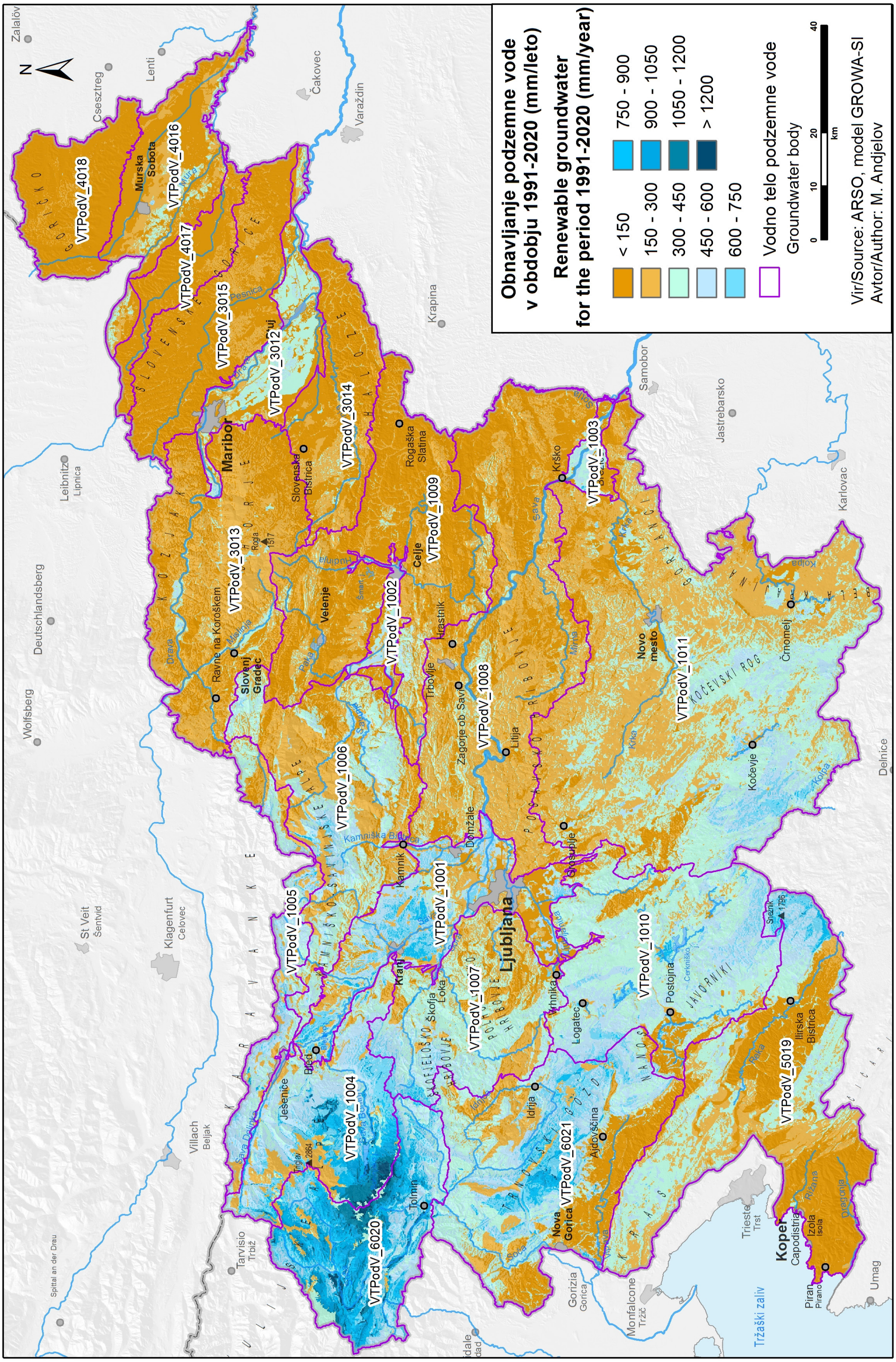
Vodnobilančni preizkus (preizkus 1) vseh komponent odtoka (GROWA-SI) kaže, da je v obdobju 1991–2020 v Sloveniji letno padlo povprečno 1.447 mm padavin, od te količine se je z evapotranspiracijo letno vrnilo v ozračje povprečno 650 mm. Povprečni skupni letni odtok je znašal 797 mm, od tega je bilo 505 mm direktnega odtoka (količina vode, ki odteče površinsko in z vmesnim odtokom) in 292 mm podzemnega odtoka (količina vode, ki napaja oz. obnavlja podzemno vodo). Največ skupnega povprečnega letnega odtoka je bilo v porečju Soče, na območju VTPodV 6020 Julijske Alpe v porečju Soče, najmanj pa v porečju Mure, na območju VTPodV 4018 Goričko, kar se odraža tudi pri količinskem obnavljanju podzemne vode (sl. 5).

Iz obnovljivih količin podzemne vode (sl. 5) se je ob upoštevanju potreb teles površinskih voda in ekosistemov, odvisnih od podzemnih voda, t. i. ekološkega odbitka (Janža et al., 2016), ocenilo razpoložljive količine podzemne vode (Andjelov et al., 2016a, 2021) in nadalje izračunal delež odvzete podzemne vode od le-te. Odvzemi s črpanjem podzemne vode so v izbranem obdobju 2014–2019 v plitvih vodonosnikih dosegli povprečno 135 milijonov m^3. Delež povprečnih letnih črpanih količin podzemne vode za obdobje 2014–2019 pa je bil, glede na model napajanja vodonosnikov GROWA-SI in izračun razpoložljive količine podzemne vode za obdobje 1991–2020, največji na območjih treh aluvialnih vodnih teles: VTPodV 3012 Dravska kotlina (25,9 %), VTPodV 1001 Savska kotlina in Ljubljansko Barje (22,4 %) in VTPodV 4016 Murska kotlina (20,9 %) (Tabela 1, sl. 6).

Analiza vpliva podnebnih sprememb na napajanje podzemne vode, po scenarijih izpustov RCP4.5 in RCP8.5 do konca stoletja, kaže na povečanje napajanja podzemne vode. Predvidoma se bo do leta 2100 po srednjem scenariju RCP4.5 napajanje enakomerno povečevalo po vsej državi v vseh obdobjih, po scenariju RCP8.5 je največje povečanje predvideno v sredini stoletja, proti koncu stoletja pa se količina napajanja ustali. Po scenariju RCP8.5 se konec stoletja kaže tudi zmanjšanje napajanja v posameznih predelih južne Slovenije.

Sezonski pregled kaže, da se bo po obeh scenarijih povečalo napajanje pozimi, v ostalih letnih časih pa je odklon napajanja nepredvidljiv. Do konca stoletja je po scenariju RCP4.5 v Sloveniji predvideno povečanje napajanja za približno 20 %, po scenariju RCP8.5 pa za približno 10 %, medtem ko so relativne vrednosti povečanja v severovzhodni Sloveniji nekoliko višje. Največjo zanesljivost vpliva podnebnih sprememb po obeh scenarijih imajo napovedi za povečanje napajanja na vzhodu države.

Analiza mesečnih povprečij piezometričnih gladin podzemne vode v vrtini Do-1 v Dobrovniku in vrtini V-66 v Petanjcih v globokih geotermalnih vodonosnikih SV Slovenije, kot del *preizkusa 1*, kaže v obdobju 2009–2019 statistično značilno zniževanje piezometrične gladine. V letu 2019 so bile, glede na obdobje 2009–2019, izmerjene najnižje piezometrične gladine v obeh vrtinah (sl. 7) in do obrata trenda ni prišlo, se pa je zniževanje gladine nekoliko upočasnilo. Hidrogeološka simulacija z modelom vodne bilance naravnega stanja geotermalnega vodonosnika Murske formacije, ki jo je izvedel Geološki zavod Slovenije, ocenjuje letno napajanje na približno 5,6 milijona m^3 (Rman et al., 2014). Povprečni odvzemi termalne podzemne



Sl. 5. Obnovljive količine podzemne vode v plitvih vodonosnikih VTPodV v obdobju 1991–2020.
Fig. 5. Renewable groundwater quantity in shallow aquifers of GWBs in the period 1991–2020.

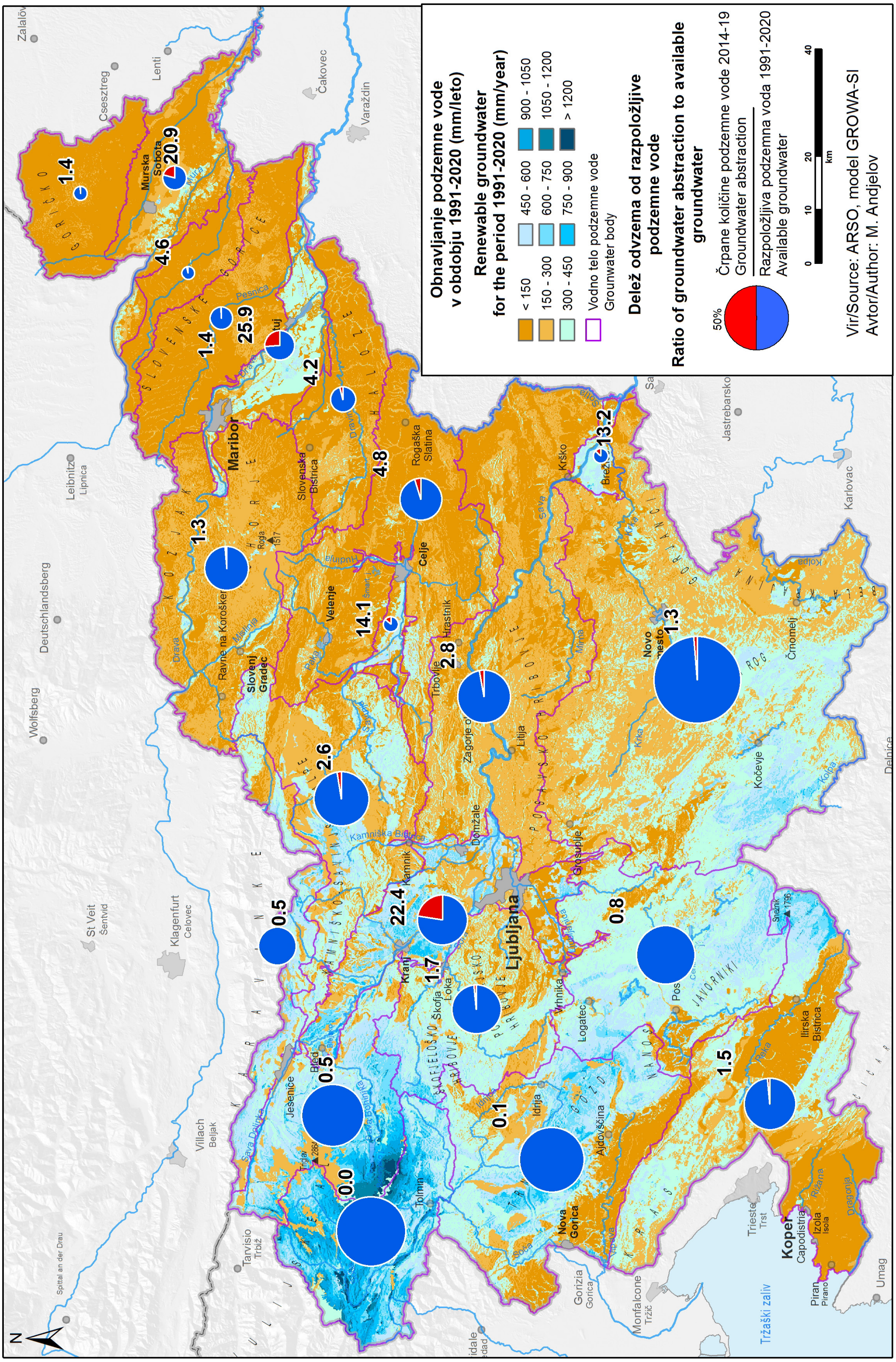
Tabela 1. Razmerja med črpanimi količinami podzemne vode (2014–2019) in razpoložljivo količino podzemne vode (1991–2020) v plitvih vodonosnikih VTPodV Slovenije.

Table 1. Rate of groundwater abstraction (2014–2019) in relation to available groundwater quantity (1991–2020) in shallow aquifers of GWBs in Slovenia.

Vodno telo podzemne vode (šifra in ime)	Razpoložljiva količina podzemne vode v obdobju 1991–2020 (m^3/leto)	Črpane količine podzemne vode v obdobju 2014–2019 (m^3/leto)	Količine umetnega napajanja vodonosnikov v obdobju 2014–2019 (m^3/leto)	Črpane količine podzemne vode / razpoložljiva količina podzemne vode (%)
Groundwater body (code and the name)	Available groundwater for the period 1991–2020 (m^3/year)	Groundwater abstraction for the period 2014–2019 (m^3/year)	Aquifer artificial recharge for the period 2014–2019 (m^3/year)	Groundwater abstraction / available groundwater (%)
1001 Savska kotlina in Ljubljansko Barje	221.403.160	49.600.836	-	22,4
1002 Savinjska kotlina	20.164.080	2.847.899	-	14,1
1003 Krška kotlina	19.678.974	2.603.761		13,2
1004 Julijske Alpe v porečju Save	338.492.669	1.510.625	-	0,5
1005 Karavanke	125.820.501	682.520	-	0,5
1006 Kamniško-Savinjske Alpe	262.596.713	6.765.793	-	2,6
1007 Cerkljansko, Škofjeloško in Polhograjsko hribovje	212.960.161	3.534.514	-	1,7
1008 Posavsko hribovje do osrednje Sotle	245.263.218	6.794.722	-	2,8
1009 Spodnji del Savinje do Sotle	156.813.961	7.503.786	-	4,8
1010 Kraška Ljubljanica	303.755.271	2.355.408	-	0,8
1011 Dolenjski kras	670.405.039	8.616.673	-	1,3
3012 Dravska kotlina	77.966.028	21.367.493	4.624.071	25,9
3013 Vzhodne Alpe	170.109.873	2.129.343	-	1,3
3014 Haloze in Dravinjske gorice	55.736.483	2.350.677	-	4,2
3015 Zahodne Slovenske gorice	44.999.217	612.698	-	1,4
4016 Murska kotlina	50.701.290	10.609.688	-	20,9
4017 Vzhodne Slovenske gorice	14.811.330	683.197	-	4,6
4018 Goričko	16.740.011	231.843	-	1,4
5019 Obala in Kras z Brkini	235.464.524	3.452.254	-	1,5
6020 Julijske Alpe v porečju Soče	426.824.855	115.482	-	0,03
6021 Goriška brda in Trnovsko-Banjška planota	371.034.890	545.106	-	0,2
Slovenija	**4.041.742.249**	**134.914.318**	**4.624.071**	**3,3**

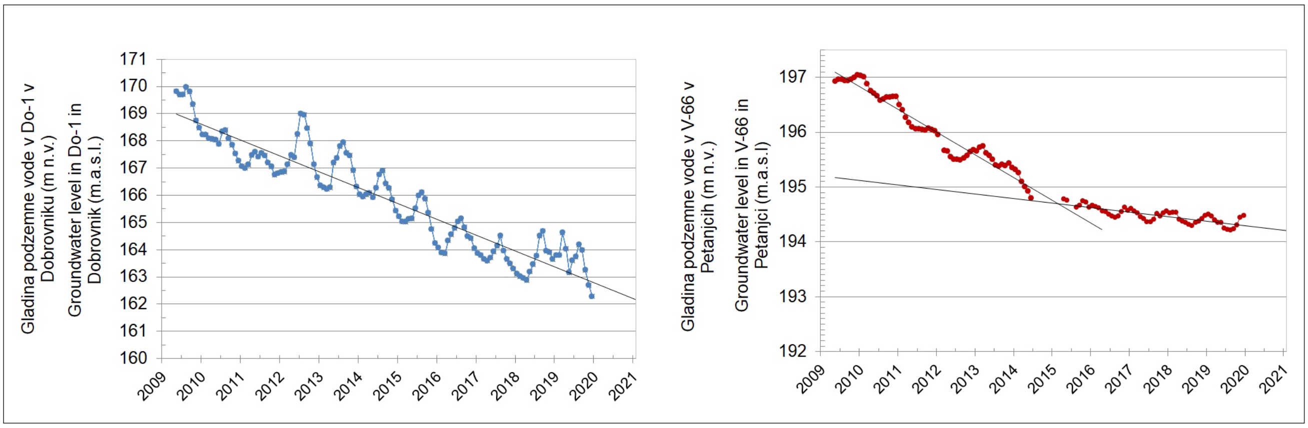
vode so bili v obdobju 2014–2019 približno 2,5 milijona m^3 letno, kar predstavlja 44 % z modelom naravnega stanja ocenjenih letno obnovljivih količin termalne podzemne vode (Andjelov et al., 2021a). Kasnejši model (Rman & Šram, 2019) je bil umerjen na dostopne podatke iz obdobja 2009–2016 in validiran s podatki gladin iz vrtin Do-1, V-66 in Fi-5 (v Renkovcih) v obdobju 2017–2018. Pokazal je bolj omejeno napajanje, ki se kaže kot izcejanje iz okoliških kamnin v geotermalni vodonosnik v višini približno 2,3 milijona m^3 termalne vode na leto. Ker je bil šele po letu 2017 vzpostavljen zanesljiv obratovalni monitoring, je negotovost numeričnega modela Murske formacije še vedno velika, vendar se z novimi vsakoletnimi meritvami in kalibracijo stalno zmanjšuje. Analiza obratovalnih monitoringov je hkrati pokazala, da je v 15–20 % objektov vsako leto ugotovljena sprememba kemijske sestave termalne vode, ki presega odstopanje ± 20 % za relevantne parametre (Lapanje et al., 2018; Tancar & Vižintin, 2021).

Rezultati *preizkusa vpliva odvzemov podzemne vode na ekološko stanje površinskih voda (preizkus 2)* kažejo, da pri nobenem obravnavanem vodnem telesu površinskih voda odvzemi podzemne vode ne povzročajo slabega ekološkega stanja. Delež vseh odvzemov od srednjega pretoka površinske vode (Q_s) je na 19 obravnavanih vodnih telesih pod mejno vrednostjo za dobro stanje, ki je pri 10 % (Andjelov et al., 2021a). Mejna vrednost je presežena le v primeru VT Hudinja povirje – Nova Cerkev (SI1688VT1), kjer je delež odvzemov



Sl. 6. Razmerje med črpanimi količinami podzemne vode (2014–2019) in razpoložljivo količino podzemne vode (1991–2020), na karti tudi obnovljive količine podzemne vode (GROWA-SI).

Fig. 6. Rate of groundwater abstraction (2014–2019) in relation to available groundwater quantity (1991–2020) in shallow aquifers of GWBs in Slovenia, together with renewable groundwater quantity (GROWA-SI).

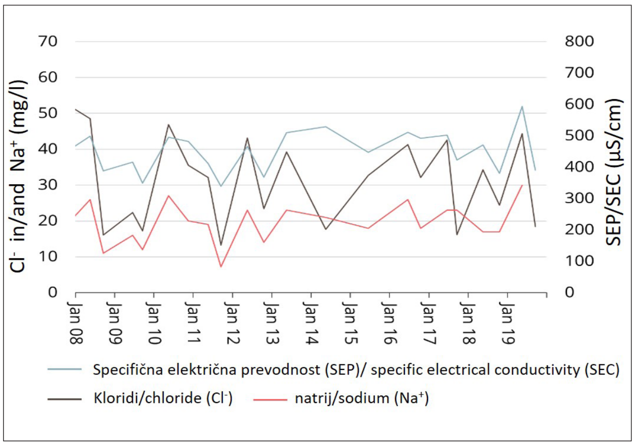


Sl. 7. Mesečna povprečja piezometrične gladine podzemne vode v opazovalnih vrtinah Do-1 (Dobrovnik) in V-66 (Petanjci) v obdobju 2009–2019 (Andjelov et al., 2021b).

Fig. 7. Monthly averages of the piezometric groundwater level in piezometers Do-1 (Dobrovnik) and V-66 (Petanjci) for the period 2009–2019 (Andjelov et al., 2021b).

12,8 %. Na tem vodnem telesu prevladuje odvzem površinske vode, tako da odvzem podzemne vode ni razlog za slabo stanje tega telesa.

Rezultati *preizkusa vpliva odvzemov podzemne na KEOPV (preizkus 3)* kažejo, da so odvzemi evidentirani na 4 KEOPV, znotraj 4 VTPodV in sicer na: Sava Medvode – Kresnice v VTpodV 1001 Savska kotlina in Ljubljansko Barje, Krakovski gozd v VTPodV 1011 Dolenjski kras, Boreci v VTpodV 4017 Vzhodne Slovenske Gorice in Mura 1 v VTpodV 4016 Murska kotlina. Odstotek odvzemov glede na povprečne obnovljive količine podzemne vode v obdobju 1991–2020 je na območju ekosistema in njegovem zaledju za območje Sava Medvode – Kresnice 0,1 %, za Krakovski gozd 0,5 %, za območje Boreci 2 % in za območje Mura 1,3 %. Črpane količine ne presegajo meje 5 %, kar glede na analizo pritiskov predstavlja zanemarljiv vpliv na KEOPV (Andjelov et al., 2021a). Podzemna voda se na teh KEOPV rabi največ za namakanje kmetijskih zemljišč, sledi oskrba s pitno vodo in raba za tehnološke namene, nekaj se je porabi tudi za lastno oskrbo s pitno vodo.

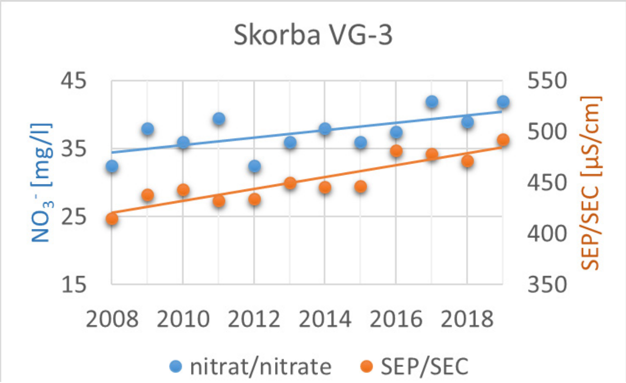


Sl. 8. Nihanje specifične električne prevodnosti vode (µS/cm), kloridov (mg/l) in natrija (mg/l) v obdobju 2008–2019 v črpališču Klariči v VTPodV 5019 Obala in Kras z Brkini.

Fig. 8. Oscillation of specific electrical conductivity (µS/cm), chloride(mg/l) and sodium (mg/l) ions for the period 2008–2019 in pumping station Klariči in GWB 5019 Obala in Kras z Brkini.

Rezultati *analize odvzemov podzemne vode na vdore slane vode ali vode slabše kakovosti (preizkus 4)* kažejo, da razmerje med odvzemi (povprečje obdobja 2014–2019) podzemne vode v črpališču Klariči (VTPodV 5019 Obala in Kras z Brkini) in z modelom GROWA-SI ocenjeno povprečno obdobno obnovljivo količino podzemne vode ne presega 1 %, kar je pod mejno vrednostjo 10 % za dobro količinsko stanje. Po podatkih ARSO monitoringa kakovosti podzemnih voda (sl. 8), je v črpališču Klariči povprečna vrednost SEP v obdobju 2008–2019 451 µS/cm in ne presega mejne vrednosti SEP naravnega ozadja (519 µS/cm) in mejne vrednosti SEP za pitno vodo (2.500 µS/cm), ki sta pogoja dobrega količinskega stanja (Andjelov et al., 2021a). Trend časovne vrste obdobja 2008–2019 za specifično električno prevodnost, kloride in natrij je statistično neznačilen.

Razmerje med črpanimi odvzemi in obnovljivo količino podzemne vode (povprečje obdobja 2014–2019) na območju VTPodV 3012 Dravska kotlina v črpališčih komunale Ptuj in Slovenska Bistrica, znaša približno 5 % in je pod mejno vrednostjo 10 % za dobro količinsko stanje. Povprečna vrednost SEP je v obdobju 2008–2019, na izbranem merilnem mestu Skorba VG-3, ki je v upravljanju komunalnega podjetja Ptuj, 480 µS/cm in je pod SEP naravnega ozadja (802 µS/cm) (Andjelov et al., 2021a). Povprečna vsebnost nitrata, 37 mg/l na tem merilnem mestu presega naravno ozadje nitrata v podzemni vodi (2 mg/l) (Mihorko & Gacin, 2019). Trend časovne vrste obdobja 2008–2019 za SEP in nitrat je statistično značilno naraščajoč (sl. 9).



Sl. 9. Nihanje indikativnih parametrov NO_3^- in SEP na merilnem mestu Skorba, (merilno mesto VG-3) v obdobju 2008–2019.

Fig. 9. Oscillation of indicative parameters NO_3^- and SEC at monitoring site Skorba, (measuring station VG-3) in the period 2008–2019.

Razprava

Analiza trendov gladin podzemnih voda (Andjelov et al., 2021a) je za vodna telesa s prevladujočo medzrnsko poroznostjo v plitvih aluvialnih vodonosnikih izpostavila nekatere statistično značilne upadajoče trende letnih povprečij gladin podzemnih voda v obdelovalnem obdobju 1990–2019 na VTpodV 1001 Savska kotlina in Ljubljansko Barje, 1002 Savinjska kotlina, 1003 Krška kotlina in VTpodV 3012 Dravska kotlina (sl. 4). Delež merilnih mest z zniževanjem gladin podzemne vode v plitvih vodonosnikih v napovedovalnem obdobju do leta 2027 sicer nikjer ne presega praga 25 % obravnavanih merilnih mest na danem VTPodV, kar je eden od pomembnih kriterijev za doseganje dobrega količinskega stanja (Uradni list RS, 2009a, 2012, 2016; Andjelov et al., 2021a). Stanje gladin ostaja primerljivo razmeram analiziranim v NUV II (Andjelov et al., 2015). Izjema je VTpodV 1003 Krška kotlina, kjer so se razmere z izgradnjo akumulacijskega bazena in tesnilne zavese za HE Brežice izboljšale in na večini merilnih mest beležimo trend zviševanja gladin podzemne vode. Analiza trendov malih pretokov v povirnih območjih vodnih teles s kraško, razpoklinsko ali mešano poroznostjo ni zaznala zmanjšanja malih letnih pretokov do leta 2027 pod mejno vrednost referenčnega obdobja. Kljub nekaterim ugotovljenim statistično značilnim trendom zmanjševanja letnih in sezonskih malih pretokov izvirov oziroma vodotokov lahko zaključimo, da so trendi posledica naravne spremenljivosti podnebja in ne prekomerne rabe podzemne vode. Glede na rezultate analize trendov gladin in pretokov v obdobju 1990–2019 količinsko stanje podzemnih voda plitvih odprtih vodonosnikov vseh vodnih teles podzemnih voda ocenjujemo kot »dobro« z visoko stopnjo zaupanja.

V plitvih vodonosnikih VTPodV je v obdobju 1990–2020 razpoložljive količine podzemne vode 4.042 milijonov m³. Letni odvzemi (črpane količine) v treh VTPodV, 3012 Dravska kotlina, 1001 Savska kotlina in Ljubljansko Barje in 4016 Murska kotlina, presegajo mejno vrednost 20 %, ki jo Evropska okoljska agencija uporablja kot začetno opozorilo količinskega pritiska na vodne vire (Evropska okoljska agencija, 2005). Delež odvzemov v primeru nobenega od treh VTPodV ni večji kot 65 %, kar kot mejno vrednost količinskega pritiska povzema evropski projekt GENESIS (Preda et al., 2014). Črpanje vode iz vodonosnikov na območju Slovenije v skupni povprečni letni količini 135 milijonov m³ predstavlja 3,3 % skupne razpoložljive količine podzemne vode. Količinsko stanje podzemnih voda plitvih odprtih vodonosnikov, glede na rezultate vodne bilance z modelom GROWA-SI v obdobju 1991–2020 (Andjelov et al., 2016b, 2021b), tako ocenjujemo kot »dobro« z visoko stopnjo zaupanja za vsa vodna telesa podzemne vode. V primerjavi z oceno količinskega stanja podzemnih voda za NUV II (Andjelov et al., 2015), novejša ocena NUV III podaja nekoliko nižje skupne razpoložljive količine podzemne vode (razpoložljive količine NUV II: 4.285 milijonov m³) in nekoliko višje količine odvzema podzemne vode (NUV II: 132,815 milijonov m³ oziroma 3,1 % razpoložljivih količin podzemne vode). Raba podzemne vode se je v zadnjem ocenjevalnem obdobju NUV III v primerjavi z NUV II povečala v 17 od skupno 21 vodnih telesih podzemne vode. Največje povečanje odvzemov zaradi črpanja je bilo ugotovljeno v vodnih telesih podzemne vode VTPodV 1003 Krška kotlina, za 1,288 milijonov m³/leto, in v VTPodV 1002 Savinjska kotlina, za 1,119 milijonov m³/leto. Nižje količine kot v NUV II so bile v NUV III ugotovljene v 4 od skupno 21 vodnih teles podzemne vode. Največje zmanjšanje črpanih odvzemov beležimo v VTPodV 1009 Spodnji del Savinje do Sotle, za 2,731 milijonov m³/leto, in v VTPodV 3012 Dravska kotlina, za 1,335 milijonov m³/leto.

Za ocenjevanje količinskega stanja termalnih voda v Mursko-Zalskem bazenu se od leta 2014 v sodelovanju med Agencijo RS za okolje in Geološkim zavodom Slovenije razvija matematični model toka podzemne vode in prenosa toplote (Rman & Šram, 2019), ki služi kot podpora oceni količinskega stanja podzemne vode in odločanju za podeljevanje novih in podaljševanje obstoječih vodnih pravic. Kljub indikacijam o zniževanju piezometrične gladine podzemne vode v opazovalnih vrtinah je količinsko stanje podzemne vode v globokem vodonosniku vodnega telesa VTPodV 4016

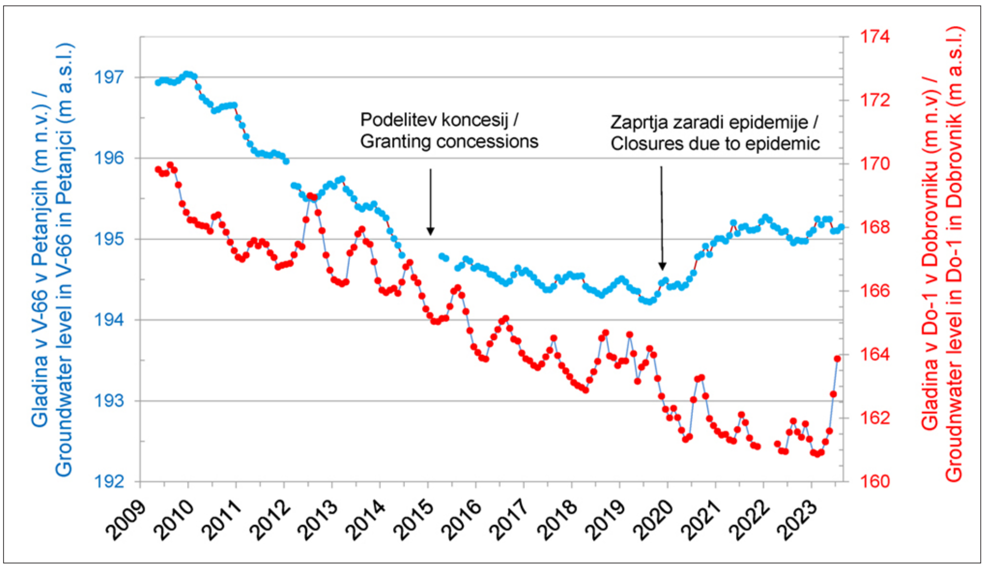
Murska kotlina opredeljeno kot »dobro« s srednjo stopnjo zaupanja. Pri tem smo upoštevali podatke obeh opazovalnih vrtin in obratovalnega monitoringa, pri čemer so zanesljive meritve obratovalnega monitoringa na območju celotnega bazena poročane šele po letu 2017, kar vpliva na večjo negotovost ocene. Isto dejstvo vpliva tudi na negotovost vodne bilance matematičnega modela (Rman & Šram, 2019), ki opozarja, da so količine odvzema termalne vode verjetno že dokaj blizu obnovljivih količin. K nižji stopnji zaupanja ocene prispeva tudi dejstvo, da državni monitoring stanja podzemnih voda globokih vodonosnikov še ni vzpostavljen. Predstavljena ocena vključuje le podatke do vključno leta 2019, ker je bila izdelana za NUV III. Za tem obdobjem smo v letih 2020–2021, v času epidemije korona virusa, opazili izrazit vpliv začasnega zaprtja nekaterih črpališč termalne vode na gladine podzemne vode. Takrat je na številnih lokacijah prišlo do obrata trenda - gladine so se bodisi stabilizirale bodisi zvišale (sl. 10). Ker je bil skupni odvzem termalne vode v letu 2022 še vedno opazno nižji, kot je bil v letu 2019 in pred tem (Rajver et al., 2023), torej kot je bil uporabljen za oceno stanja za NUV III, so trendi trenutno ugodni. V letu 2023 se je takšen obrat trenda prvič zaznal tudi v opazovalni vrtini v Dobrovniku.

Količinsko stanje podzemne vode je po preizkusu vpliva odvzemov podzemne vode na ekološko stanje površinskih vodnih teles ocenjeno kot »dobro« s srednjo stopnjo zaupanja. Pri nobenem obravnavanem vodnem telesu površinskih voda odvzemi podzemne vode ne povzročajo slabega ekološkega stanja. Stopnja zaupanja rezultatov preizkusa je ocenjena kot srednja predvsem zaradi nezadostnega poznavanja hidravličnih odnosov med površinskimi in podzemnimi vodami. Izdelava ocene je izpostavila potrebo po pregledu metodološkega pristopa tega preizkusa. Potrebno je preveriti metodologijo na območju kraških vodnih teles in aluvialnih vodonosnikov, saj zaradi posebnih hidrogeoloških značilnosti lahko pri interpretaciji prihaja do napačnega razumevanja rezultatov.

Ocena preizkusa vpliva odvzemov podzemne vode na kopenske ekosisteme, odvisne od podzemne vode, ne odkriva znatnega vpliva črpanja podzemne vode na obravnavane kopenske ekosisteme, kar zagotavlja oceno količinskega stanja kot »dobro«. Preizkus ima srednjo stopnjo zaupanja, predvsem zaradi pomanjkanja informacij o mejnih vrednostih gladine podzemne vode za ohranjanje habitata in zaradi pomanjkanja podatkov o gladini podzemne vode na nekaterih območjih KEOPV.

Preizkus vpliva odvzemov podzemne vode na vdore slane vode je bil opravljen za vodonosni sistem 50621 Brestovica – Timava (VTPodV 5019 Obala in Kras z Brkini), ki je domnevno v stiku z morsko vodo, obenem pa predstavlja strateško pomemben vir regionalne oskrbe s pitno vodo (Urbanc, 2020). Ugotovljeno je bilo, da črpanje podzemne vode ne povzroča vdora slane vode, kar so potrdili tudi raziskovalni rezultati 30-dnevnega črpalnega poskusa na štirih vrtinah vodnega vira Brestovica – Klariči v letu 2008 (Urbanc et al., 2012) ter rezultati raziskav s ciljem izboljšanja konceptualnega modela in transporta podzemne vode v zahodnem delu kraškega vodonosnika Krasa (Petrič et al., 2018, 2019, 2020, 2021, 2022).

Preizkus vpliva odvzemov podzemne vode na vdore vode slabše kakovosti je bil opravljen tudi za VTpodV 3012 Dravska kotlina, za katerega je bilo količinsko stanje podzemne vode opredeljeno kot »slabo«. Že v NUV II na vodnem območju Donave iz leta 2016 (Vlada RS, 2016a) je opredeljeno,



Sl. 10. Mesečna povprečja piezometrične gladine podzemne vode v opazovalnih vrtinah Do-1 (Dobrovnik) in V-66 (Petanjci) v obdobju 2009–2023 z opaznim obratom trenda (Rman et al., 2023).

Fig. 10. Monthly averages of the piezometric groundwater level in piezometers Do-1 (Dobrovnik) and V-66 (Petanjci) for the period 2009–2023 with evident trend reversal (Rman et al., 2023).

da okoljski cilji glede količinskega stanja v vodnem telesu podzemne vode VTPodV Dravska kotlina do leta 2021 morda ne bodo doseženi. Na osnovi NUV II iz leta 2016 je Računsko sodišče RS v poročilu »Učinkovitost dolgoročnega ohranjanja virov pitne vode« ugotovilo, da do leta 2021 obstaja tveganje, da bo v drugem, pliocenskem vodonosniku prišlo do poslabšanja količinskega stanja podzemne vode (RSRS, 2019a). Na podlagi Revizijskega poročila je Ministrstvo za okolje in prostor predlagalo popravljalne ukrepe v odzivnem poročilu, ki so opisani v Porevizijskem poročilu (RSRS, 2019b). Tveganje za slabo količinsko stanje v tem vodnem telesu je opredeljeno tudi v osnutku NUV III na vodnem območju Donave za obdobje 2022–2027 (MNVP, 2021). »Slaba« ocena količinskega stanja za VTpodV 3012 Dravska kotlina pritrjuje ugotovitvam računskega sodišča o vdoru onesnažene vode iz zgornjega, kvartarnega vodonosnika v spodnji, pliocenski vodonosnik, povzročenega s prekomerno rabo podzemne vode. V prihodnje bo potrebna izvedba raziskav za nadaljnji razvoj konceptualnega modela pliocenskega vodonosnika, ki vključujejo natančno opredelitev napajalnega zaledja vodnega telesa in napajalnega zaledja območij črpanja podzemne vode, natančno opredelitev dinamike toka in gladine podzemne vode tako zgornjega kvartarnega kot tudi spodnjega pliocenskega vodonosnika in poglobitev znanja o geološki zgradbi vodonosnika, ki zajema analizo prisotnosti slabše prepustnih plasti nad obravnavanim vodonosnikom. Za potrditev tehnične primernosti črpalnih objektov bi bil, z namenom doseganja dobrega stanja vodnega telesa podzemne vode, potreben tudi ustrezen tehnični pregled objektov in sanacija le-teh v primeru neprimernega stanja.

Podnebni scenariji do konca 21. stoletja za Slovenijo kažejo na pozitiven trend naraščanja povprečne letne temperature zraka, medtem ko pri količini padavin signali sprememb niso tako enoznačni (Bertalanič et al., 2018). Največje spremembe v skupni količini padavin bodo v zimskem času, ko se pričakuje več padavin in s tem tudi večje količine napajanja podzemne vode (Draksler, 2019). Ker se bo temperatura zraka zviševala, se v prihodnje pričakuje povečan pojav zimskih padavin v obliki dežja. V poletnem času večjih sprememb v skupni količini padavin do sredine stoletja ne pričakujemo, zmanjšalo pa se bo število padavinskih dni, kar pomeni, da bo večina padavin padla v zelo kratkem času. Zato lahko pričakujemo močnejše in pogostejše nalive ter neurja, pogosteje pa se bomo srečevali tudi z vmesnimi sušnimi obdobji, na kar kažejo tudi kazalci hidrološke suše podzemne vode v zadnjih desetletjih (Pavlič, 2023).

Zaključek

Ocena količinskega stanja podzemnih voda za NUV III je celovit in standardiziran obdobni pregled rezultatov monitoringa ter analize količinskega stanja podzemnih voda. Usmerjena je v podporo načrtovanju ukrepov za izboljšanje oz. dolgoročno ohranjanje dobrega stanja podzemnih voda v Sloveniji.

Na podlagi rezultatov izvedenih preizkusov se količinsko stanje v ocenjevalnem obdobju 2014–2019 v večini vodnih teles podzemne vode v Sloveniji ocenjuje s skupno oceno »dobro« s srednjo do visoko stopnjo zaupanja. Izjema je vodno telo podzemne vode VTpodV 3012 Dravska kotlina, kjer je bilo zaradi neizpolnjevanja kriterijev dobrega količinskega stanja, s preizkusom vpliva odvzemov podzemne vode na vdore slane vode ali vode slabše kakovosti, stanje ocenjeno kot »slabo« s srednjo stopnjo zaupanja.

V prihodnosti lahko pričakujemo močnejše in pogostejše nalive ter neurja, pogosteje pa se bomo srečevali tudi z vmesnimi sušnimi obdobji, zato se bo potrebno v prihodnjem načrtu upravljanja z vodami resneje in celostno osredotočiti na prihodnje izzive spopadanja z ekstremnimi hidrološkimi pojavi, ki jih povzroča spremenjeno podnebje ter se nanje ustrezno prilagoditi. Večjo pozornost bo v prihodnje potrebno nameniti tudi vzdržni rabi podzemne vode v globokem geotermalnem vodonosniku na severovzhodu države (vodno telo podzemne vode VTPodV 4016 Murska kotlina).

Zahvala

Razvoj metodologije za oceno količinskega stanja podzemnih voda je plod večletnega dela sodelavcev ARSO, kjer izpostavljamo strokovni prispevek bivših kolegov Nika Trišiča in dr. Jožeta Uhana. Za njun doprinos se iskreno zahvaljujemo. Zahvala gre tudi recenzentoma revije za hiter in strokoven pregled članka ter konstruktivne pripombe.

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Using Ground Penetrating Radar (GPR) for detecting a crypt beneath a paved church floor

Uporaba georadarja (GPR) za zaznavo kripte pod tlakovanimi tlemi cerkve

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Ključne besede: georadar (GPR), cerkev Sv. Marjete, kripta, podzemni prostor, baron Erberg, Dol pri Ljubljani

Abstract

After the discovery of an archive document regarding an underground crypt beneath the floors of the Church of St. Margaret (Sv. Marjeta) in Dol pri Ljubljani, Slovenia, further research was carried out to confirm its presence. An area filled with construction waste was discovered during a recent small-scale renovation of the church floor. This finding suggested the potential underground chamber may have been partly filled in during one of the previous restorations. A non-invasive GPR study was carried out along eight profiles inside the church to prove the existence of an underground crypt. Results show the presence of an air-filled chamber, confirmed later by a hole drilled in the floor. Additional findings in the church archive and pictures taken by a camera, lowered through a drilled hole, revealed three previously unknown caskets in the crypt. According to the archives, two of them belong to Baron Wolf Daniel Erberg and his wife who died in 1783 and 1774, respectively.

Izvleček

Po odkritju uradnega dokumenta o obstoju podzemne kripte pod tlemi cerkve Sv. Marjete v Dolu pri Ljubljani v Sloveniji so bile za njeno potrditev izvedene nadaljnje raziskave. Med nedavno manjšo prenovo tal v cerkvi so odkrili območje, zapolnjeno z gradbenimi odpadki. Ta ugotovitev nakazuje, da je bil morebiten podzemni prostor verjetno zasut med eno od prejšnjih obnov. Da bi zagotovili več dokazov o obstoju kripte na neinvaziven način, so bile v notranjosti cerkve izvedene georadarske meritve v osmih profilih. Rezultati kažejo na obstoj kripte, napolnjene z zrakom, kar je bilo kasneje potrjeno z izvrtano luknjo v tleh. Novi dokumenti, najdeni v arhivu in posnetki kamere, spuščene skozi luknjo v tleh, so razkrili tri prej neznane krste v kripti. Glede na arhivske podatke, dve od njih pripadata baronu Wolfu Danielu Erbergu ter njegovi ženi, ki sta umrla v letih 1783 in 1774.

Introduction

The Church Sv. Marjeta (St. Margaret), located in Dol pri Ljubljani, Slovenia, was first mentioned in 1262 (Grebenc, 2012) and again in 1427, as a Gothic building. Under the leadership of architect Mihael Perski, the church underwent extensive reconstruction in 1753 (Grebenc, 2012). Since then, there has been no major reconstructions apart from the re-paving of the church floor in 1886.

We (priest Alojzij Grebenc serving at this church), have been researching the history of the church for many years and also written two books on the subject (Grebenc, 2012, 2013). While searching through the church archives, we came across a document issued in 1836 by the diocese to the Erberg Barons, a local noble family. The document was a permit for building an underground crypt on the church premises, however all further correspondence between the Erberg family and the diocese has been lost in the destruction of the rectory in 1944.

During a recent small-scale renovation, one of the floor stones beneath the wooden benches (pews), was removed (black line in Fig. 1). This revealed an area filled with construction waste material, suggesting that an underground chamber could have existed in the past and has been partly filled in at the time of the last paving of the church floor in 1886. In the search for more evidence of an underground chamber, a Ground Penetrating Radar (GPR) study was carried out. By using this non-invasive geophysical method, we wanted to determine whether such an underground chamber does exist beneath the church floor, and if so, is there any part of it left that has not been filled-in with waste material.

The GPR study was conducted inside the church where there was enough space for the profiles to be recorded. This method has been successfully applied in studies researching known underground chambers/crypts (e.g. Leucci et al., 2021) as well as previously unknown underground chambers (e.g. Barilaro et al., 2007). GPR has been widely used in numerous surveys to date for researching both natural air-filled subsurface voids (Lago et al., 2022; Lan et al., 2022; Zajc et al., 2015) and manmade subsurface air-filled structures (Mendoza et al., 2023; Obrocki et al., 2019).

Methodology

Location of GPR Profiles

The GPR profiles were recorded inside the church, along the stone paved floor in all the areas where the internal layout permitted the passing of a GPR cart in a straight line (Fig. 1). Longitudinal profiles were recorded along the aisle between pews about 1 m apart and on each side of the pews. A transverse profile (P4) was recorded in front of the pews, parallel to the steps leading to the altar (Fig. 1). At the time of the measurements, an electrical cable was laid out diagonally along the aisle. The location where profiles P1-P3 crossed the cable was marked during recording.

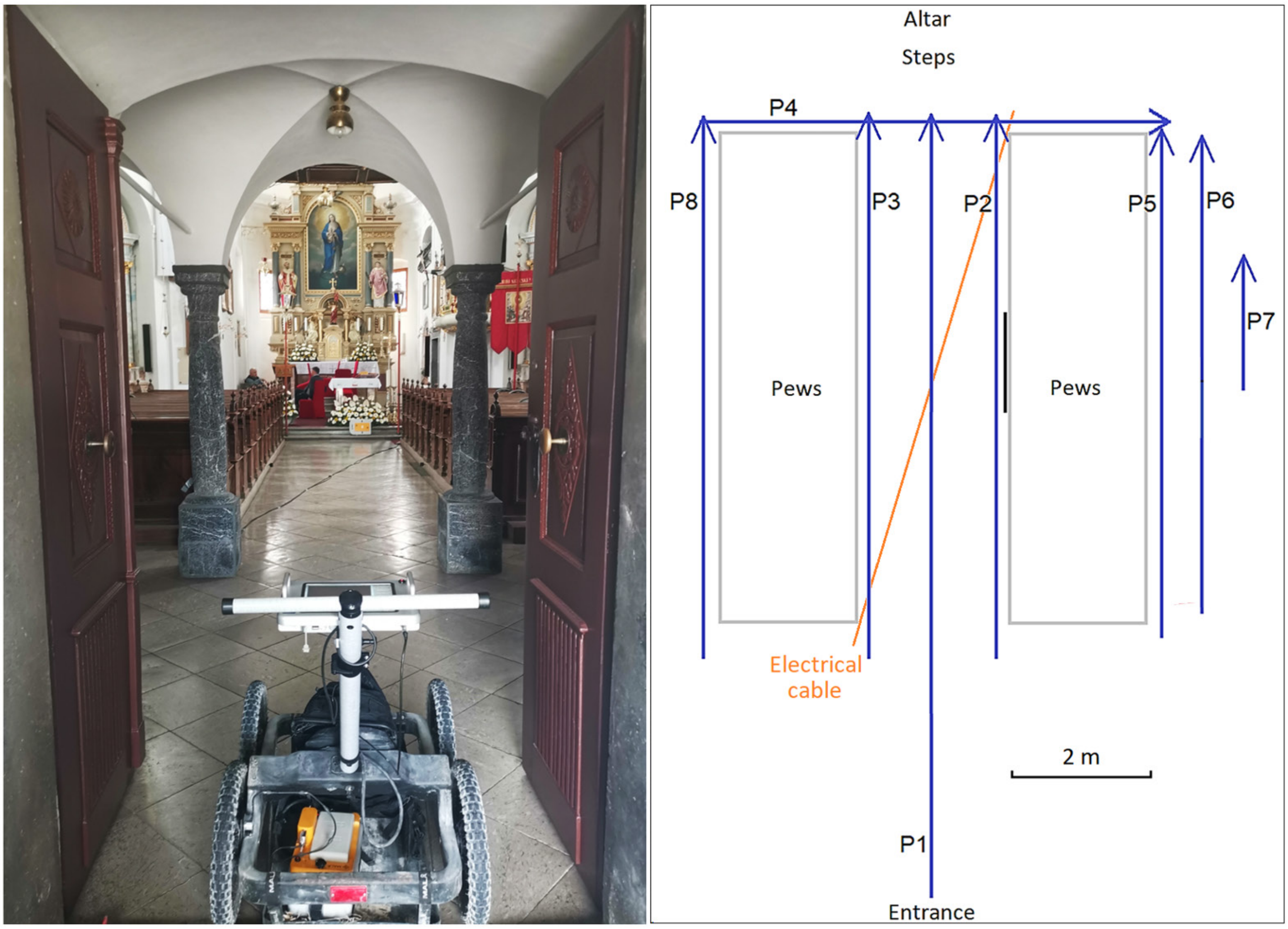


Fig. 1. Left – GPR measurements with GPR cart inside the church; right – GPR profiles (blue lines), electrical cable (orange line), location of removed floor stone (black line).

Equipment Used

For the recording of the profiles, a MALÅ Pro-Ex control unit and antennas mounted on a cart (Fig. 1) with two different frequencies, 500 MHz and 800 MHz were used. This ensured a sufficient depth penetration through the church floor and enabled a comparison of results with different resolutions.

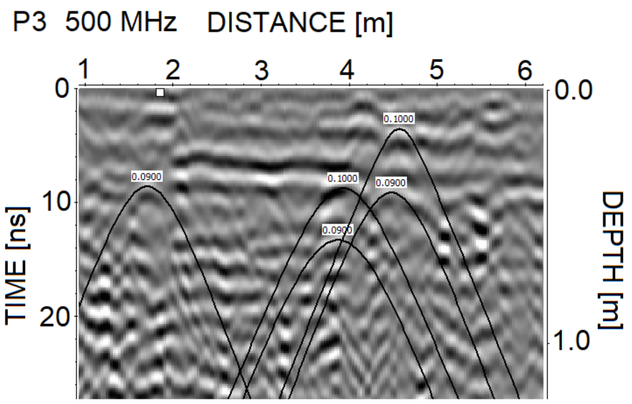


Fig. 2. Examples of different signal velocities, determined with hyperbola fitting.

Data Processing

The GPR profiles were processed using ReflexW, v. 8.5 by Sandmeier Software. The procedures and parameters of the processing flow are shown in Table 1. Due to the presence of different types of sediments, as well as fills of construction waste beneath the church floor, the subsurface is extremely heterogeneous. When the signal passes through the different types of materials, its velocity changes and therefore varies significantly with depth. The velocity also changes laterally as the profiles are recorded over different mediums, e.g. waste material, sediments and air-filled chambers. Figure 2 shows an example of different signal velocities within the profile P3, determined with the hyperbola fitting procedure. Consequently, an average signal velocity of 0.09 m/ns was used for the time-to-depth conversion across all GPR profiles. High velocity variation along the profiles was also the reason that data migration could not be successfully applied. As the purpose of the study was to find a potential air-filled chamber and no exact depths needed to be extracted from the GPR data, a rough estimation of the signal velocity was sufficient for determining the depth scale.

Results

By comparing profiles recorded with the 500 and 800 MHz antennas, it is evident that the same features can be identified in both. An example of the comparison is shown for profile P2 (Fig. 3), which was recorded along the church aisle in the direction from the entrance to the steps in front of the altar. A continuous linear boundary (yellow line) indicates the thickness of the church paved floor at the depth of approx. 30 to 40 cm. Chaotic reflections and anomalies indicate the presence of subsurface voids, which represent underground air-filled chambers (red frames). Such patterns in GPR profiles are caused by multiple signals that reflect off walls and other objects inside the air-filled voids. When the diameters of the voids are significantly larger than the GPR frequency wavelength, they produce irregular reverberation patterns (Kofman et al., 2006; Luo & Lai, 2020) or so-called chaotic reflections (Thitimakorn et al., 2016). These areas appear closer to the church entrance and are not present at the location of the previously removed floor stone (black line in Fig. 3), which revealed the area filled in with construction waste. Here, the penetration depth is hindered due to a higher signal attenuation and signal scattering (green frames), caused by the presence of heterogeneous materials. A strong anomaly can also be seen at the point of crossing an electrical cable on the floor of the church (blue frames). By analysing the 500 MHz parallel longitudinal GPR profiles that show the presence of chaotic reflections, it is evident that these appear in the same area of the church (red areas in Fig. 4) and therefore indicate the location of the air-filled underground chamber.

Processing steps	Parameter	
	500 MHz	800 MHz
DC Shift	60 – 68 ns	30 – 36 ns
Time-zero correction	- 5.5 ns	- 3.3 ns
Background removal	Whole line	Whole line
Gain	Energy decay	Energy decay
Bandpass filtering	240/350/600/850 (MHz)	350/550/1000/1300 (MHz)
Time-depth conversion (hyperbola fitting)	0.09 m/ns	0.09 m/ns

Table 1. GPR data processing steps applied.

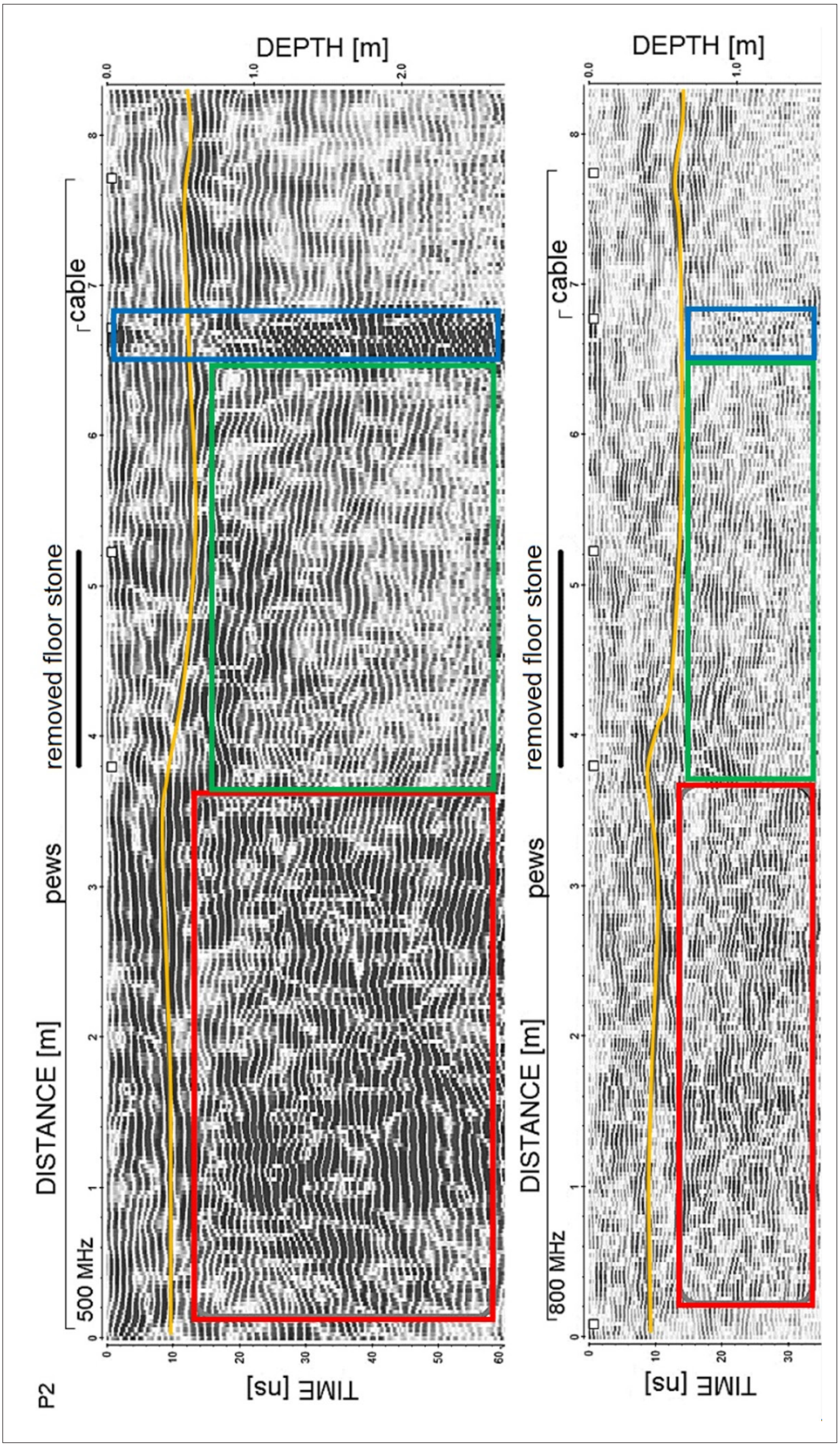


Fig. 3. Comparison of 500 MHz (top) and 800 MHz (bottom) radargrams for P2 profile with marked floor boundary (yellow line), area with chaotic reflections (red frames), area of high signal attenuation (green frames) and effects from crossing an electric cable (blue frames). See Fig. 1 for the location of the profile.

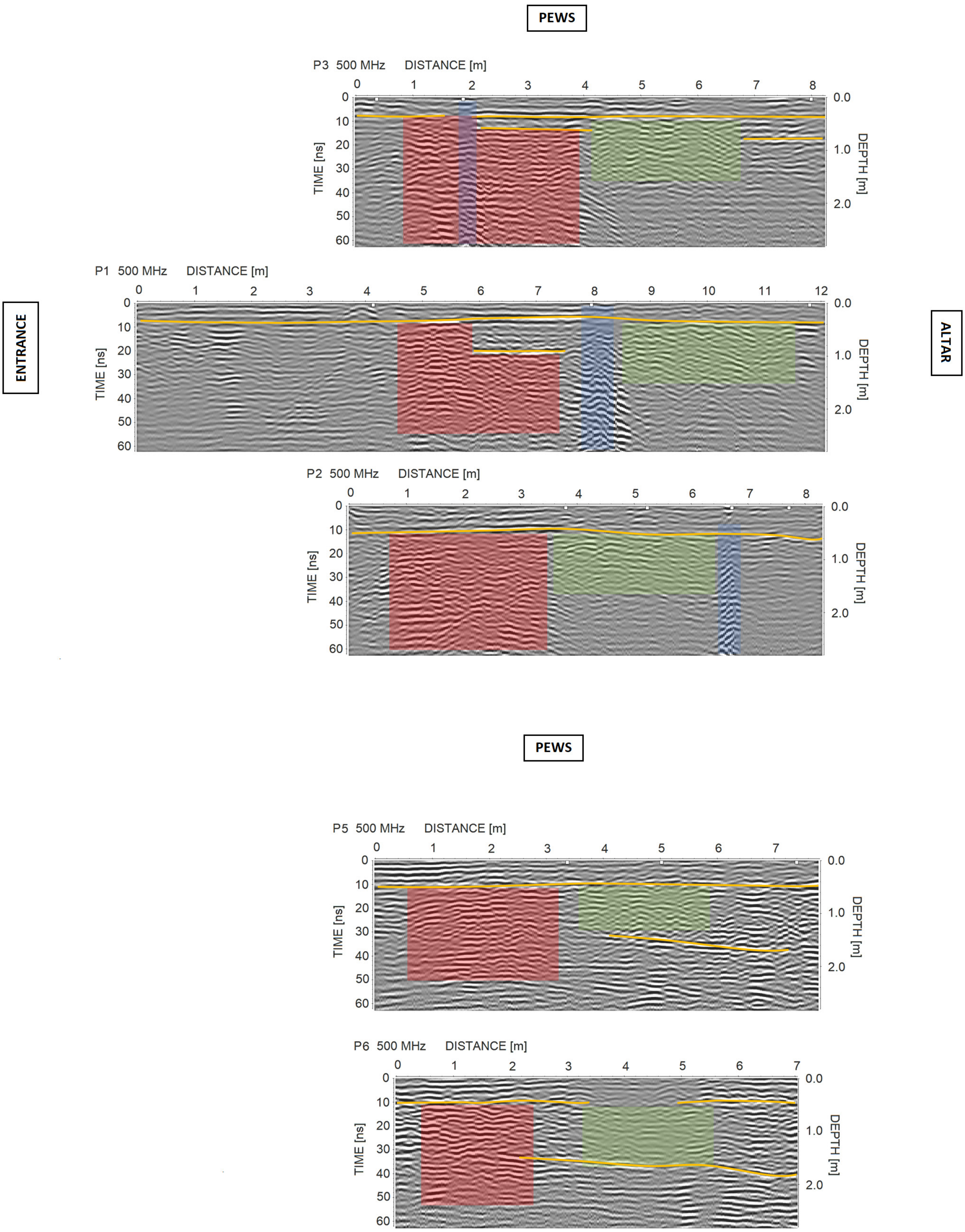


Fig. 4. Longitudinal 500 MHz GPR profiles P1 to P3, P5 and P6, showing the location of chaotic reflections (red area), high signal attenuation (green area), effect from crossing an electric cable (blue area) and linear reflections (yellow lines). See Fig. 1 for location of GPR profiles.

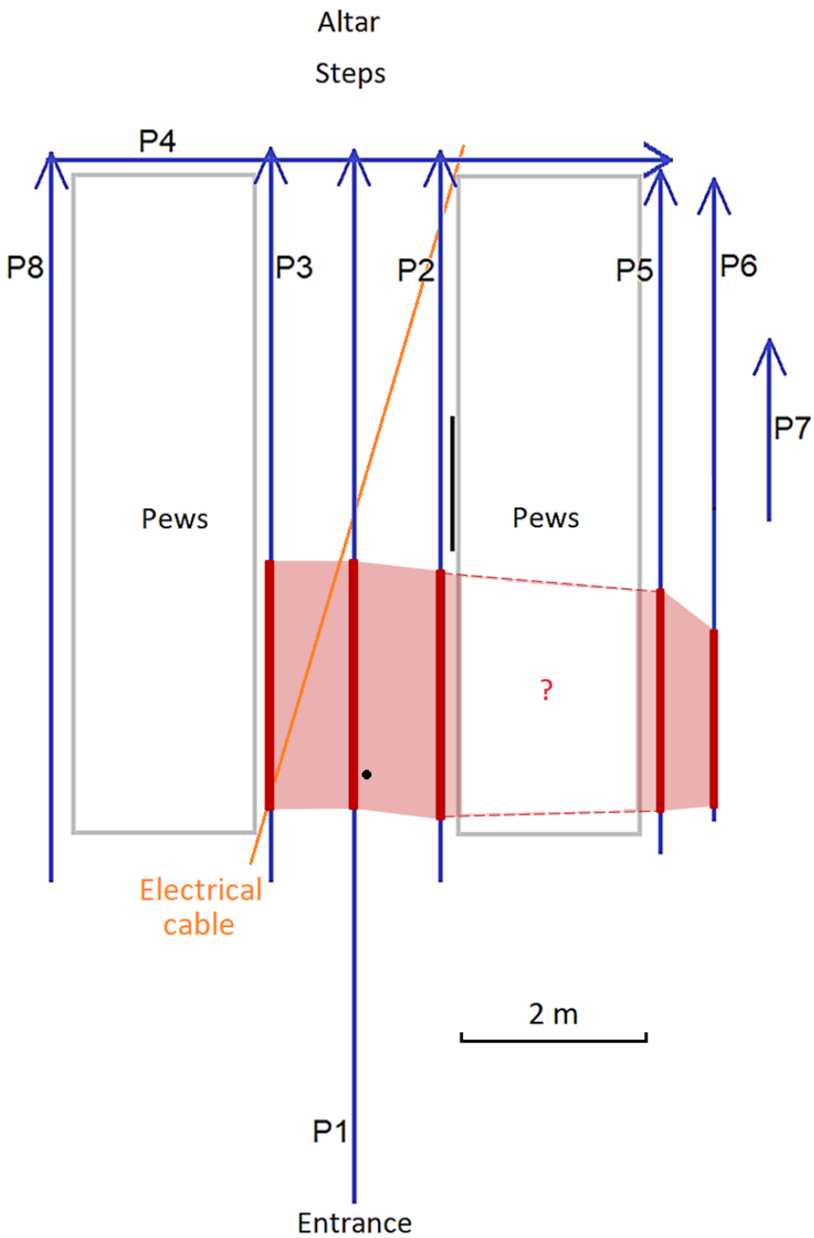
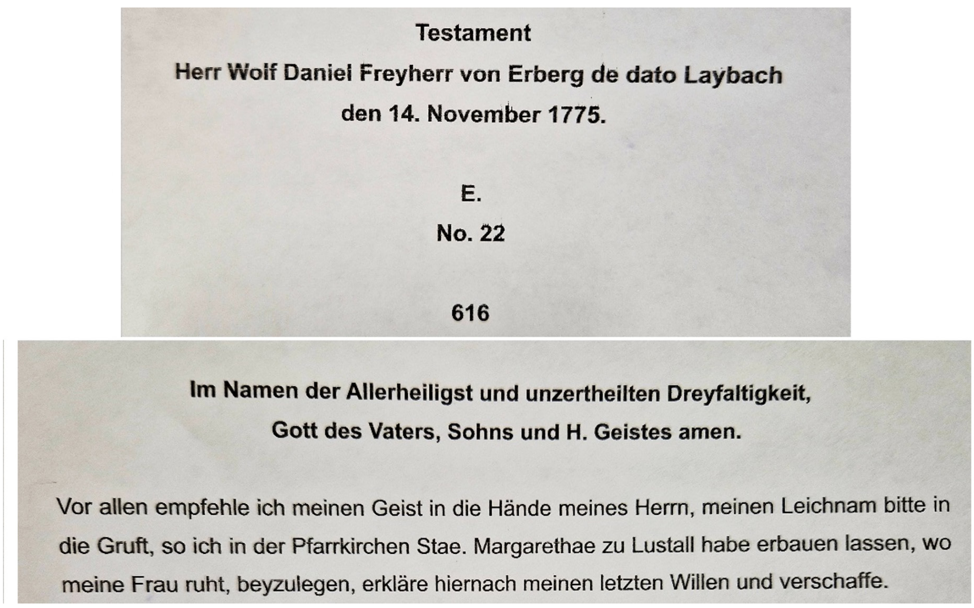


Fig. 5. Plan sketch based on GPR results from Fig. 3, depicting the area of underground air-filled chamber (red polygon) and location of drilled hole (black circle).



Testament

Herr Wolf Daniel Freyherr von Erberg de dato Laybach

den 14. November 1775.

E.

No. 22

616

Im Namen der Allerheiligst und unzertheilten Dreyfaltigkeit,

Gott des Vaters, Sohns und H. Geistes amen.

Vor allen empfehle ich meinen Geist in die Hände meines Herrn, meinen Leichnam bitte in die Gruft, so ich in der Pfarrkirchen Stae. Margarethae zu Lustall habe erbauen lassen, wo meine Frau ruht, beyzulegen, erkläre hiernach meinen letzten Willen und verschaffe.

Fig. 6. Last will and testament of Baron Wolf Daniel Erberg, where he states he wishes to be buried next to his late wife in the crypt of the St. Margaret church in Dol pri Ljubljani (Lustall) (from the Archives of the Republic of Slovenia).

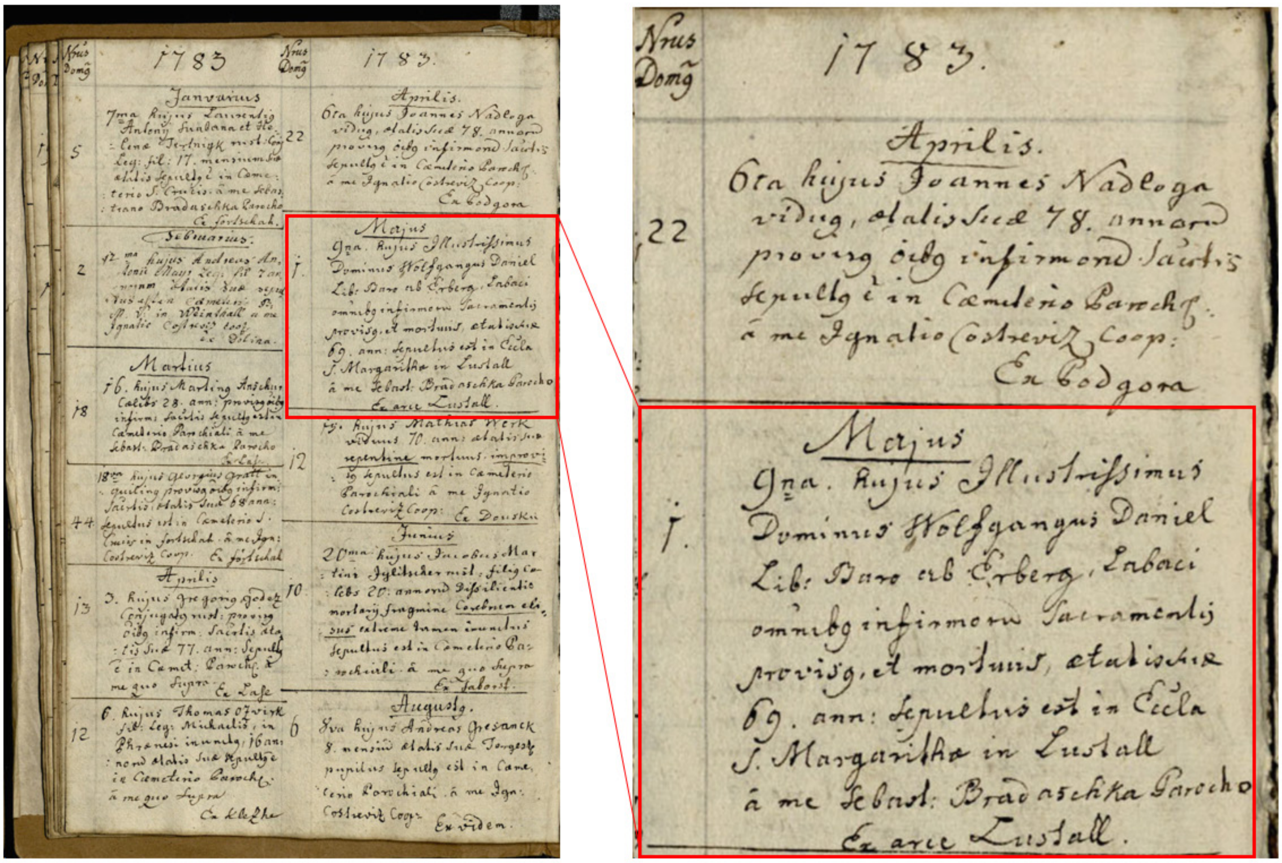


Fig. 7. Entry in the death records of the Church of St. Margaret in Dol pri Ljubljani, where it states that Baron Wolf Daniel Erberg has died aged 69 and is buried in the church crypt (NŠAL, 2023).

Discussion

Based on the GPR results, the plan sketch in Figure 5 was created. It shows the areas of chaotic reflections seen on individual GPR profiles linked into a connected area (red polygon). This area represents the part of the subsurface chamber not filled in with construction waste material. Similar chaotic reflections have been linked to the presence of subsurface voids in other GPR studies (e.g. Thitimakorn et al., 2016). Due to the low number of profiles and lack of data below the pews it is not possible to exactly determine the spatial extent of the crypt using these GPR results. We can only provide a rough estimation of its spatial occurrence. For a more detailed analysis, pews would need to be removed and a dense 3D GPR survey would need to be performed. For the purpose of verifying the existence of the crypt, we found the recorded eight profiles were sufficient.

These GPR results were presented at an international conference (Zajc, 2023) and prompted a more thorough investigation of the church register of burials as well as the archdiocesan archive. Two more documents mentioning the church crypt were found. The first was a last will and testament from the Baron Wolf Daniel Erberg from 1775 (Fig. 6), written in German, where he states that he wishes to be buried alongside his late wife in the crypt of the Church of St. Margaret in Lustall (German name for Dol pri Ljubljani). Since his wife died in 1774, a year before this last will was written, it provides proof that the crypt does exists somewhere on the church premises and at least one person was buried in it.

The second written record found after the GPR survey was completed, was the entry in the church death records (Fig. 7), where it states that in May of 1783, Baron Wolf Daniel Erberg has died aged 69 and is buried in the crypt of the Church of St. Margaret in Dol pri Ljubljani (entry written by priest Sebastian Bradaška). This provided even more evidence on the existence of the crypt and encouraged to continue with the investigation. First, a small hole was drilled into the church floor in the area where the GPR results show signs of an underground chamber. The telescopic inspection camera lowered into the hole revealed an underground air-filled room with an arched ceiling, thus confirming GPR results. However, the low resolution of the camera and insufficient lighting made it impossible to determine the size of the room or to define any other objects inside. Therefore, in

Fig. 8. Still photographs taken from the recordings of the crypt with an arched ceiling. Left – three partially uncovered caskets; right – inscription on one of the caskets (author: J. Igličar).

November 2023, a larger hole of approx. 10 cm in diameter was drilled in the same area (black circle in Fig. 5) and a light source was lowered into the chamber to investigate its contents with a higher resolution camera. The video recordings showed a room about 3 × 4 m in size and about 2 m deep, located beneath the church aisle, containing three wooden caskets. The caskets are partially uncovered, revealing the body remains underneath the wooden lids (Fig. 8). There are also inscriptions written on the sides of the caskets, however, due to the poor resolution of the images, they are not fully readable. Based on the existing records, it is assumed that the crypt was built by the Baron Erberg family during the last extensive reconstruction of the church in 1753 and the entry was most likely filled up by construction waste material during the last renovation of the church floor in 1886. Currently, it is not yet known who the remains in the third casket belong to.

Conclusion

The GPR results provided proof of the existence of an underground crypt, mentioned in the archives of the Church of Sv. Marjeta (St. Margaret) in Dol pri Ljubljani. Moreover, by carrying out the GPR study, we were able to precisely locate the crypt. Based on the GPR results, further investigation of the church archives prompted an underground camera inspection, which confirmed its presence in this exact area. This confirmation is of great cultural and historical importance, therefore further investigations will be carried out in the future.

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Impact assessment of the Gajke and Brstje landfills on groundwater status using stable and radioactive isotopes

Ocena vpliva odlagališč Gajke in Brstje na stanje podzemne vode z uporabo stabilnih in radioaktivnih izotopov

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Abstract

Waste disposal in landfills represents a severe threat to aquatic environments on the local, regional, and global levels. In Slovenia, there are 69 registered landfills where groundwater is regularly monitored. However, isotope techniques are not regularly employed. Therefore, we employed isotope analysis of hydrogen, carbon, and oxygen in combination with total alkalinity to assess the impact of the selected landfill on groundwater and to evaluate the biogeochemical processes at work. The $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, ^{3}H activity and total alkalinity were determined in October 2020 at 12 sampling points from the surrounding area of the Gajke and Brstje landfills and leachate from the Gajke landfill. The $\delta^{18}O$ (-9.24 ± 0.3 ‰) and $\delta^{2}H$ (-64.9 ± 2.7 ‰) in groundwater indicate that the main water source consists in direct infiltration of precipitation, with no significant isotopic fractionation. Total alkalinity in the investigated area ranges from 5.45 to 73 mM and $\delta^{13}C_{DIC}$ from –14.9 to +6.1 ‰, respectively. Higher values of total alkalinity (up to 73 mM), $\delta^{13}C_{DIC}$ (up to +6.1 ‰), $\delta^{18}O$ (-7.64 ‰) and ^{3}H (209.8 TU) are detected in the leachate, indicating biogeochemical process related to CO_2 reduction or methanogenesis. Methanogenesis could be present at locations GAP-10/13 (Brstje landfill) and G-2 (Gajke landfill) with $\delta^{13}C_{DIC}$ values ranging from –8.2 to –7.6 ‰ and with dissolved oxygen values around 0 % and elevated ^{3}H values (from 16 to 18 TU). This study demonstrates the effectiveness of isotopic analysis as a valuable tool for monitoring landfills, revealing shifts in biogeochemical processes within the groundwater there.

Izvleček

Odlaganje odpadkov na odlagališčih predstavlja resno grožnjo za vodna okolja na lokalni, regionalni in globalni ravni. V Sloveniji je 69 registriranih odlagališč, kjer se redno izvajajo obratovalni monitoringi kemijskega stanja podzemne vode. Kljub temu izotopske tehnike niso rutinsko uporabljene. Zato smo uporabili analizo izotopov vodika, ogljika in kisika v kombinaciji s skupno alkalnostjo, da bi ocenili vpliv izbranega odlagališča na podzemno vodo in ovrednotili biogeokemične procese. $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, aktivnost ^{3}H in skupna alkalnost so bile določene v oktobru 2020 v 12 vodnjakih v okolici odlagališč Gajke in Brstje in v izcedni vodi iz odlagališča Gajke. Vrednosti $\delta^{18}O$ (-9,24 ± 0,3 ‰) in $\delta^{2}H$ (-64,9 ± 2,7 ‰) v podzemni vodi kažejo, da je glavni vir vode neposredna infiltracija padavin, brez bistvene izotopske frakcionacije. Totalna alkalnost na preiskanem območju se spreminja od 5.45 do 73 mM, $\delta^{13}C_{DIC}$ od –14.9 do +6.1 ‰. Višje vrednosti totalne alkalnosti (do 73 mM), $\delta^{13}C_{DIC}$ (do +6.1 ‰), $\delta^{18}O$ (-7.64 ‰) in ^{3}H z 209.8 TU so zaznane v izcedni vodi CERO Gajke (kanal), kar kaže na biogeokemijski proces redukcije CO_2 ali metanogeneze. Metanogeneza bi lahko bila prisotna tudi na lokacijah GAP-10/13 (odlagališče Brstje) in G-2 (odlagališče Gajke) z $\delta^{13}C_{DIC}$ vrednostima od -8.2 do -7.6 ‰ in z vrednostjo raztopljenega kisika okrog 0 % ter povišano vrednostjo ^{3}H (od 16 do 18.2 TU). V tej raziskavi smo dokazali, da so izotopi koristna orodja v monitoring raziskavah odlagališč in kažejo na spremembe biogeokemičnih procesov v podzemni vodi.

Introduction

Economic development, population growth, and technological developments are resulting in ever-increasing amounts of deposited waste, making the importance of ecological waste management and environmental protection ever more apparent. Landfills, which are potential local sources of pollution, are generally considered minor local inconveniences and can also pose problems in larger areas, especially if the pollution spreads from the landfill to the groundwater and surface waters (Bhalla et al., 2013; Abiriga et al., 2020, 2021). Depending on the nature of the contaminants and their chemical properties, they may remain or decompose in groundwater for decades or even centuries. Once a waste facility is closed, proper functioning of landfill systems must be ensured, so operational monitoring of groundwater status and, in some cases, surface water status monitoring must be conducted to determine the status of groundwater during and after landfill operations have concluded. Operational monitoring of groundwater status is likely to be conducted in the area of the hydrogeologic target zone, which is a lithostratigraphic unit where contamination could be expected due to indirect or direct discharge of contaminants from a source of contamination to groundwater. Operational monitoring includes measurements of hydrogeological and chemical parameters, which we use to assess the impact of a landfill on the status of groundwater. An environmental permit is required to operate the landfill, which specifies the scope and content of monitoring; the content and scope are explained in more detail in the groundwater monitoring programme. In the event that the landfill is determined to have an impact on the status of groundwater based on the chemical analyses performed, it is also necessary to prepare a programme of measures that must include, among other things, an estimate of the discharge of pollutants from the landfill to groundwater and an assessment of the magnitude of the impact on the recipients (Serianz et al., 2017; Cerar et al., 2022).

In recent years, several studies have been published on the determination of chemical parameters in landfill leachate (Hussein et al., 2019; Ančić et al., 2020; Baettker, et al., 2020) and their impact on groundwater quality (Kapelewska et al., 2019; Chidichimo et al., 2020). Groundwater quality is usually assessed by defining chemical parameters and comparing the data with standards set in legislation. Such an approach provides information only on specific contaminants and provides little information on overall water quality. As different materials or wastes are introduced into the disposal body, the leachate also has a different chemical composition. As a result, there are also differences in the formation of a groundwater pollution plume along the length of the groundwater stream. An important factor in understanding the occurrence of contaminants in groundwater is also their zonation, which is due to the fact that landfill leachate alters the physicochemical properties of groundwater by creating reduction conditions that affect the behaviour of individual contaminants in groundwater (Abiriga et al., 2021).

Hackley et al. (1996) already suggested using the isotopes of hydrogen (δ^2H), carbon (δ^{13}C), and oxygen (δ^{18}O) of the major landfill constituents of landfill gas and leachate to identify landfill leachate contamination. Landfill gases (CO_2 and CH_4) and landfill leached products (water and dissolved inorganic carbon) have a characteristic isotope composition with respect to the surrounding environment (Hackley et al., 1996; Kerfoot et al., 2003, Bakkaloglu et al., 2021, Vavilin & Lokshina, 2023). Recently, several studies (Adeolu et al., 2011; Castañeda et al., 2012; Wimer et al., 2013; Negrel et al., 2017; Lee et al., 2020; Andrei et al., 2021) have observed that stable isotopes found in landfill leachates, such as δ^{13}C, δ^2H and δ^{18}O, are influenced by processes within municipal solid waste (MSW) landfills, mainly on the methanogenesis phase of the landfill. In addition, δ^{13}C has frequently been used in environmental monitoring studies of landfills and in the determination of the origin of dissolved inorganic carbon in groundwater (DIC) (North et al., 2006; Porowska, 2015; Nigro et al., 2017; de Medeiros Engelmann et al., 2018). Several studies included tritium (^{3}H) analysis as a tool to assess leachate contamination (Nigro et al., 2017; Raco & Battaglini, 2022; Gupta & Raju, 2023).

In Slovenia, there are 69 registered landfills where the chemical parameters of groundwater in the area of the landfill is monitored as part of the larger operational monitoring of the status of groundwater, while isotopic studies are not routinely performed. The only known case study in Slovenia applying the stable isotope analysis of oxygen (δ^{18}O) and hydrogen (δ^2H) in water and carbon in the dissolved inorganic carbon ($\delta^{13}C_{DIC}$) in combination with ^{3}H activity concentrations were conducted at the Puconci landfill (Brenčič et. al., 2013). The combination of techniques used in the investigation of groundwater, surface water, and leakage water proved to be useful in identifying the influence of leakage water on surface and groundwater, the complexity of contamination below the landfill, and also provided a picture of the methane-forming conditions in the landfill. One operational landfill in Slovenia is the Gajke landfill, where in the recharge area about 500 m upstream, there is also the closed Brstje landfill for non-hazardous waste. The results of the operational monitoring of groundwater status at the Brstje landfill showed that it has an impact on groundwater status, as warning levels for pollutants have been exceeded for several years (Cerar et al., 2019). When analysing the spatial distribution of pollutants in groundwater, it should be considered that pollutants in groundwater in the area of the Gajke landfill may originate from leachate or may be the result of contact between groundwater and waste or may already flow into the area of the landfill via groundwater from the Brstje landfill upstream. In such cases, it may be very difficult or even impossible to isolate the individual impacts on the condition of the groundwater. It is therefore essential to consider both landfills simultaneously when analysing pollutants in space and time.

In this case study, we hypothesise that a multi-parameter isotope approach could be applied to separate the potential impact of two landfills, Gajke and Brstje on the groundwater in the municipality of Ptuj. By applying in-situ measurements in combination with determination of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, and ^{3}H in groundwater at all available sampling points and in leachate from Gajke before treatment we characterised the spatial changes of measured parameters in autumn 2020. The results will be useful for improving the management of the landfills and could in future serve as example of improved water monitoring programme, incorporating isotope measurements, for other landfills in Slovenia.

Case study area characteristics

Gajke landfill

The active Gajke landfill for non-hazardous waste is located in an abandoned gravel pit north of the settlement of Spuhija, in the municipality of Ptuj (Fig. 1). The landfill, including the accompanying areas, currently covers 7.5 ha. It is surrounded by agricultural land on all sides. Waste disposal at the Gajke landfill started in 2003. In total, 572.886 t of waste were deposited from 2003 through 2018. Mixed municipal waste was no longer landfilled with the adoption of new regulations in 2016, as the regulations stipulated the need for post-treatment of this waste. Currently, all municipal waste is transported to Ormož for treatment and disposal. According to the environmental permit, the Gajke landfill still has the status of an active repository.

The bottom of the landfill is sealed with three layers of mineral clay (each layer 25 cm thick) and a 2.5 mm thick PEHD plastic film on top. A protective layer of geotextile is laid on the ground above the PEHD film, on top of which a 40 cm thick drainage layer of gravel is placed. A separating drainage felt is laid over the drainage layer. The collection and discharge of leachate and precipitation water is regulated. Leachate is collected in the leachate basin, then cleaned by a reverse osmosis treatment plant and discharged into the sewage system to the wastewater treatment plant in Ptuj. Precipitation from road and work areas is collected and discharged into the soil collection basin (lagoon), from where it is pumped into the sewer system to the wastewater treatment plant in Ptuj. Clean precipitation and backwater collect in the earth ditches and canals, from where they lead to subsidence chambers and sink into the ground.

Brstje landfill

The closed Brstje landfill for non-hazardous waste is located in the municipality of Ptuj, approx. 500 m north-west of the Gajke landfill (Fig. 1). The nearest residential houses are 100 m away from the landfill and are located in the Brstje district. The landfill, including the accompanying areas, covers 6.8 ha. The Brstje landfill consists of the older northern part of the deposition fields and the younger southern part of the deposition fields. The area was filled in several phases and subphases, which employed different ways of disposing of the waste and protection measures used to reduce negative environmental impacts. The exact geometry and area of the deposited waste is not known, nor is the volume and mass of the deposited waste.

The beginnings of waste disposal in the area of the Brstje landfill date back to the 1970s. Exact information on the earliest days of waste disposal there is not known. Data on the amount of waste deposited is only available for the southern landfill. Thus, the actual amount of waste deposited in the entire landfill is far higher. A total of 66,818 t of mixed municipal waste was deposited at the southern landfill. The youngest part of the landfill, where waste was deposited between 1996 and 2001, is the southernmost landfill.

The landfill is special because it is not located on the embankment, but rather the waste is deposited in the former gravel pit at a depth of 5 to 7 m below the surface. On the eastern side, the gravel

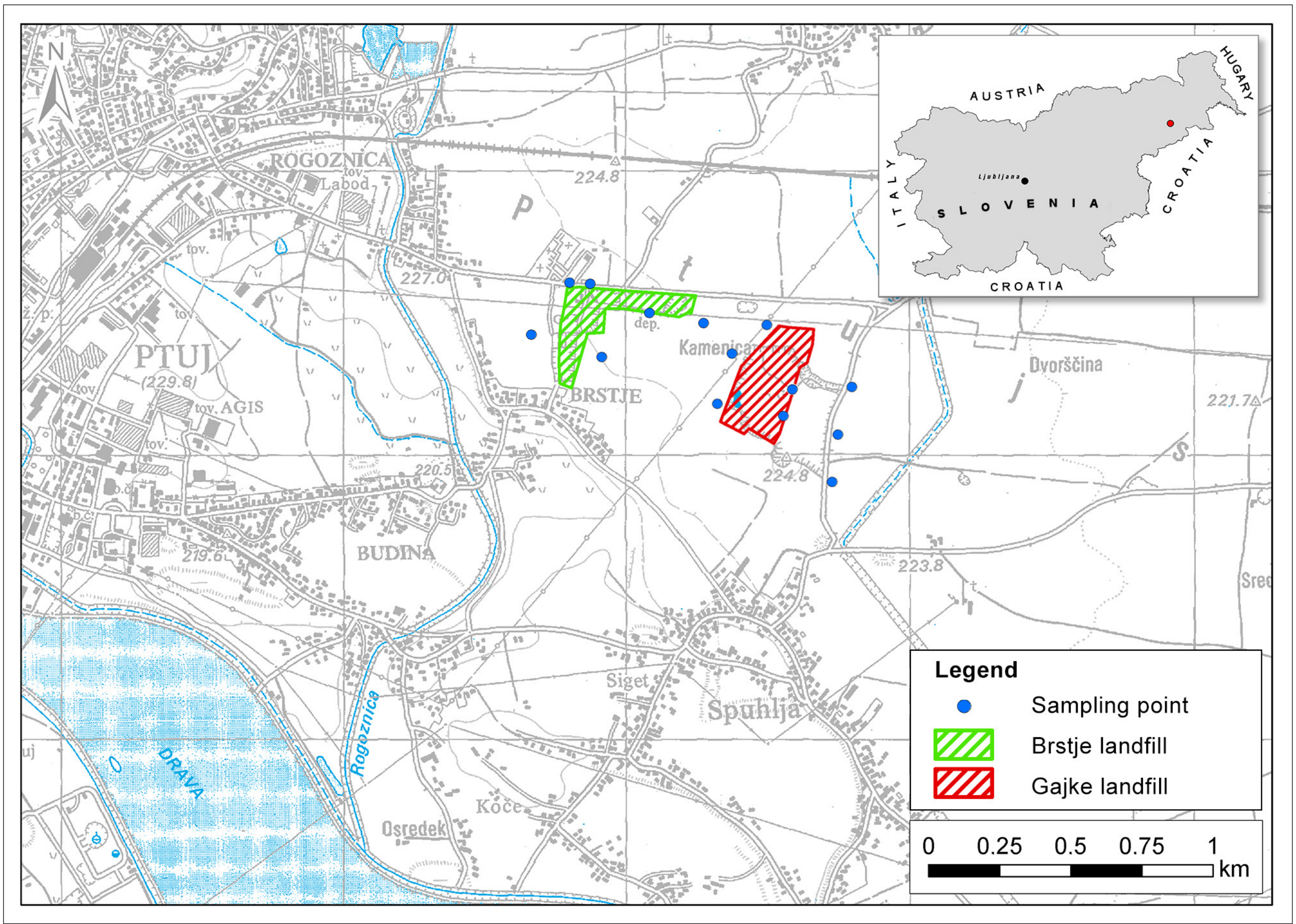

Fig. 1. Overview map of the area of the Gajke and Brstje landfills.

pit is recultivated with a poplar plantation. The old and new parts of the landfill are covered with a less permeable top layer of clay, geocomposite and a layer of soil and humus.

In the bottom of the new part, an impermeable PEHD foil with a drainage system with suction pipes for pumping out the leachate was installed, which is also a special feature of this landfill. In older deposit fields, the leachate drainage system is not regulated. All water drains gravitationally into the groundwater. Precipitation water is drained through the cover layer into the peripheral subsidence ditch.

Geographical and hydrological characteristics of the area

The Gajke and Brstje landfills are located in Ptujsko polje, which from the morphological point of view consists of two Drava terraces and is surrounded on all sides by agricultural land. The largest part of the field is occupied by a high terrace with an elevation of 222–224 m, where there are also landfills. In the western part of the field, the terrace is 7–8 m high, in the central part 4.5 m high, and in the eastern part it 2–3 m high.

About 500 m upstream northwest of the Gajke landfill is the closed Brstje landfill. The nearest surface water is the Rogoznica stream, which flows into the Drava River southeast of the landfill (Fig. 1) (Cerar et al., 2019).

Geological and hydrogeological features in the area of the landfills

The Gajke and Brstje landfills are located on the Quaternary aquifer of the Ptujsko polje, which consists in the upper part of alluvial deposits from the Drava, Pesnica, and Rogoznica rivers. These are mainly sediments of medium-grained sandy gravel, between which there are lenses of silt and clay with limited extension. The lower part is dominated by fine- and medium-grained gravels with more sand and silt, as well as sand layers with silt. The base of the Quaternary sediments is formed by fine-grained sediments of Pliocene age (Fig. 2).

The first hydrogeological unit in the landfill area is represented by a slightly permeable ($K=10^{-3}$ m/s), open Quaternary aquifer, with groundwater at a depth of about 8–9 m below the surface, freely fluctuating in the range between 2.5 and 3.2 m, depending on the hydrologic conditions.

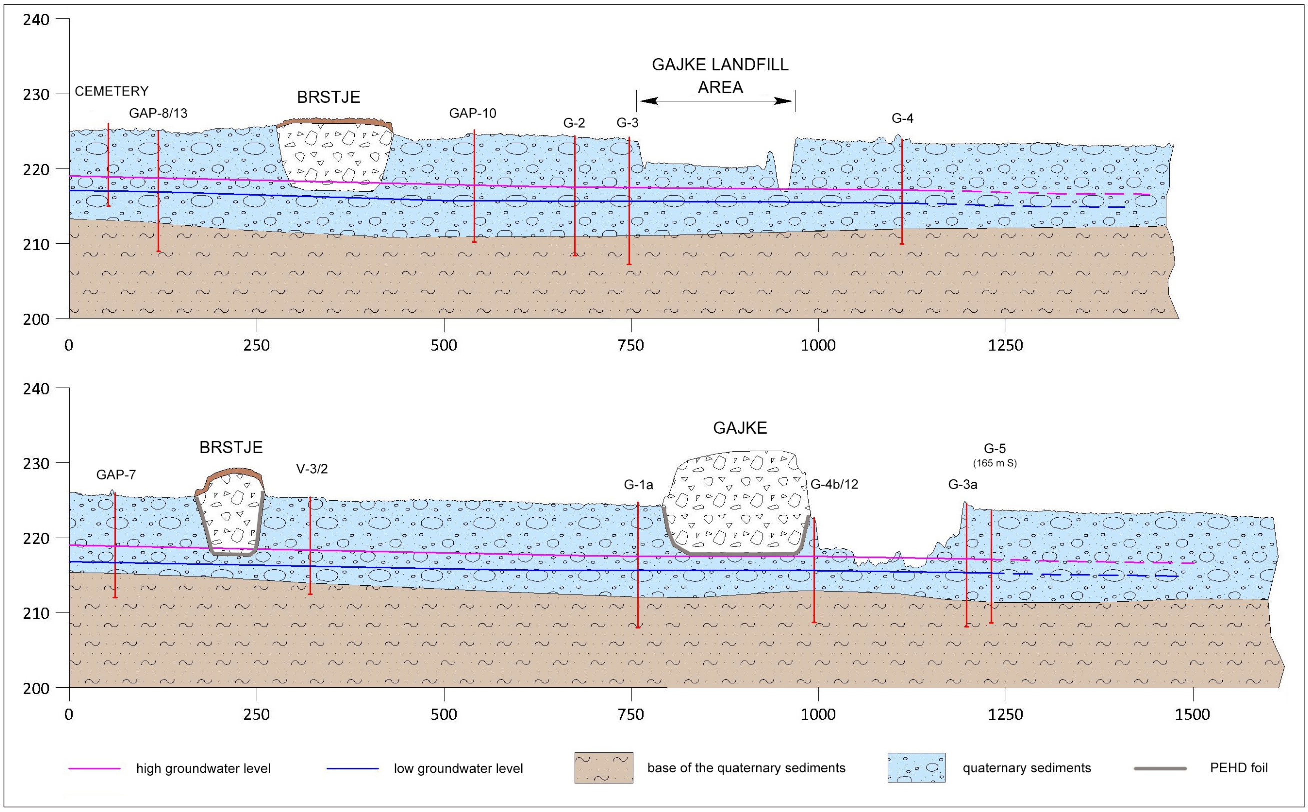

Fig. 2. Simplified hydrogeological cross-section through Gajke and Brstje landfills.

Groundwater flows in the Quaternary aquifer in the NW–SE direction to the Drava River, into which it discharges at 4 to 10 km (Fig. 3). The direction of groundwater flow is approximately the same with respect to the different hydrological conditions, with the largest deviations observed mainly in the south-eastern part of the Gajke deposit, where the flow is directed further to the northeast during floods. The groundwater flow gradient is 0.002 and depends on the intensity of recharge from precipitation. Groundwater velocity is estimated to be 2 to 3 m/day.

Depending on the depth of the deposited waste and the groundwater table, it is an indirect input of pollutants since the landfill is in or above the unsaturated zone. During the flood period, the bottom of the deposit body (the outside of the liner system) is occasionally in contact with groundwater (Cerar et al., 2019).

Methods and materials

Sampling

Sampling for isotope analysis was conducted in 27–28 October, 2020, by Javne službe Ptuj d.o.o. in collaboration with the NLZOH (National Laboratory of Health and Food, Maribor), following the prescribed instructions outlined below. Water samples for $\delta^{18}O$ and $\delta^{2}H$ analysis were gathered in 60 mL HDPE bottles, which were prewashed twice with the sample and had no headspace. Samples for $\delta^{13}C_{DIC}$ and total alkalinity (TA) analysis were filtered through a 0.45 μm membrane filter and transferred into two glass ampoules, each with a volume of 12 ml and no headspace, using gas-tight syringes. For ^{3}H analysis, 1 L of unfiltered water was collected in an HDPE container. Prior to stable isotope analysis, the samples were stored in the refrigerator at temperatures ranging from 4 to 6 °C, while samples for ^{3}H analysis were stored at room temperature. Sampling was conducted at a total of 13 locations (Table 1). Groundwater was collected from 12 wells in the Gajke and Brstje landfill areas and leachate was collected from a channel from the Gajke landfill (Fig. 3, Table 1). Sampling of groundwater from seven wells was performed by the NLZOH concurrently with the regular operational monitoring of groundwater conditions in accordance with SIST ISO 5667-11:2010 (referred to as "monitoring" in Table 1). Five other wells and leachate were sampled by the Javne službe Ptuj d.o.o. only for TA and isotope analysis (referred to as "other" in Table 1) and in situ measurements were not conducted.

Table 1. Locations of sampling points and time and type of sampling.

Sampling point	Date and time of sampling		Location*	N (D96)	E (D96)	Z_{ground} (m)	Z_{well} (m)	Type of sampling
G-1a	26.10.2020	08:00	upstream	142665	569926	224.70	224.79	monitoring
G-2	26.10.2020	08:35	upstream	142842	569978	224.28	224.38	other
G-3	26.10.2020	09:00	upstream	142944	570102	224.38	224.23	other
G-3a	26.10.2020	10:30	downstream	142556	570352	224.39	224.58	monitoring
G-4	26.10.2020	10:00	downstream	142724	570403	223.80	223.97	other
G-4b/12	26.10.2020	11:05	downstream	142622	570160	222.48	222.70	monitoring
G-5	26.10.2020	09:25	downstream	142388	570332	223.58	223.62	monitoring
GAP-7	26.10.2020	13:15	upstream	142911	569273	225.86	226.01	monitoring
GAP -8/13	26.10.2020	13:45	upstream	143090	569480	225.69	226.14	other
GAP -10/13	26.10.2020	11:45	upstream	142952	569880	224.66	225.19	monitoring
V-3/2	26.10.2020	12:15	upstream	142832	569521	225.44	225.44	monitoring
cemetery	26.10.2020	12:40	upstream	143094	569409	/	226.03	other
leachate	27.10.2020	07:30	laterally	142716	570192	218.30	/	other

* - according to the direction of groundwater flow in the Gajke landfill area

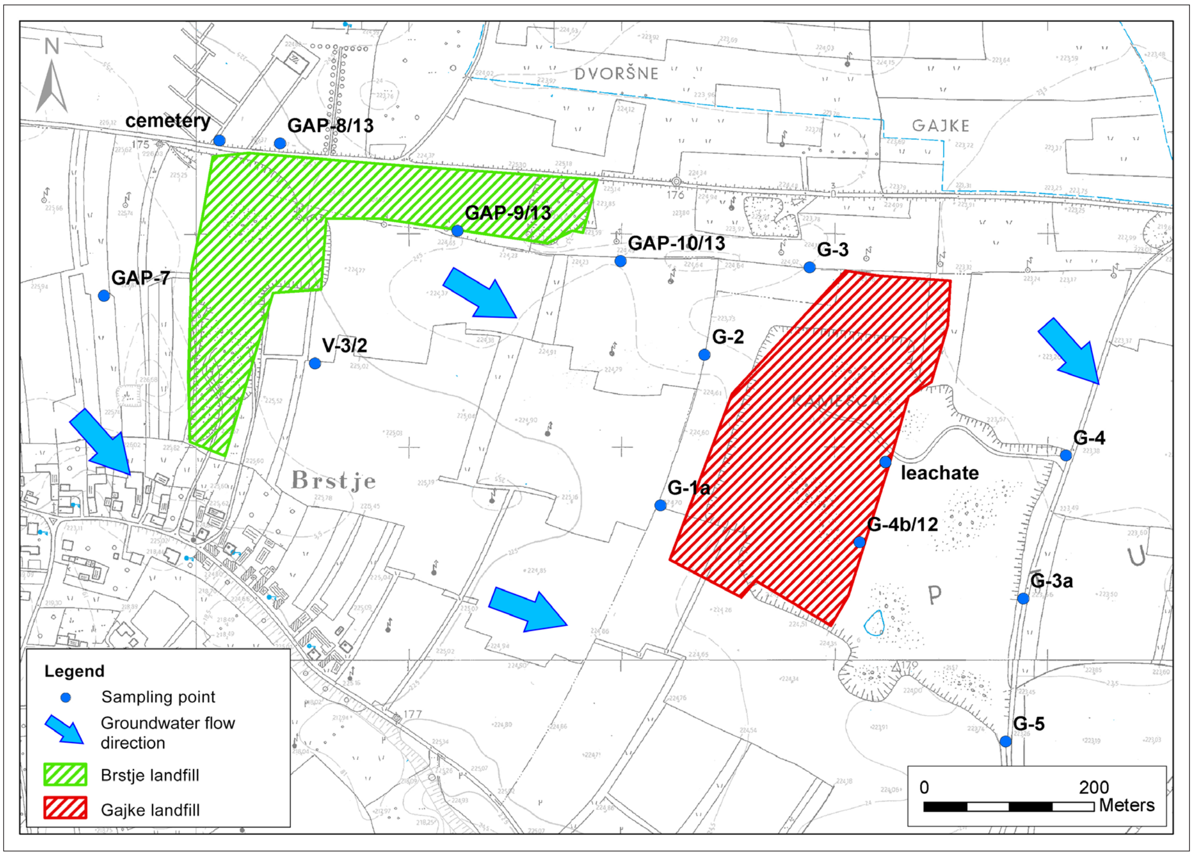

Fig. 3. Sampling points of groundwater and leachate in the Gajke and Brstje landfill area.

Analysis

All water samples received were analysed for isotope analysis at the Jožef Stefan Institute laboratories using the procedures described below. Since leachate analysis is not routinely performed, we anticipated problems with the analysis of this water. Ultimately, the only difficulties encountered were in determining the δ^2H, which could not be eliminated despite repeated analyses, so the result is not reported for this parameter.

TA was measured using Gran titration (Gieskes, 1974) with a precision of ±1 % within 24 hours of sample collection. Approximately 8–10 g of the sample was weighted in a plastic HDPE bottle with a magnetic stirrer. The pH electrode of the Mettler toledo Seven compact pH meter S220 was calibrated using certificate buffers with values of 7.00 and 4.00 ±0.02. With this method we determined the change in pH depending on the volume of added acid with a known concentration, which is added to a solution of unknown concentration (Vreča et al., 2020).

$\delta^{13}C_{DIC}$ was determined using the Europa-Scientific 20-20 with TG preparation module. Approximately 200 µL of phosphoric acid (Sigma-Aldrich p.a., ≥85 %) was added to a 12 mL vial and purged with helium (He). Subsequently, the water sample (0.5 –5 mL, depending on total alkalinity) was injected into the ampoule, and CO_2 was measured from headspace. For one point normalization of samples, a Carlo Erba solution (8 mg/12mL) with a known value of –10.8 ±0.2 was used to calibrate $\delta^{13}C_{DIC}$ measurements (Spötl, 2005; Vreča et al., 2020).

δ^2H and $\delta^{18}O$ were determined using the H_2-H_2O (Coplen et al., 1991) and CO_2-H_2O (Epstein & Mayeda, 1953; Avak & Brand, 1995) equilibration technique. Measurements were performed on a dual inlet isotope ratio mass spectrometer (DI IRMS, Finnigan MAT DELTA plus, Finnigan MAT GmbH, Bremen, Germany) with an automated H_2-H_2O and CO_2-H_2O HDOeq 48 Equilibration Unit (custom built by M. Jaklitsch). All measurements were performed together with laboratory reference materials (LRM) calibrated periodically against primary IAEA calibration standards to VSMOW/SLAP scale. Samples were measured as independent duplicates and results were normalized to the VSMOW/SLAP scale using the Laboratory Information Management System for Light Stable Isotopes (LIMS) programme (https://water.usgs.gov/water-resources/software/RSIL-LIMS/). For independent quality control, we used internal LRM and USGS commercial reference materials. The overall measurement uncertainties are estimated to be less than 1 ‰ and 0.05 ‰ for δ^2H and $\delta^{18}O$, respectively (Vreča et al., 2020).

The results for $\delta^{13}C_{DIC}$, δ^2H and $\delta^{18}O$ are expressed in a standard δ notation in per mil (‰) relative to international standards (Coplen et al., 1991; Coplen, 1994; IAEA, 2018).

For ^3H analysis, the samples were distilled prior to tritium enrichment in order to remove dissolved solids and other possible interferences. The ^3H was enriched using electrolysis. After electrolysis, the sample was transferred to stainless steel distillation flasks for a second distillation. Then 10 g of sample solution was mixed with 12 mL of Ultima Gold LLT scintillation cocktail and measured in Quantulus 1220 (Perkin Elmer) liquid scintillation counter for 5 h, together with a tritium-free water sample (dead water) to correct for detector noise and background and according to standards used to determine ^3H detection efficiency. In the STC 131/20 analytical report (Štrok & Svetek, 2020; Appendix 2), results for ^3H activity (As) are expressed in $Bqkg^{-1}$. Tritium units (TU = tritium unit) are commonly used in isotope hydrology, where 1 TU represents 1 ^3H atom per 10^{18} ^1H atoms. Therefore, the results were converted to TU for interpretation of the results, considering 1 TU = 0.118 BqL^{-1} (Ingraham, 1998; Gat et al., 2001) and 1 kg = 1 L.

Spatial analysis

The spatial distribution of individual parameters was carried out using GIS software ESRI® ArcMap™ (v. 10.5.) using the interpolation method of natural neighbours, which uses Thiessen polygons or Voronoi diagrams and weighted averages of neighbouring values to arrive at the most appropriate values. Experientially, this method is most suitable for the given spatial data density.

Results and discussion

The results of the in-situ measurements (temperature (T), pH, electrical conductivity (EC), redox potential (Eh) and dissolved oxygen (DO)) received from the client and performed by NLZOH, of isotope analysis ($\delta^{18}O$, δ^2H, $\delta^{13}C_{DIC}$, ^3H) and TA are presented in Table 2.

To assess the potential impact of the Gajke and Brstje landfills on groundwater quality status, maps illustrating the spatial distribution of $\delta^{18}O$, δ^2H, $\delta^{13}C_{DIC}$, TA, and ^3H in groundwater were created for the entire study area. To separate the impacts of the two landfills, isotope groundwater data were compared with analytical results from additional sampling of leachate prior to reverse osmosis at the Gajke landfill. Leachate from the Brstje landfill was not analysed due to the unregulated drainage system. These leachates are collected at the bottom of the protected deposit field through pipes to the leachate where no changes have been observed for years, as leachate has not been detected since 2005. Monthly inspections of the leachate shaft and meter inventory are carried out, which is also performed several times a year by a representative of the Javne službe Ptuj d.o.o. Only the older parts of the landfill, where there are poplars and plateau, have no soil protection, although there is upper protection in the form of asphalt and poplars.

Table 2. Results of in-situ measurements (T, pH, EC, Eh, DO), isotope analysis ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C_{DIC}$, ^{3}H) and TA from 27–28 October, 2020 are summarised from Vreča et al. (2020) and Štrok & Svetek (2020).

Sampling point	T (°C)	pH	EC (µS/cm)	Eh (mV)	DO (mg/L)	DO (%)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	$\delta^{13}C_{DIC}$ (‰)	TA (mM)	^{3}H (TU)
G-1a	13.9	7.1	788	342	6.59	65.9	-9.57	-67.0	-14.9	7.72	5.9
G-2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-9.22	-65.3	-8.2	7.12	18.8
G-3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-9.30	-65.1	-10.6	7.70	11.8
G-3a	16.3	7.1	778	309	0.12	1.3	-8.87	-62.1	-14.3	7.85	5.9
G-4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-9.60	-67.5	-13.4	7.83	7.3
G-4b/12	19	7.0	790	335	5.51	61.3	-9.69	-68.6	-14.4	7.74	4.6
G-5	13.6	7.1	752	343	7.16	71.1	-9.47	-66.5	-13.4	8.11	4.4
GAP-7	14.9	7.1	794	426	7.63	77.8	-9.17	-65.1	-14.7	7.84	5.2
GAP -8/13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-8.81	-61.3	-14.8	5.5	6.0
GAP -10/13	14.4	6.9	977	329	0.06	0.6	-9.24	-65.2	-7.6	9.84	16.2
V- 3/2	14.2	7.1	750	331	1.73	17.4	-9.37	-65.9	-14.6	7.08	6.6
cemetery	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-8.56	-59.3	-14.4	6.07	7.5
leachate CERO Gajke (canal)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-7.64	n.d.	+6.1	73	209.8

n.d. - not determined

Field measurements

Groundwater temperatures at the Brstje landfill are lower compared to the measured groundwater temperatures in the Gajke area. The groundwater temperature in the Brstje landfill area is between 13.9 °C and 14.9 °C, while in the Gajke landfill area it is between 13.6 °C and 19 °C (Table 2). The G-3a (16.3 °C) and G-4b/12 (19 °C), which are located downstream (Fig. 3) of the Gajke landfill, are outstanding. Variable temperatures are result of different thickness and position of wastes which influences the heat-generating (exothermic) reactions.

The pH of the groundwater in the area of the Gajke landfill is constant at all sampling points (between 7.0 and 7.1). In the area of the Brstje landfill, the pH value varies between 6.9 and 7.1, and the pH value of the groundwater is comparable to that of the groundwater in the area of the Gajke landfill.

EC values in the entire study area fall in the interval from 750 to 977 µS/cm, deviating from the sampling point GAP-10/13 (977 µS/cm), which is located on the eastern edge (downstream) of the old deposition field of the Brstje landfill and about 200 m northwest (upstream) of the Gajke landfill (Fig. 3). The reason for the deviating values of the electrical conductivity on GAP-10/13 are the additional pressures on the groundwater caused by the Brstje landfill, which were already identified in the study by Cerar et al. (2019).

According to the measured contents of DO in the groundwater in the area of the Gajke and Brstje landfills, constant suboxic conditions prevail at the G-3a and GAP-10/13 sampling points. The measured DO content at these two sites is below the lower limit of quantification (LOQ = 0.5 mg/L). Somewhat higher values were obtained at V-3/2, where they are 1.73 mg/L. At the other monitoring points, DO values are higher, ranging from 5.51 to 7.63 mg/L (Table 2).

The Eh indicates the prevailing oxidation to transient oxidation-reduction conditions, expressed as values of 309–343 mV, with the upstream monitoring point GAP-7 standing out with a value of 426 mV, indicating higher aeration of the groundwater (7.63 mg/L), which is also confirmed by the highest concentration of DO.

Isotope composition of oxygen and hydrogen

Values for $\delta^{18}O$ in groundwater in the vicinity of the two landfills vary from -9.69 to -8.56 ‰ (Fig. 4). The lowest $\delta^{18}O$ values are observed at locations around the Gajke landfill, while the highest values were detected at locations northwest of Brstje and at G-3a in the south-eastern part of the study area downstream from the Gajke landfill. In leachate, the measured value for $\delta^{18}O$ is -7.64 ‰ and is slightly higher than in groundwater samples, indicating the influence of secondary processes on the $\delta^{18}O$ (Tazioli, 2011), as confirmed by positive $\delta^{13}C_{DIC}$ and higher TA values (Table 2).

The values for δ^2H in groundwater in the two landfills follow the changes in $\delta^{18}O$ and vary between -68.6 and -59.3 ‰ (Table 2, Fig. 5). In the leachate, δ^2H was not measured due to technical problems.

All measured $\delta^{18}O$ and δ^2H values in groundwater indicate that the main water source consists in direct infiltration of local precipitation and does not indicate the considerable influence of evaporation or other secondary processes. The isotope composition was monitored in the period 2016–2018 at Murska Sobota and Sv. Urban, i.e., locations NE and SW of the investigated area (Vreča et al., 2022). The average $\delta^{18}O$ and δ^2H values amounted −9.28 ‰ and −65.8 ‰ for Murska Sobota and −8.53 ‰ and −59.2 ‰ for Sv. Urban.

The $\delta^{18}O$ values vary as a function of temperature and are lowest at sites where temperatures are lowest. Unfortunately, water temperature was not measured at all sites where samples were collected. Only G-4b/12 deviates, where water temperature was relatively high (19 °C) and $\delta^{18}O$ was lowest (-9.69 ‰). The result indicates different water properties at this site (δ^2H and ^3H activity are also the lowest) and is due to the location of G-4b/12, which is at the edge of the storage field and has a higher temperature compared to the other points.

Values for $\delta^{18}O$ and δ^2H in groundwater indicate that the main source of water is direct infiltration of precipitation, with no significant isotopic fractionation, and that the isotope composition depends on water temperature, which was determined at only 7 sampling points. It is estimated that the $\delta^{18}O$ and δ^2H values in groundwater downstream of the Brstje landfill decrease, while they increase again slightly at the G-3a. This indicates that the impact of the Gajke landfill cannot be completely excluded.

Total alkalinity

The TA values in groundwater around the two landfills range from 5.45 to 8.11 mM, deviating GAP-10/13 with slightly higher values of 9.84 mM (Fig. 6). In the leachate the measured value is 73 mM. The spatial distribution shows that the highest values (9.84 mM) appear at the downstream sampling point of GAP-10/13 and then decrease at sampling points: G-1a and G-4b/12 (around 7.7 mM) downstream of the Gajke landfill. The lowest values (5.45 mM) are located upstream (GAP-8/13) from the Brstje landfill.

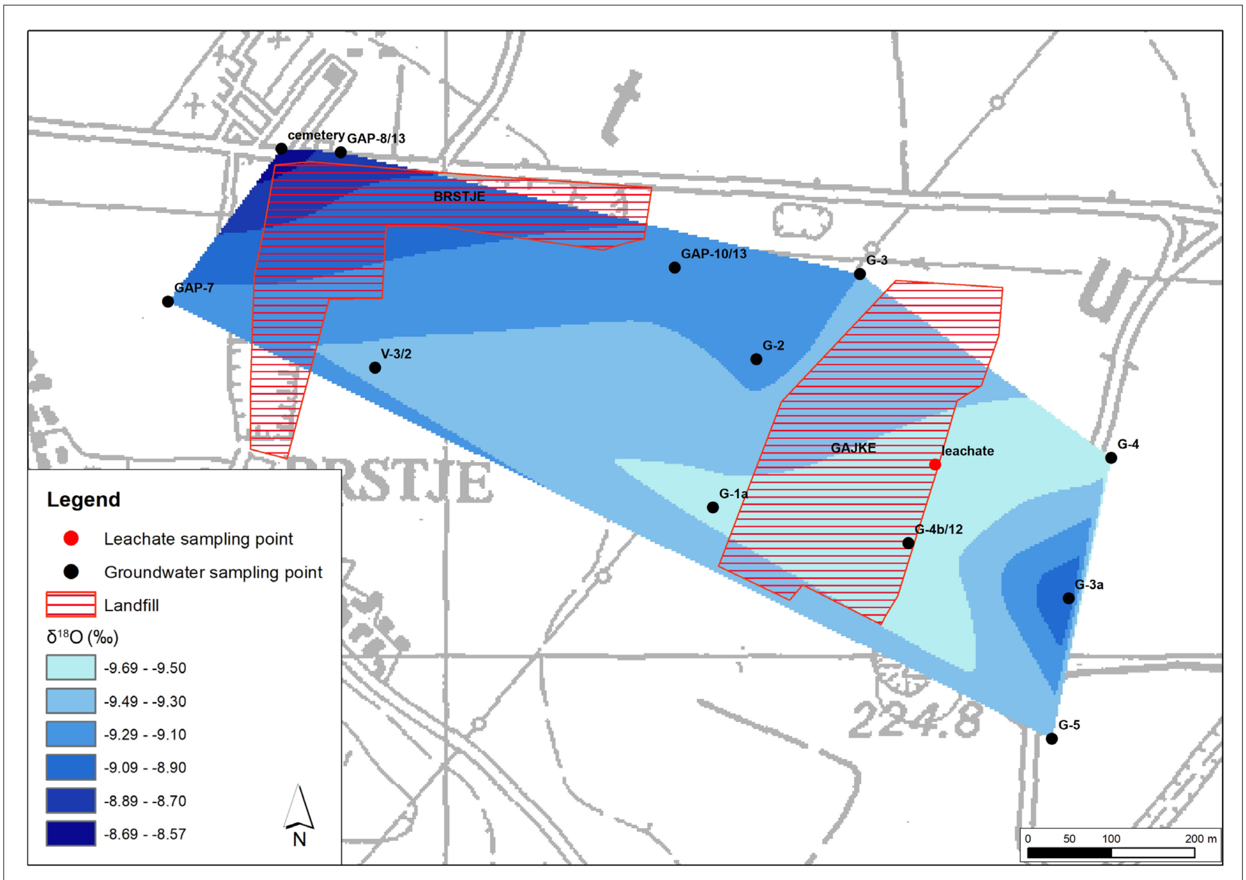

Fig. 4. Spatial distribution of $\delta^{18}O$ (‰) in groundwater in the Gajke and Brstje landfill area.

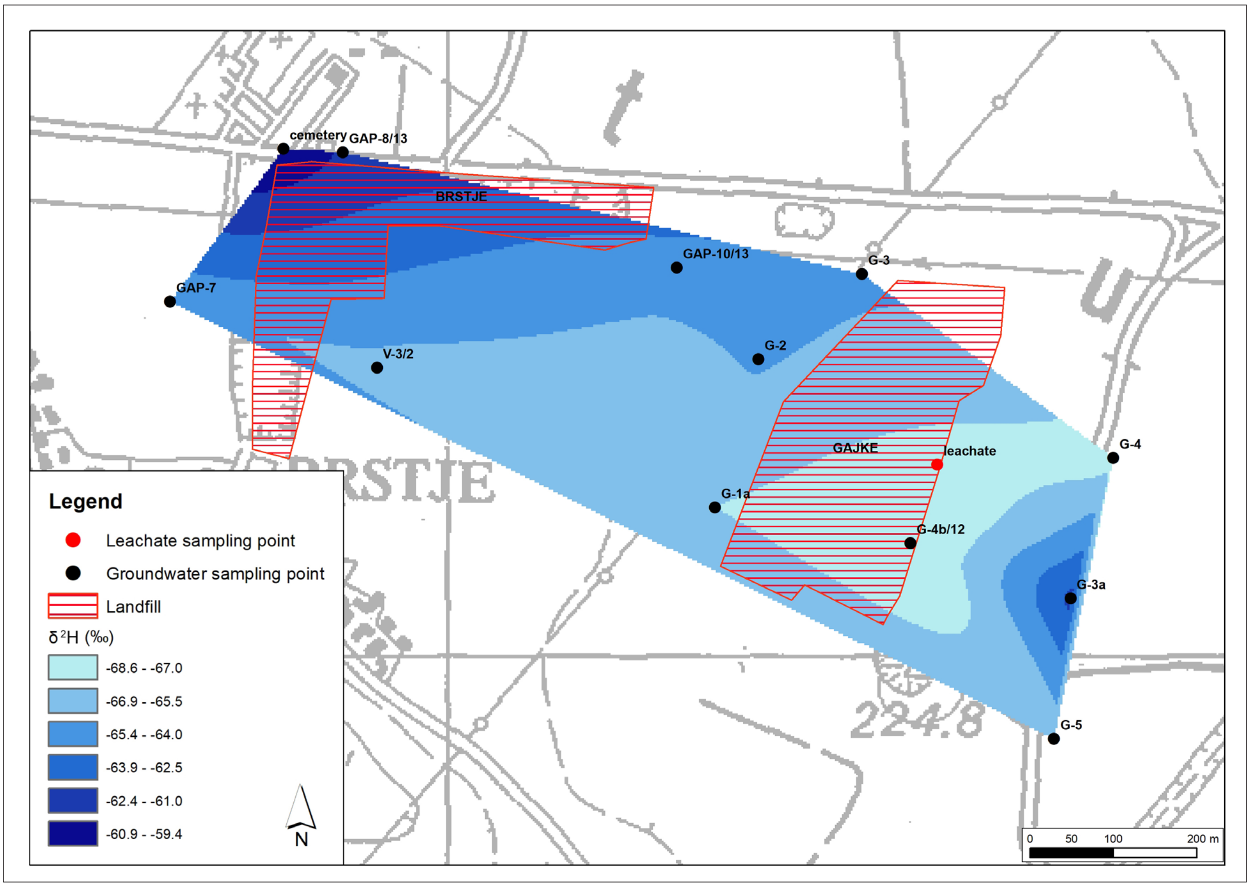

Fig. 5. Spatial distribution of δ^2H (‰) in groundwater in the Gajke and Brstje landfill area.

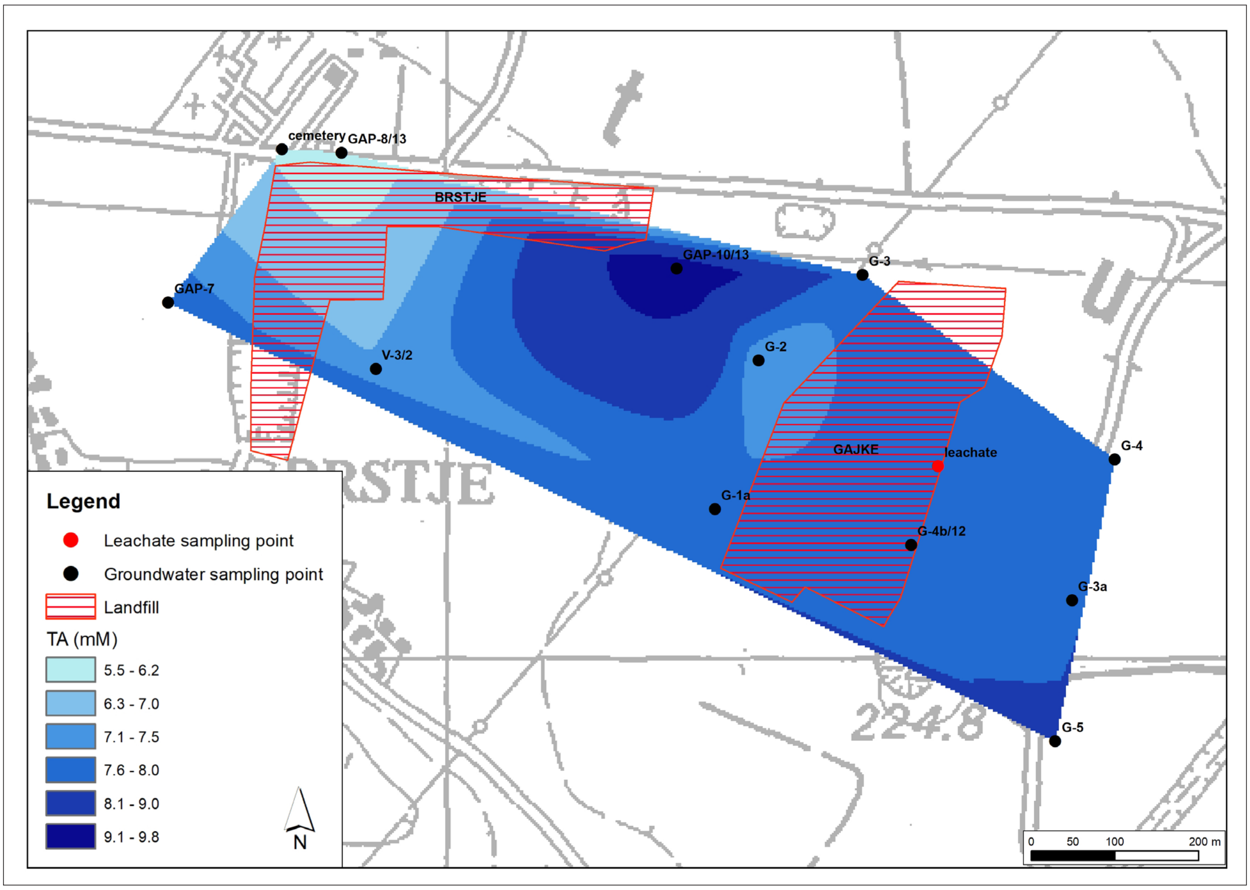

Fig. 6. Spatial distribution of TA (mM) in groundwater in the area of the Gajke and Brstje landfill area.

Isotope composition of carbon from dissolved inorganic carbon

The $\delta^{13}C_{DIC}$ values in groundwater in the two landfills vary from -14.9 to -8.2 ‰ (Table 2, Figs. 7 and 8). The spatial distribution of $\delta^{13}C_{DIC}$ shows that the lowest values were measured upstream of the Brstje landfill at GAP-8/13 (-14.8 ‰), where the impact of the landfill leachate is not expected. Slightly higher $\delta^{13}C_{DIC}$ values are observed at downstream monitoring point G-4 (-13.4 ‰) and G-5 (-13.4 ‰) from Gajke landfill compared to G-4b/12 with $\delta^{13}C_{DIC}$ of –14.4 ‰. To confirm the influence of leachate, measurements should be repeated several times during the hydrological year.

The measured $\delta^{13}C_{DIC}$ value in the leachate from the Gajke landfill is +6.1 ‰ (Table 2, Figs. 7 and 8). This value characterizes degradation of organic matter, including methanogenesis under anoxic conditions in landfills. Leachate becomes enriched with a heavier carbon isotope (^{13}C) during this process (Fig. 8).

The highest positive $\delta^{13}C_{DIC}$ values in groundwater at locations GAP-10/13 (-7.6 ‰) and G-2 (-8.2 ‰) indicate a significant impact on the carbon cycle in groundwater (see Table 2, Figs. 7 and 8). Furthermore, at GAP-10/13, recorded dissolved oxygen concentrations around 0 % (Table 2) could suggest the presence of methanogenesis in groundwater (North et al., 2006). However, this presence isn't as pronounced as in the leachate. North et al. in 2006 found $\delta^{13}C_{DIC}$ ranged from +2.8 to +15.8 ‰ in all analysed leachate samples, indicating the presence of methanogenesis.

The maximum values of $\delta^{13}C_{DIC}$, TA, and ^{3}H were detected at monitoring points GAP-10/13 (-7.6 ‰, 9.84 mM, 16.2 TU) and G-2 (-8.2 ‰, 7.12 mM, 18.8 TU) and gradually decreased toward monitoring points G-4b/12 and G-4 downstream of the Gajke landfill. This indicates that no significant impact is expected downstream of the Gajke landfill but occurs in the north-central part of the Gajke landfill. Similar results have already been observed during "benchmarking".

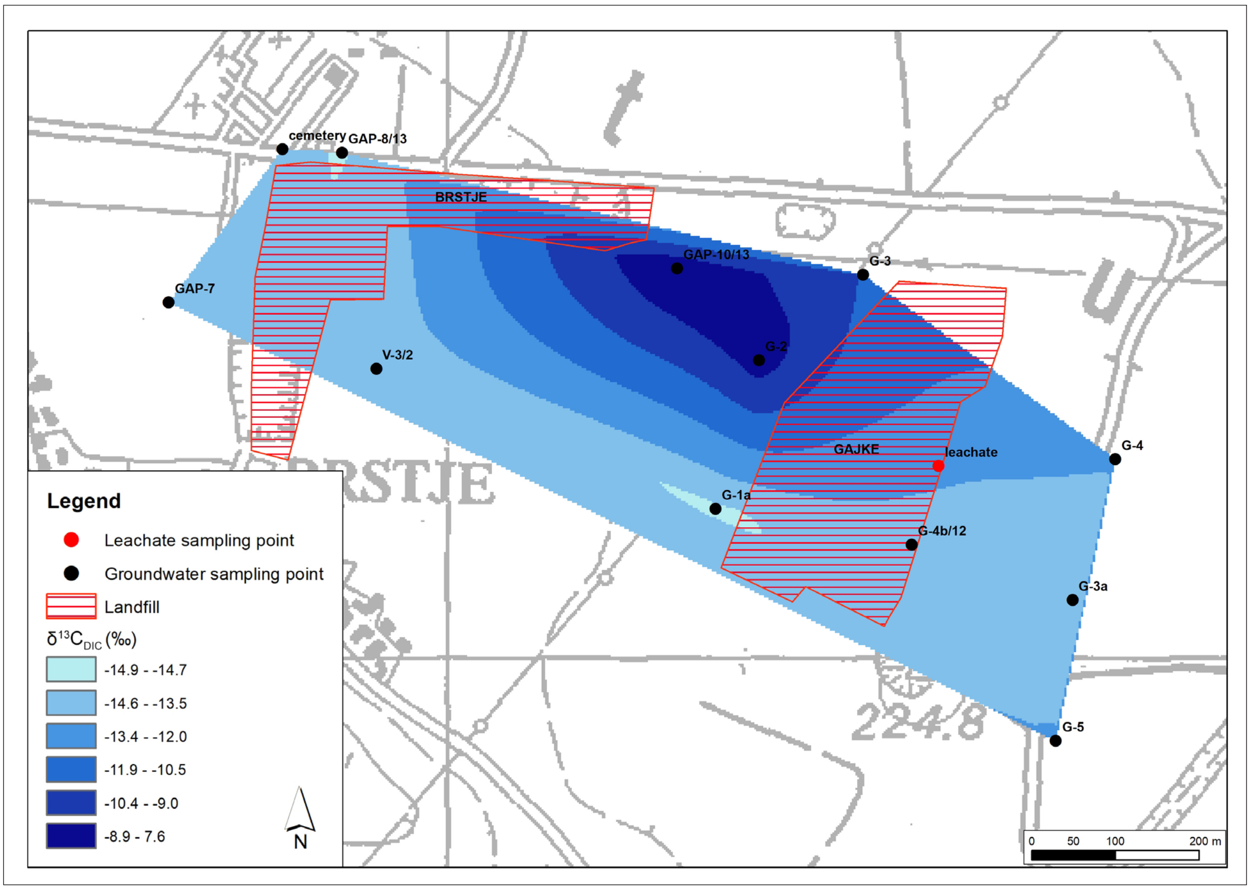

Fig. 7. Spatial distribution of $\delta^{13}C_{DIC}$ (‰) in groundwater in the Gajke and Brstje landfill area.

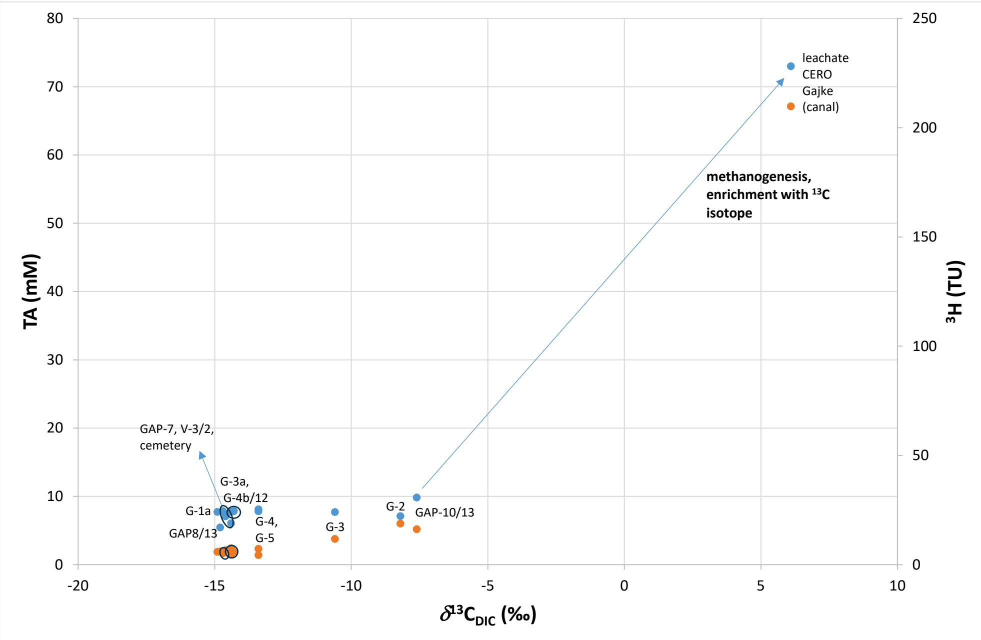

Fig. 8. TA and ^{3}H versus $\delta^{13}C_{DIC}$ with associated locations.

Tritium

Groundwater ^{3}H activities in the surrounding area of two landfills range from 4.4 to 18.7 TU (Figs. 8 and 9). The highest activities of ^{3}H occur in wells GAP-10/13 (16.2 TU), G-2 (18.8 TU), and G-3 (11.8 TU), all of which are upstream of the Gajke landfill and may be attributed to the influence of the Brstje landfill, whose leachate was not sampled. The lowest activities were found upstream of the Brstje landfill and downstream of the Gajke landfill. Downstream of Gajke, ^{3}H deviates at G-4 (7.3 TU), and the southward changes show the same trend as the change in boron concentration (Cerar et al., 2019). The spatial distribution of ^{3}H in groundwater shows similar characteristics to TA and $\delta^{13}C_{DIC}$ (Figs. 6, 7 and 8).

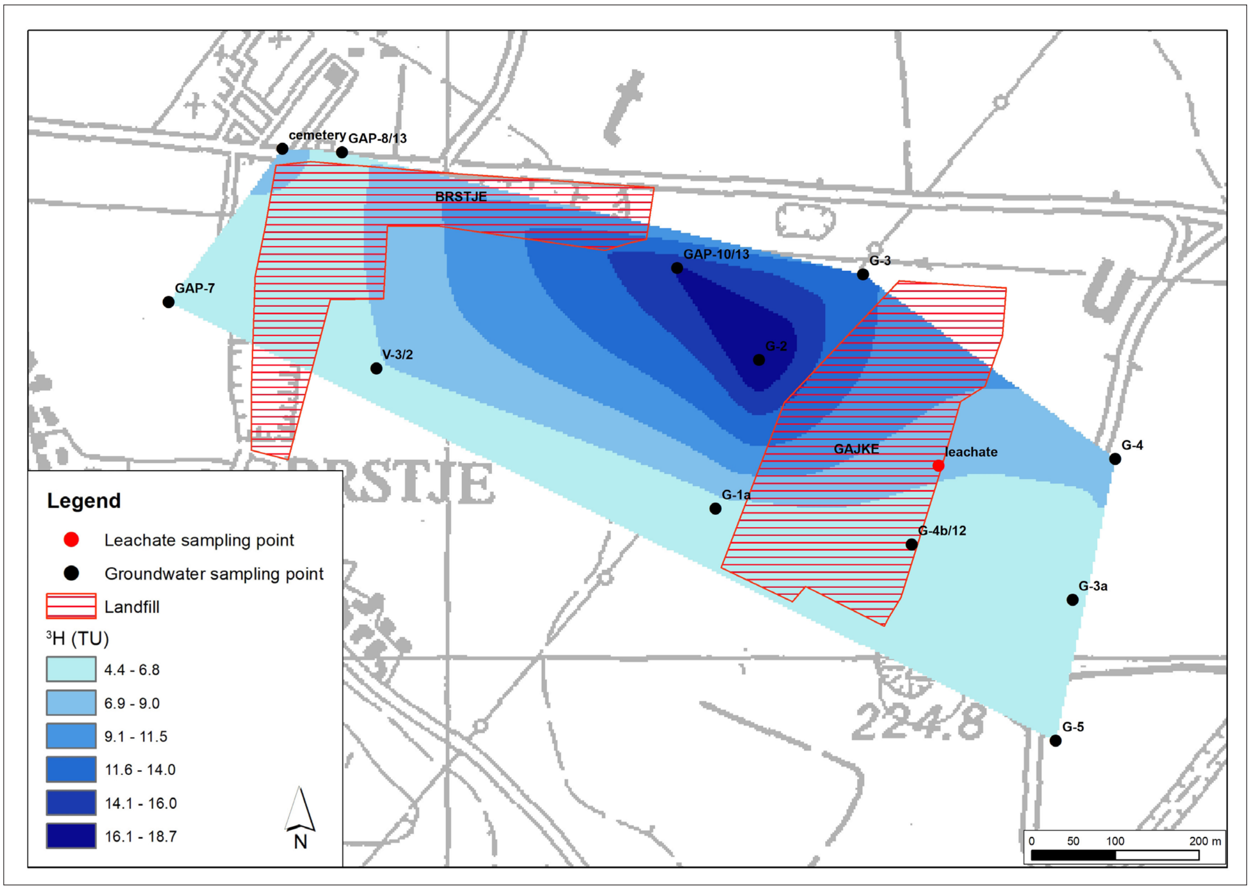

Fig. 9. Spatial distribution of ^{3}H (TU) in groundwater in the Gajke and Brstje landfill area.

In the leachate of the Gajke landfill, the measured activity is significantly higher than in the groundwater and is 209.8 TU (Fig. 8). High ^3H activities are characteristic of leachate and can be as high as 1,000 TU (Tazioli, 2011). In monthly precipitation over Slovenia, ^3H activity rarely exceeds 20 TU (Internet 1) and amounts to an annual average of less than 10 TU over the past decade (Kern et al., 2020; Vreča et al., 2022), making the ^3H parameter a very good indicator of pollution from landfills. Raco and Battaglini (2022) found ^3H values in leachate ranging from 55 to 923 TU, while Gupta and Raju (2023) found in their study of landfill leachate and groundwater sample ^3H value from 8.11 TU and 3.03 TU, respectively. We could conclude that higher measured activity in GAP-10/13 is the result of pollution from the Brstje landfill.

Conclusions

The results of the present study show that isotope analysis is a valuable tool for monitoring landfills, revealing shifts in biogeochemical processes within groundwater and allowing prediction of contamination plumes in the potential impact area. The results will further improve the picture of the spatial distribution of conservative contaminants, while also identifying possible scenarios for the input of leachate from the Gajke Landfill into the aquifer. Tritium, which demonstrates high activity in leachate, proved to be the most reliable parameter for such a prediction. The analyses performed proved to be an effective method to determine the dispersion of loads from landfills, especially in terms of predicting the spatial distribution of the loads and possible scenarios of the load of the aquifer by leachate.

However, it should be noted that this paper summarises the results of a single sampling. For a more reliable assessment, we suggest repeating the same analyses in different water conditions (low, medium, high) or establishing monthly monitoring of $\delta^{18}O$, δ^2H, $\delta^{13}C_{DIC}$, and ^3H in the groundwater at all 12 sampling points in order to allow for adequate isotopic characterization of the water. In addition, we propose including sampling of the Rogoznica stream upstream and downstream of the Brstje landfill in the monitoring, as knowledge of surface water infiltration and surface/groundwater interactions are also important in any evaluation of the results. Further, systematic research is necessary due to climate extremes that can significantly impact the flow of groundwater, thus affecting the spread of pollution clouds.

Acknowledgments

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GEOLOGIJA 66/2, 301-311, Ljubljana 2023

Poročila in ostalo - Reports and More

Poročilo o aktivnostih Slovenskega geološkega društva v letu 2022

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V letu 2022 je bil veliki del časa in energije usmerjen v organizacijo 6. slovenskega geološkega kongresa, ki je potekal v soorganizaciji SKIAH-a (Slovenski komite za hidrogeologijo) od 3.–5. 10. 2022 v Rogaški Slatini. Razvoj Rogaške Slatine je neposredno povezan z izviri mineralne vode, ki so posledica geoloških struktur in procesov in zato je bila izbrana za lokacijo osrednjega dogodka slovenskih geologov.

Sl. 1. Grafična podoba 6. slovenskega geološkega kongresa.

Grafična podoba kongresa, ki je sestavljena iz delčkov različnih oblik in barv, ponazarja posamezne veje geologije in združeni v celoto dajo celovito sliko okolja, v katerem živimo, tako tisto na površju, ki jo vidimo, kakor tisto pod površjem, ki nam je skrita. To je ubesedil tudi slogan kongresa »Vedeti (ne) vidno – vloga geologije v naši družbi«. Kongresa se je udeležilo 115 udeležencev, ki so svoje dosežke, raziskave in aktivnosti predstavili v 63 predavanjih in 25 posterjih.

Pomemben dogodek kongresa je bila okrogla miza, z naslovom slogana kongresa in na kateri smo opozorili na aktualne družbene izzive, kot so ekstremni vremenski dogodki, varnostni konflikti, samooskrba, odpornost, zeleni prehod, krožno gospodarstvo, geo- in bio diverziteta, aktiven snovni krog in kako lahko geologi pripomoremo k rešitvi trenutne krize in izoblikujemo optimistično vizijo za prihodnost. Šest panelistov pod vodenjem ga. Renate Dacinger, se je osredotočilo na problematiko vode, hrane, raznolikost narave, ekstremne dogodke, surovine, energijo in našo družbo. Razpravljavci na okrogli mizi so bili mag. Joerg Prestor (GeoZS), doc. dr. Matjaž Glavan (UL Biotehnična fakulteta), Ervin Vivoda (Ministrstvo za okolje in prostor Sektor za zmanjševanje posledic naravnih nesreč), izr. prof. dr. Maja Turnšek (UM Fakulteta za turizem), Tina Zajc Benda (EIT RawMaterials) in Simona Kaligarič (Zavod RS za naravo, območna enota Maribor), najprej izpostavilo aktualne izzive, nato pa skušalo poiskati rešitve in sinergije med različnimi aktivnostmi, potrebami in stališči.

Najbolj izstopajoč obkongresni dogodek je bila foto razstava »Geopestrost pred domačim pragom«, ki je bila namenjena promociji in počastitvi prvega mednarodnega dneva geopestrosti. Na natečaj je prispelo 37 fotografij 9 avtorjev. Razstava je bila na ogled obiskovalcem zdraviliškega parka še po zaključenem kongresu.

Sl. 2. Razstava izbranih fotografij v zdraviliškem parku.

Sl. 3. Zmagovalna fotografija foto natečaja »Korita pri Klužah« avtorja Boruta Stojilkovića.

Obrazložitev izbora: barvna in oblikovna dovršenost ter pogled iz perspektive, običajno skrite človeškim očem, razkriva lepoto moči in povezanosti hidroloških in geomorfoloških pojavov, ki so objeti z bujnim zelenilom žive narave. Zanimiva centralna kompozicija, prevladujoča zelena barva in nenavaden pogled, na drugače poznan motiv, naredijo to fotografijo izstopajočo.

Kongres se je zaključil s strokovnimi ekskurzijami, ki so udeležence kongresa popeljale na različne konce Slovenije in jih seznanile z aktualnimi geološkimi problematikami. Pohorje je bilo predstavljeno kot ekstenzijski kompleks, ki pripada najzahodnejšemu delu Panonskega bazena. Obiskali smo litostratigrafske formacije med Rogaško Slatino in Bočem ter geološko pot v Kozjanskem krajinskem parku, ogledali smo si gradnjo vzhodne cevi Karavanškega cestnega predora in se seznanili z upravljanjem ranljivih teles podzemne vode na Dravskem polju. Podrobnosti o kongresu in spremljajočih dogodkih, spletno obliko kongresnih povzetkov in opis ekskurzij so dosegljivi na spletni strani (6. slovenski geološki kongres 2022).

V januarju 2022 je izšla knjiga »Obrazi geologije«, v kateri so geologi izpostavili do tri besede, ki jih označujejo kot geologe pri njihovem delu ali kaj za njih je geologija. Knjiga je izšla v nakladi 700 izvodov in jo je mogoče kupiti na društvu ali pa si jo ogledati v nekaterih knjižnicah.

Sodelovali smo pri pripravi slovenskega logotipa Dneva geopestrosti, ki ga je oblikovala Nataša Kastelic iz Designa studio in se bo uporabljal ob mednarodnem logotipu na vseh dogodkih posvečenih geopestrosti.

MEDNARODNI DAN
GEOPESTROSTI
SLOVENIJA

Sl. 4. Slovenski logotip geopestrosti.

Opis logotipa: logotip v grafičnih potezah in barvah združuje vse glavne elemente geopestrosti. V linijah logotipa so skriti osnovni geološki pojavi – fosili in minerali kot gradniki kamnin. Oblika spirale ponazarja tudi geološki čas. Geomorfološke značilnosti predstavljajo linije (izohipse), ki rišejo osnovno obliko logotipa. Hidrogeološke značilnosti so predstavljene s kapljicami in modro barvo. Oranžna in rjava barva zastopata tla. Osnovna oblika logotipa je lahko korozijska votlinica ali kraška jama, eden najpomembnejših geoloških pojavov v Sloveniji. V notranjosti jame je stilizirana oblika Slovenije s silhueto človeka, ki sobiva z naravo in njeno geopestrostjo.

Ob prvi obeležitvi Mednarodnega dneva geopestrosti, ki je potekalo 6. oktobra 2023 v Dovžanovi soteski v Tržiču je bilo društvo, posredno preko svojih članov, vključeno v organizacijo dogodka in izvedbo terenskega ogleda znamenitosti soteske. Dogodek je bil medijsko zelo odziven.

Tudi v letu 2022 so bili člani skupine za promocijo geološke znanosti zelo aktivni in delovni. Na sestanku s predstavniki Zavoda za šolstvo (skrbniki za geografijo in biologijo) so predstavili ideje glede spremembe geoloških vsebin v učnih načrtih, ki so jih pripravili v okviru sekcije.

Člani sekcije so sodelovali na konferencah s prispevki:

- Geološki stolpi spregovorijo skozi interaktivnost in digitalno pripovedništvo.
- Slovenska geološka pot med Tolminom in Stržiščem – le kaj je želel prof. Buser pokazati?
- Geologija v vzgoji in izobraževanju prihodnosti, da ali ne?
- Educational challenge on the value chain of raw materials from a geological perspective.

Izvedli so delavnice in dogodke:

- Geologija okoli nas? : naravoslovni dan za 9. razrede OŠ Železniki, 20. 10. 2022, OŠ Železniki.
- Termalna voda: geološko-geotermalne delavnice za učence petih razredov OŠ Stična, 13. 9. 2022, Terme Čatež.
- Termalna voda: geološko-geotermalne delavnice za učence petih razredov OŠ Zagradec, 22. 9. 2022, Terme Čatež.

Ter izobraževanja:

- Interaktivno poučevanje in učenje o mineralih in kamninah v učilnici in naravi: geološke vsebine v obstoječih učnih načrtih: učni pripomočki in geološke učne zbirke: prepoznavanje glavnih kamninotvornih mineralov z uporabo interaktivnih učil in učnih pripomočkov: PPU: Programi profesionalnega usposabljanja.
- Interaktivno poučevanje in učenje o mineralih in kamninah v učilnici in naravi: prepoznavanje glavnih kamninotvornih mineralov z uporabo interaktivnih učil in učnih pripomočkov: PPU: Programi profesionalnega usposabljanja.

Člani sekcije za geokemijo so v preteklem letu nadaljevali z delom začrtanim že v preteklih letih. Še vedno je v ospredju geokemija okolja. Raziskujejo kemične procese, vsebnosti in porazdelitve na zemeljskem površju, torej v našem okolju.

S podatki, ki jih pridobijo s študijami, prepoznavajo različne geokemične razmere in tista okolja, ki so obremenjena. Še posebno jih zanimajo tista, ki so obremenjena predvsem zaradi človekovih dejavnosti, ki so se dogajale v preteklosti ali se dogajajo danes. Raziskujejo torej spremembe v okolju zaradi vpliva antropogenizacije. Na 6. slovenskem geološkem kongresu je bila geokemija zelo dobro zastopana, v sekciji geokemija okolja smo poslušali kar 10 predavanj.

Stratigrafska komisija je začela z izdelavo tabelaričnega pregleda slovenskih litostratigrafskih enot, ki bo tvoril osnovo za nadaljnje kritično vrednotenje obstoječe litostratigrafske razdelitve in njeno reambulacijo.

Slovensko geološko društvo, kot član Evropske zveze, je v letu 2022 sodeloval v petih evropskih projektih Obzorje 2020 (Horizon 2020).

Nadaljevale in zaključile so se aktivnosti na projektu ENGIE – vzpodbujanje deklet za izbiro poklica geoznanstvenice (Empowering Girls to become the geoscientists of tomorrow). V okviru projekta ENGIE smo v letu 2022 sodelovali na treh delovnih paketih. Organizirali smo več dejavnosti; terenske dneve, znanstvene klube in dneve odprtih vrat. Na dogodkih je bilo udeleženih več kot 500 udeležencev. Sodelovali smo z aktivnostmi na Evropski noči raziskovalcev. Dejavnosti projekta ENGIE smo izvajali v okviru projekta Humanities rocks!, kjer je bila tema dejavnosti »Žival v človeku«. Namen aktivnosti Žival in človek je bil predstaviti evolucijsko zgodovino človeškega telesa, značilnosti določenih organov in s pomočjo multisenzorične izkušnje razumeti njihove funkcije. Za delavnico je izdelana brošura, plakat in različni izzivi. V slovenski jezik sta bila prevedena tudi publikacija GEAS Ženske, ki proučujejo Zemljo (izvirnik v španščini GEAS Mujeres que estudian la Tierra). Publikacija bo izdana elektronsko, predvidena pa je tudi tiskana verzija (GEAS: Women who study the Earth - ENGIE Project). Projekt je se zaključil 31. 12. 2022.

Projekt CROWDTHERMAL – Sodelovanje družbe pri razvoju geotermalnih projektov z uporabo alternativnih virov financiranja (Community-based development schems for geothermal energy) je trajal od septembra 2019 do decembra 2022. Cilj projekta je spodbujati družbo pri neposrednem sodelovanju v geotermalnih projektih s pomočjo alternativnih finančnih shem in drugih orodij za vključevanja družbe. Zato smo se v letu 2022 udeležili nekaj spletnih seminarjev, pripravili več obvestil o napredku projekta, sodelovali v anketi za izboljšanje uporabniške izkušnje pri rabi Core service projekta (https://www.crowdthermalproject.eu/crowdthermal-core-services/) ter pregledali objavljena gradiva. Nova Core service storitev naj bi predstavljala enotno vstopno točko za povpraševanje o povečanju moči v geotermalnih projektih preko financiranja skupnosti alternativnega financiranja, vključevanja družbe in zmanjševanja tveganj pri geotermalnih projektih, ki vključujejo okoljske študije, upoštevanje ekonomskih vidikov, zmanjševanje finančnega tveganja in vključevanje dejavnika družbenega sprejemanja. Obsega Drevo odločanja, Interaktivni vodnik za integrirano financiranje geotermalne energije, Orodja za oceno in blažitev tveganj, Izvedbeni okvir za razvoj geotermalne energije v skupnosti, Podatkovni katalog za samostojno učenje, Pogosta vprašanja in Meta-podatkovno bazo geotermalnih projektov. Projekt se je zaključil v letu 2022.

V sklopu aktivnosti na projektu ROBOMINERS – Razvoj bio-navdihnjenega robotskega rudarja (Resilient Bio-Inspired Modular Robotic Miner) je bil narejen prevod tretjega obvestila za javnost (https://www.slovenskogeoloskodrustvo.si/images/pdf_dokumenti/Projektna_dok/20220612_ROBOMINERS_PR3_May_2022_final_SLO_prevod.pdf) z naslovom »Raziskovalci pri projektu ROBOMINERS so testirali prototip robota za izkoriščanje mineralnih surovin z majhnih ali težko dostopnih nahajališč».

V letu 2023 se bodo diseminacijske aktivnosti nadaljevale – obveščanje slovenske javnosti o poteku projekta, prevodi obvestil za javnost in posredovanje vseh obvestil; aktivnosti bo več, saj se projekt v letu 2023 zaključil.

Projekt REFLECT - Redefiniranje lastnosti geotermalnih tekočin v ekstremnih pogojih (Redifining geothermal fluid properties at exreme conditions to optimiza future geothermal energy extraction) je bil podaljšan do junija 2023. Cilj projekta REFLECT je preprečiti težave povezane s kemijo geotermalnih tekočin še preden nastanejo, tako v geosferi, vrtini in sestavnimi deli sistemov rabe toplote (izmenjevalci in elektrarne). Zato je bil v 2022 objavljen Evropski atlas geotermalnih tekočin v različnih naravnih sistemih (https://www.reflect-h2020.eu/efa/) in objavljeno novo orodje za geokemično modeliranje (porousMedia4Foam) ter priporočila za preprečevanje obratovalnih težav. V letu 2022 smo se udeležili in promovirali več spletnih seminarjev, dopolnili smo podatke za Slovenijo za podatkovno bazo ter na petem IAG-CEG Kongresu v Rogaški Slatini predstavili poster European Geothermal Fluid Atlas elaborated within the project REFLECT.

V letu 2023 načrtujemo nadaljnjo diseminacijo rezultatov.

CRM-geothermal – Surovine iz geotermalnih fluidov: Pojav, obogatitev in pridobivanje projekt se izvaja od julija 2022 in bo potekal do maja 2027. V novembru 2022 smo šele pristopili k projektu, zato se vsebinske aktivnosti še niso izvajale. Projekt CRM-GEOTHERMAL se ukvarja z razvojem inovativne tehnološke rešitve, ki združuje pridobivanje kritičnih surovin in energije iz geotermalnih tekočin. Ta bo pomagala Evropi izpolniti strateške cilje Zelenega dogovora EU in Agende za trajnostni razvoj, hkrati pa zmanjšala odvisnost od uvoženih CRM-jev. Kombinirano pridobivanje toplote in mineralov iz geotermalnih rezervoarjev ponuja vrsto prednosti: maksimiranje donosnosti naložbe, minimaliziranje vpliva na okolje, izogibanje dodatni rabi zemljišč, ne pušča rudarske dediščine, dosega skoraj ničelni ogljični odtis in omogoča domačo dobavo kritičnih surovin. Naša naloga bo predvsem zagotoviti podatke o potencialu geotermalnih tekočin v Sloveniji.

V letu 2023 načrtujemo udeležbo na spletnih sestankih in seminarjih, izpolnitev vprašalnikov o sprejemanju javnosti za geotermalne in rudarske projekte, pripravo seznama deležnikov in diseminacijo projektnih aktivnosti in rezultatov.

V sklopu Slovenskega geološkega društva deluje Slovenski nacionalni odbor INQUA (SINQUA), ki povezuje raziskovalce kvartarja ter skrbi za pretok informacij med slovensko in mednarodno kvartarno znanstveno sfero. Glavni cilj je napredek na področju kvartarnih znanosti, pri čemer si prizadevamo za interdisciplinarno zastopanost članov in večje medsebojno sodelovanje. Vpeti smo v aktivnosti INQUA komisij in fokusnih skupin, sodelujemo pri organizaciji znanstvenih srečanj in delavnic.

V letu 2022 smo sodelovali v aktivnostih INQUA komisij in fokusnih skupin. Predstavnik SINQUA je sodeloval na spletnih sestankih, volitvah in pri odločanju mednarodnega Sveta INQUA. Kot člani INQUA smo nadaljevali sodelovanje pri oblikovanju skupnih aktivnosti v okviru različnih komisij. Člani SINQUA smo vpeti v aktivnosti komisij CMP (Coastal and Marine Processes), PALCOM (Paleoclimates), SACCOM (Stratigraphy and Chronology) in TERPRO (Terrestrial Processes, Deposits and History).

Člani so sodelovali pri organizaciji »XXI Congress of the International union for Quaternary Research ”Time for Change”[1]«, ki se bo odvijal julija 2023 v Rimu. Člana SINQUA sta bila vpeta v »Scientific Advisory Committee«, dve članici sta sodelovali pri predlogu dveh sekcij »Millennial paleo-landscape reconstructions of coastal areas - From field data to modelling approaches« ter »Quaternary Mediterranean Glaciers«, več članov je skupaj prijavilo dve kongresni ekskurziji: »Life with geohazard at the contact of the Alps, the Dinarides and the Pannonian Basin« in »Quaternary archives in the Northeastern Adriatic karst environments«. Sodelovali so tudi pri pripravi vsebin za INQUA novičnik »Quaternary Perspectives«[2].

V okviru CMP komisije so v 2022 nadaljevali z vodenjem aktivnosti v okviru štiriletnega projekta NEPTUNE[3], kjer članica SINQUA sodeluje kot ena od vodij projekta. V okviru projekta so v 2022 izvedli serijo šestih mesečnih spletnih seminarjev „NEPTUNE talks“, kjer so uveljavljeni znanstveniki predavali na temo spreminjanja morskih in priobalnih okolij. V septembru so v Neaplju izvedli 3. NEPTUNE srečanje s številčno mednarodni udeležbo. Novembra so izdali dvojno posebno številko INQUA znanstvene revije »Quaternary International«[4], kjer so uspeli zbrati 15 izvirnih znanstvenih člankov na temo poznopleistocenskih sprememb obalnih in priobalnih okolij. Prijavili so NEPTUNE sekcijo za kongres v Rimu, na katero je bilo prijavljenih preko 40 povzetkov.

Člani SINQUA so pripravljali posebno številko revije »Quaternary« z naslovom »Seas, Lakes and Rivers in the Adriatic, Alpine, Dinaric and Pannonian Regions during the Quaternary: Selected Papers from “6th RMQG”«[5], ki je sledila mednarodnemu znanstvenemu srečanju v organizaciji SINQUA s partnerji v predhodnem letu in bo zaključena v letu 2023.

V letu 2023 bodo nadaljevali sodelovanje pri organizaciji INQUA kongresa v Rimu, izvedli vodenje dveh prijavljenih sekcij in predkongresnih ekskurzij ter se v večjem številu udeležili kongresa. Udeleževali se bodo tudi ostalih znanstvenih srečanj in delavnic v organizaciji INQUA in njenih fokusnih skupin. Namen imajo organizirati in izvesti 2. SINQUA srečanje. Zaključili bodo pripravo posebne številke »Quaternary«.

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1 Spletna stran INQUA kongresa: https://inquaroma2023.org/

2 Spletna stran novičnika »Quaternary Perspectives«: https://www.inqua.org/publications/quaternary-perspectives

3 Spletna stran projekta NEPTUNE: http://dist.altervista.org/neptune/index.html

4 Spletna stran posebne številke »Quaternary International«: https://www.sciencedirect.com/journal/quaternary-international/vol/638/suppl/C

5 Spletna stran posebne številke »Quaternary«: https://www.mdpi.com/journal/quaternary/special_issues/6th_RMQG

Na pobudo ProGEO – The European Association for the Conservation of the Geological Heritage je UNESCO določil 6. oktober za mednarodni dan geopestrosti. Slovensko geološko društvo je v sodelovanju s ProGEO in ob koordinaciji Zavoda Republike Slovenije za varstvo narave izvedlo obeležitev prvega mednarodnega dneva geopestrosti in sodelovanje v projektu UNESCO 737 SMART GEOLOGY.

EMU in IMA – European Mineralogical Union in International Mineralogical Association. V preteklem letu je bila med 20 in 24 junijem v okviru EMU v Torinu organizirana šola z naslovom „Minerals in wastes“. Mednarodna šola EMU o mineralnih sestavinah odpadkov, njihovi karakterizaciji, predelavi in ravnanju. Dogodek je bil delno financiran, a žal ni bilo odziva pri študentih.

V letu 2023 se študentom sofinancira obisk na Goldschmidt konferenci v Lyonu v primeru aktivne udeležbe na konferenci.

V letu 2022 je Slovensko geološko društvo štelo 91 članov. Članarino za leto 2022 smo povečali, tako je sedaj za člane 20 evrov, za študente pa 10 evrov. Vabljeni, da podaljšate članstvo oziroma postanete član.

Poročilo o drugi mednarodni poletni geotermalni šoli v Ljubljani, 3.–8. julij 2023

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Večja raba geotermalne energije in hitrejša vpeljava inovativnih tehničnih rešitev za postavitev sistemov rabe plitve geotermije, termalne vode ali geotermalnih elektrarn je možna le z ustreznim prenosom znanja, ki zajema tudi formalno izobraževanje. Na Oddelku za geologijo Naravoslovnotehniške fakultete Univerze v Ljubljani (NTF UL) smo v okviru predmeta Termogeologija na magistrski stopnji že drugič organizirali mednarodno poletno geotermalno šolo, tokrat z naslovom »Napredki pri razvoju rabe geotermalne energije za ogrevanje, hlajenje in proizvodnjo elektrike«. Potekala je med 3. in 8. julijem 2023 v Ljubljani v organizaciji Geološkega zavoda Slovenije (GeoZS) in Naravoslovnotehniške fakultete s podporo Islandske šole za energijo iz Reykjavika ter sofinanciranjem s projektov INFO-GEOTHERMAL ter Geothermal-DHC.

Na dogodku je sodelovalo deset predavateljev iz sedmih držav: prof. dr. Mihael Brenčič (NTF UL, Slovenija), doc. dr. Nina Rman (GeoZS, Slovenija), dr. Hrvoje Dorotić (Energetski institut Hrvoje Požar, Hrvaška), izr. prof. María Sigríður Guðjónsdóttir (Reykjavik University, Islandija), dr. Juliet Newson (Iceland School of Energy, Islandija), dr. Bjarni Palsson (Landsvirkjun, Islandija), prof. dr. Rao Martand Singh (Norwegian University of Science and Technology, Norveška), doc. dr. Alexandros Daniilidis (Delft University of Technology, Nizozemska), Jeff Birkby (Hot Springs Association, ZDA) in Nicholas Fry (University of Calgary, Kanada).

Sodelujoče smo seznanili z načini razvoja novih geotermalnih projektov, z dobro prakso raziskav, tehnologijo rabe in načini upravljanja s plitvo geotermalno energijo ter rabo termalne vode in pare. V predavanjih je bila pozornost posvečena tudi možnostim optimizacije delovanja z namenom, da je vpliv rabe geotermalnih sistemov na okolje in človeka čim manjši in dolgoročno sprejemljiv. Poleg predavanj na NTF UL je v torek potekala ekskurzija v severovzhodno Slovenijo, kjer smo obiskali proizvodnjo toplotnih črpalk KRONOTERM v Trnavi; sistem daljinskega ogrevanja Lendave z geotermalnim dubletom v upravljanju Petrol d.d.; sedež Petrol Geo d.o.o. in opuščeno plinsko vrtino Pg-8, na kateri Dravske elektrarne Maribor, Petrol Geo d.o.o., Univerza v Mariboru in GeoZS v okviru projekta Si-Geo-Electricity testirata pilotno geotermično elektrarno; geotermalne vrtine in sistem kaskadne rabe termalne vode v Termah 3000 Moravske Toplice. Ob povratku v Ljubljano smo si ogledali vrtanje geosond za ogrevanje Dijaškega doma Vič v izvedbi podjetja Vrtine Palir d.o.o. V četrtek 6. julija so na GeoZS potekale terenske vaje s prikazom uporabe karotažne opreme, meritev gladine in določanja fizikalno-kemijskih lastnosti podzemne vode, geotermalnega in hidrogeološkega laboratorija ter opreme za izvajanje testa toplotnega odziva tal (TRT). Na Agenciji RS za okolje so nam predstavili državno mrežo spremljanja kemijskega in količinskega stanja podzemne vode. Vsi udeleženci so na študentski konferenci predstavili svoje delo - knjiga povzetkov je dostopna na spletu https://www.geo-zs.si/?option=com_content&view=article&id=1119, sodelovali pri izvedbi projektnega dela in opravili izpit za pridobitev 3 kreditnih (ECTS) točk.

Program je uspešno zaključilo 24 udeležencev, od tega 18 študentov (1 diplomskega študija, 7 magistrskega in 10 doktorskega študija) ter 6 mlajših zaposlenih. Predstavnic ženskega spola je bilo 11, kar znaša le nekaj manj kot polovico vseh udeležencev. Udeleženci so prihajali iz 15 držav: Egipta, Francije, Hrvaške, Indije, Indonezije, Italije, Kanade, Kitajske, Kameruna, Libanona, Madžarske, Nepala, Pakistana, Poljske in Slovenije. Približno petina izhaja iz področij energetike, strojništva in gradbeništva.

V anketi zadovoljstva so prav vsi udeleženci potrdili, da bodo priporočili sodelovanje na mednarodni poletni šoli svojim kolegom. Priporočili so več vsebin o tehnologiji rabe in klimatizaciji, skladiščenju energije, numeričnem modeliranju in uporabi znanja na praktičnih primerih.

Naslednjo mednarodno poletno geotermalno šolo načrtujemo čez dve leti, poleti 2025.

Zahvala

Poletna šola je bila organizirana in financirana v okviru več projektov. Projekt INFO-GEOTHERMAL -Podpiranje učinkovite kaskadne uporabe geotermalne energije z dostopom do uradnih in javnih informacij financirajo Islandija, Lihtenštajn in Norveška s sredstvi Finančnega mehanizma Evropskega gospodarskega prostora (EGP) 2014-2021 v višini 1.073.529,41 €. Projekt COST Action CA18219 Geothermal-DHC - Raziskovalna mreža za vključitev geotermalne tehnologije v sisteme razogljičenja ogrevanja in hlajenja je podprt s strani programa Obzorje 2020 oziroma COST European Cooperation in Science and Technology. Del aktivnosti je bil podprt z delom v okviru ARIS programske skupine P1-0020 Podzemne vode in geokemija.

Sl. 1. Terenske vaje z meritvami v vrtini v Ljubljani.

Sl. 2. Udeleženci poletne šole na ekskurziji pri vrtini Pg-8.

Slovesnost ob 70-letnici izhajanja revije Geologija

Urška ŠOLC

Geološki zavod Slovenije, Dimičeva ulica 14, SI–1000 Ljubljana, Slovenija; e-mail: urska.solc@geo-zs.si

Geološki zavod Slovenije, izdajatelj revije Geologija in uredništvo revije sta organizirala slovesnost ob 70 letnici izhajanja revije. Dogodek je potekal v petek, 29. septembra 2023 v Cankarjevem domu v Ljubljani. Slovesnost je bila posvečena pomenu revije Geologija za razvoj geoznanosti v Sloveniji in tudi splošnemu pomenu znanstvenih revij za razvoj znanstvenega okolja.

V uvodnem nagovoru je direktor Geološkega zavoda Slovenije, dr. Miloš Bavec, spregovoril o pomenu revije za razvoj geoznanosti in za uveljavljanje slovenskih raziskovalcev na tem področju.

Pogled uglednega raziskovalca in profesorja o pomenu znanstvene periodike za napredek znanosti, družbe in posameznika je z udeleženci slovesnosti delil predsednik Znanstvenega sveta Javne agencije za znanstvenoraziskovalno in inovacijsko dejavnost Republike Slovenije, akademik, prof. dr. Peter Križan, ki je v svojem nagovoru poudaril, da so znanstvene revije temeljna sestavina raziskovalnega ekosistema in nadvse pomembne za razširjanje znanja, preverjanje kakovosti in verodostojnosti informacij ter povezovanje znanstvenikov.

Glavna in odgovorna urednica revije Geologija dr. Mateja Gosar nas je v svojem govoru popeljala prek sedem desetletij dolgo zgodovino revije Geologija. Prvo obdobje izhajanja revije je bilo zaznamovano z obdobjem po drugi svetovni vojni, ko so bile potrebe po mineralnih surovinah precejšnje in je bila želja po surovinski samozadostnosti velika. Zato so v začetnem obdobju objavljali večinoma dela o raziskovanju nahajališč mineralnih surovin. V kasnejšem obdobju vsebine člankov v Geologiji pokrivajo področja regionalne geologije, stratigrafije, geomorfologije, paleontologije, sedimentologije, petrologije, mineralogije, mineralnih surovin, geofizike, seizmologije, hidrogeologije, geokemije okolja, geološko pogojenih nevarnosti in drugih tem s področja znanosti o Zemlji.

Poudarila je, da je objavljanje v znanosti nujno potrebno saj z objavo raziskovalnemu okolju omogočimo, da presodi znanstveno vrednost objavljenih raziskav. Opozorila je, da so se tudi motivi za objavljanje člankov skozi zgodovino spreminjali. Prvotno je bila osnovna želja predstaviti rezultate lastnega izvirnega raziskovalnega dela drugim raziskovalcem ali narediti pregled raziskav določene teme. V novejšem času so prišli v ospredje tudi drugi motivi, kot na primer pridobiti izkušnje pri pisanju člankov, interes za razvoj znanstvenega področja in izpolnitev raznovrstnih pogojev. Povedala je, da so v zadnjih desetih letih med avtorji prevladovali zaposleni na Univerzi v Ljubljani in na Geološkem zavodu Slovenije. Zahvalila se je pregledovalcem, ki vestno opravljajo recenzije in poudarila njihov izjemen pomen pri ustvarjanju kvalitetne revije.

V zaključnem delu nagovora je poudarila pomen celotne raziskovalne skupnosti področja geoznanosti za dobro delovanje revije, saj je dela, ki ga je potrebno opraviti veliko. Izjemno pomembno je tako dobro delovanje uredništva, kot tudi vloga avtorjev in recenzentov, brez katerih revija ne more obstajati. Pozvala je vse zbrane, da naj v bodoče še bolj intenzivno sodelujejo z revijo v vseh naštetih vlogah.

Uredništvo revije Geologija je na slovesnosti podelilo priznanja izjemnim posameznikom, ki so s svojim delom v zadnjih desetih letih prispevali k razvoju revije in geološke znanosti:

- red. prof. dr. Mihaelu Brenčiču za najaktivnejšega člana uredniškega odbora
- doc. dr. Luki Galetu za najaktivnejšega avtorja
- dr. Poloni Vreča, prvi avtorici največkrat citiranega članka objavljenega v reviji Geologija v podatkovni zbirki Scopus.

Izdajatelj revije Geologija Geološki zavod Slovenije je na slovesnosti podelil zahvale sodelavkam in sodelavcem, ki so dnevno vpeti v uredniško delo in so najbolj zaslužni, da revija redno izhaja in se neprestano razvija:

- dr. Mateji Gosar za odlično vodenje uredništva in predanost razvoju revije Geologija
- ga. Bernardi Bole za skrbno, vestno in uspešno delo tehnične urednice revije Geologija
- ga. Vidi Pavlica za oblikovanje revije Geologija
- g. Maksu Šinigoju za tehnično podporo pri digitalizaciji in indeksaciji arhivskih izvodov revije Geologija.

Foto: Arhiv GeoZS

European Geosciences Student Network meeting in Slovenia, Avgust 2023, Zavrh pri Borovnici

Valentina PEZDIR[1], Teja POLENŠEK[2], Jernej LOBODA[2], Luna GRUM VERDINEK[3], Sebastian FARISELLI[4], Marko ŠTERN[5], Lea DVORŠČAK[6] & Anže TESOVNIK[7]

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This year we organized the 26th European Geosciences Student Network (EUGEN) meeting from 7 – 13th of August in Zavrh pri Borovnici.

Originally, the EUGEN was to happen in Ljubno ob Savinji. During the last year we were preparing for the event and spent a productive weekend at the Kamp na Otoku in Ljubno ob Savinji. Previous two EUGEN meetings in Slovenia happened in 2003 and 2014, both located in western Slovenia. Therefore, we focused on eastern Slovenia, where we prepared field trips to present mining in this part of Slovenia, igneous and metamorphic rocks of Pohorje massive, as well as karst geology and geomorphology in Logar valley and Snežna cave.

Unfortunately, due to the heavy flooding in the beginning of August we had to change locations on very short notice. With great help of the local fire department (PGD Zavrh, Pokojišče, Padež) we moved to Zavrh pri Borovnici. With quick thinking we provided and arranged food, drinks and transport. With help from field trip organizers there was also no lack of interesting and diverse field trips, more focused on the Central Slovenia.

Even with news of the floods spreading to other countries, there were still more than 90 participants from 16 different countries (Austria, Croatia, Finland, France, Germany, Great Britain, Italy, Luxemburg, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland).

During the week we organized three field trip days with total of six different topics. The participants had the option to learn about the local geology of Borovnica and its surroundings and paleontology of central Slovenia, as they visited outcrops

Fig. 1. Palaeontology field trip.

for the Toarcian anoxic event. They also had the option to learn about the tunnel construction sites in Slovenia and flysch deposits as part of the field trip to the Slovenian coast. To learn more about the karst in Slovenia, we visited a karst cave (Križna jama), followed by a visit to Cerknica lake. As mining is an important part of Slovenian heritage, we organized visits to Sitarjevec mine and Velenje coal mine. Additionally, the participants learned more about geothermal water in Slovenia and operation of the Slovenian thermal baths in Dobrna. We also visited the Ljubljana Marshes nature park. Many researchers and professors from the Faculty of Natural Sciences and Engineering and the Geological Survey of Slovenia (GeoZS) showed great help in performing and execution Geological Survey of Slovenia (GeoZS) showed great help in performing and executing the field trips.

During the week, various lectures were held in the evenings, where the participants learned about the geology of the whole of Slovenia, the operation of GeoZS and PhD Baltic Teach project. The participants also had the opportunity to participate and present their works in the field of geology. We had the opportunity to learn about *Kyrgyzstan summer school* and *Diagenesis, porosity and reservoir potential of the Karchowice and Diplopora Beds in Upper Silesia*. As part of the last lecture, EUGEN e.V. presented their organization and their international cooperation.

Of course, there was no shortage of fun during EUGEN's time. Wednesday was dedicated to the Geolympic games, where participants get to mingle and compete with each other. On Saturday 12.8. we concluded the event with a cultural and geological tour of Ljubljana.

Even though we struggled with reorganization of the event, facing the possibility of cancelation, we managed to organize a successful event, that attracted many new student participants from all over Europe. At the end of EUGEN week, the participants decided that the 27th EUGEN meeting in 2024 will happen in France.

The event was sponsored by IRGO Consulting d.o.o., Geological Survey of Slovenia, Bo-Ratec GmbH, Javno podjetje Vodovod Kanalizacija Snaga d.o.o., Združeni NTF, Slovensko geološko društvo, Študentski svet Naravoslovnotehniške fakultete, GIH, geologija in hidrogeologija, Judita Črepinšek s.p. and Pharsol d.o.o.

Fig. 2. Participants of EUGEN 2023 (photo: Jernej Loboda).

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