GEOLOGIJA

2018 | št.: **61/1**

GeoZS
Geološki zavod
Slovenije

ISSN
Tiskana izdaja / Print edition: 0016-7789
Spletna izdaja / Online edition: 1854-620X

GEOLOGIJA

61/1 – 2018

GeoZS
Geološki zavod Slovenije

GEOLOGIJA	2018	61/1	1-125	Ljubljana

GEOLOGIJA
ISSN 0016-7789

Izdajatelj: Geološki zavod Slovenije, zanj direktor Miloš Bavec
Publisher: Geological Survey of Slovenia, represented by Director Miloš Bavec
Financirata Javna agencija za raziskovalno dejavnost Republike Slovenije in Geološki zavod Slovenije
Financed by the Slovenian Research Agency and the Geological Survey of Slovenia

Vsebina številke 61/1 je bila sprejeta na seji Uredniškega odbora, dne 18. 7. 2018.
Manuscripts of the Volume 61/1 accepted by Editorial and Scientific Advisory Board on July 18, 2018.

Naslov uredništva / Editorial Office: GEOLOGIJA Geološki zavod Slovenije / Geological Survey of Slovenia
Dimičeva ulica 14, SI-1000 Ljubljana, Slovenija
Tel.: +386 (01) 2809-700, Fax: +386 (01) 2809-753, e-mail: urednik@geologija-revija.si
URL: http://www.geologija-revija.si/

GEOLOGIJA izhaja dvakrat letno. / GEOLOGIJA is published two times a year.
GEOLOGIJA je na voljo tudi preko medknjižnične izmenjave publikacij. /
GEOLOGIJA is available also on exchange basis.

Izjava o etičnosti

Izdajatelji revije Geologija se zavedamo dejstva, da so se z naglim naraščanjem števila objav v svetovni znanstveni literaturi razmahnili tudi poskusi plagiatorstva, zlorab in prevar. Menimo, da je naša naloga, da se po svojih močeh borimo proti tem pojavom, zato v celoti sledimo etičnim smernicam in standardom, ki jih je razvil odbor COPE (Committee for Publication Ethics).

Publication Ethics Statement

As the publisher of Geologija, we are aware of the fact that with growing number of published titles also the problem of plagiarism, fraud and misconduct is becoming more severe in scientific publishing. We have, therefore, committed to support ethical publication and have fully endorsed the guidelines and standards developed by COPE (Committee on Publication Ethics).

Baze, v katerih je Geologija indeksirana / Indexation bases of Geologija: Scopus, Directory of Open Access Journals, GeoRef, Zoological Record, Geoscience e- Journals, EBSCOhost

Cena / Price

Posamezni izvod / Single Issue	Letna naročnina / Annual Subscription
Posameznik / Individual: 15 €	Posameznik / Individual: 25 €
Institucija / Institutional: 25 €	Institucija / Institutional: 40 €

Tisk / Printed by: GRAFIKA GRACER d.o.o.

Slika na naslovni strani: Sotočje Soče (levo) in Idrijce (desno) pri Mostu na Soči v času izpraznitve akumulacijskega jezera v začetku leta 2018. Jezero je bilo izpraznjeno prvič po 18 letih zaradi vzdrževalnih del na zapornicah in odstranjevanja dela sedimenta. (foto: J. Šimon)

Cover page: Confluence of Soča (left) and Idrijca (right) rivers in Most na Soči during emptied accumulation lake at the beginning of the year 2018. The lake was discharged due to maintenance works on locks and removal of part of the sediment. (photo: J. Šimon)

VSEBINA – CONTENTS

GEOLOGIJA *61/1*, 5-24, Ljubljana 2018

https://doi.org/10.5474/geologija.2018.001

Vsebnosti arzena in nekaterih drugih prvin v potočnih sedimentih in vodah porečja Medije, osrednja Slovenija

Contents of arsenic and some other elements in stream sediments and waters of the Medija drainage basin, central Slovenia

Tamara TERŠIČ, Miloš MILER, Martin GABERŠEK & Mateja GOSAR

Geološki zavod Slovenije, Dimičeva ulica 14, SI–1000 Ljubljana, Slovenija
e-mail: tamara.tersic@geo-zs.si; milos.miler@geo-zs.si; martin.gabersek@geo-zs.si; mateja.gosar@geo-zs.si

Prejeto / Received 10. 1. 2018; Sprejeto / Accepted 12. 4. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Ključne besede: sedimenti, vode, arzen, antimon, vplivi rudarjenja, Kotredeščica, Medija
Key words: sediments, waters, arsenic, antimony, mining impacts, Kotredeščica, Medija

Izvleček

V Znojilah, severno od vasi Kotredež, je v prvi polovici 20. stoletja deloval manjši rudnik antimonita. Po poplavah v letih 1994 in 2010, ko je vsakič odplavilo del materiala iz odlagališča rudarskih odpadkov, se je zvrstilo več raziskav obremenjenosti tal in rastlin na območju občine Zagorje ob Savi. Ugotovili so, da je območje doline Kotredeščice med naselji Rove in Znojile obremenjeno z arzenom. V letu 2017 smo v dolini Kotredeščice in Medije na 13 lokacijah vzorčili rečne sedimente in vode, da bi ugotovili vire povišanih vsebnosti arzena in antimona ter morebitne povišane vsebnosti drugih 10 obravnavanih prvin. Sedem vzorcev je bilo odvzetih iz Kotredeščice, 2 vzorca iz Orehovice, 4 vzorci pa iz Medije. Analiza je pokazala, da vsebnosti obravnavanih prvin, z izjemo As in Sb, niso povišane. Ugotovljena mediana za As v vzorcih sedimenta znaša 29,5 mg/kg. Vsebnost As v sedimentih je najvišja v zgornjem toku Kotredeščice in upada po toku navzdol. Ugotovljena mediana za Sb v sedimentih znaša 6,4 mg/kg. Najvišje vsebnosti Sb so v sedimentih zgornjega toka Kotredeščice ter Orehovice. V vodi znaša mediana za As 0,85 µg/l, za Sb pa 2,39 µg/l. Najvišje koncentracije v vodi so bile izmerjene v Kotredeščici. S SEM/EDS analizo sedimentov smo ugotovili, da se As večinoma pojavlja v obliki železovih oksihidroksi sulfatov z manjšimi vsebnostmi As in v manjši meri kot mineral arzenopirit. Sb je vezan v nekoliko porozna mineralna zrna antimonita. Sklepamo, da so ugotovljene povišane vsebnosti As in Sb v sedimentih in vodah posledica spiranja in raztapljanja materiala iz odlagališč rudarskih odpadkov in tudi povišanega naravnega ozadja za As in Sb na tem območju, ki je posledica naravnih rudnih pojavov antimonita.

Abstract

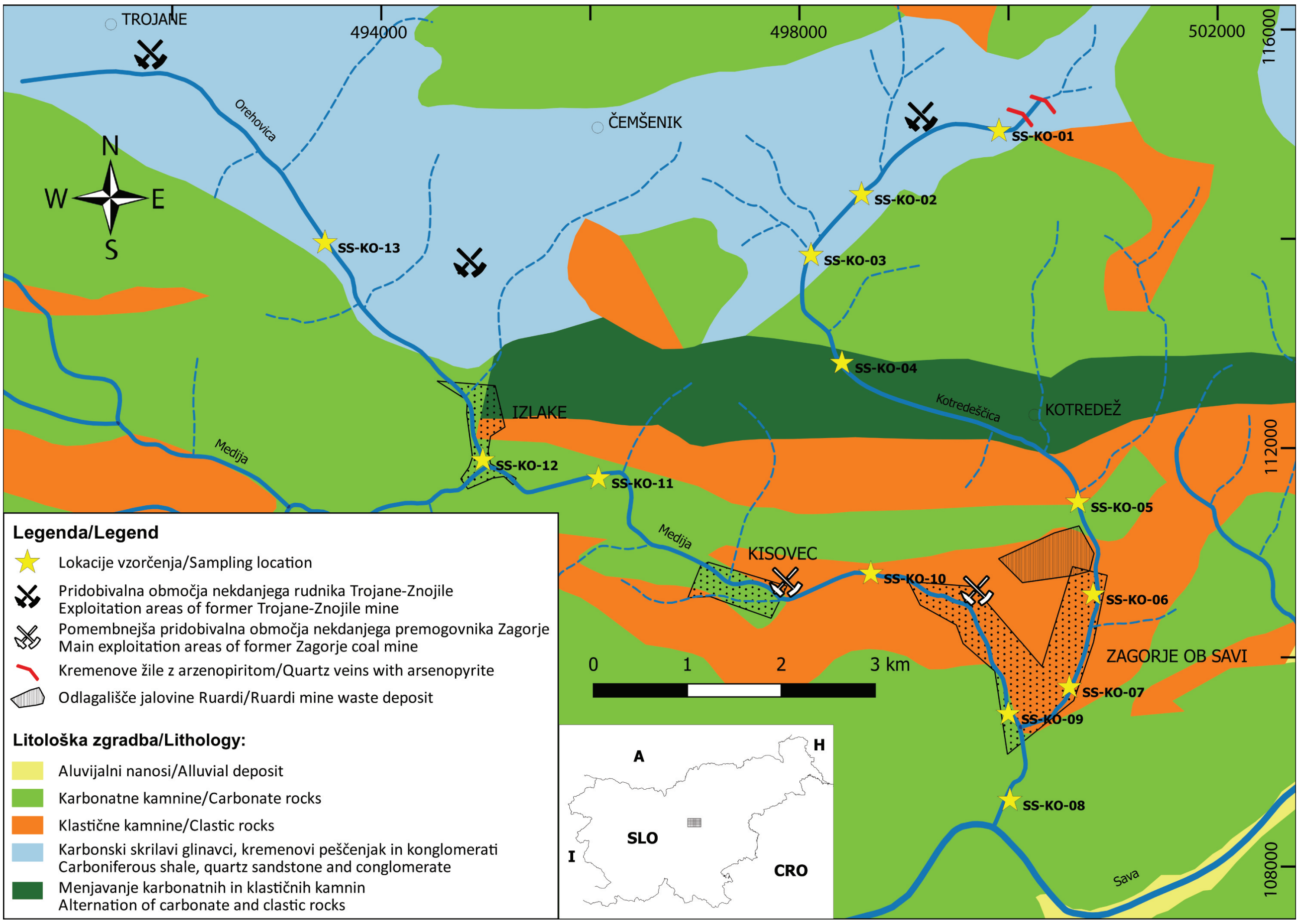
In Znojile, north of the Kotredež village, a small antimonite mine was operating in the first half of the 20th century. After flooding in 1994 and 2010, when part of the material from the mine waste deposit was washed away, a number of investigations on soil and plants contamination in the area of Zagorje ob Savi municipality were carried on. It was established that the area of Kotredeščica valley, between Rove and Znojile settlements, is enriched with arsenic. In 2017 river sediments and water at 13 locations in Kotredeščica and Medija valleys were sampled in order to establish the sources of increased arsenic and antimony contents. 7 samples were taken from Kotredeščica, 2 samples from Orehovica and 4 samples from Medija. The determined median for As in sediment samples is 29.5 mg/kg. As contents are the highest in the upper course of Kotredeščica and decrease downstream. The established median for Sb in sediment samples is 6.4 mg/kg. The highest contents were determined in the sediments in the upper course of Kotredeščica and in Orehovica. In water samples the determined medians for As and Sb are 0.85 µg/l and 2.39 µg/l respectively, the highest concentrations were measured in Kotredeščica. With SEM/EDS analysis of sediments it was established that As is mostly present in the form of iron oxyhydroxy sulphates with smaller amounts of As and to a lesser extent in the form of mineral arsenopyrite. Sb is bound to somewhat porous mineral grains of antimonite. We assume that increased As and Sb contents in sediments and waters are the consequence of washing out and dissolution of the material from mine waste deposits as well as the increased natural background for As and Sb in this area, which is the consequence of the natural ore occurrences.

Uvod

Na območju doline potoka Kotredeščica, severno od Zagorja ob Savi, se v zadnjih letih pojavljajo domneve o onesnaženju okolja z arzenom. Kotredeščica je levi pritok potoka Medija, ki teče skozi Zagorje ob Savi in se kot levi pritok izliva v reko Savo. Kotredeščica teče skozi vas Kotredež, kjer se ji pridruži potok Potočnica, kasneje pa še potok Konjščica. V Medijo se izliva v Zagorju ob Savi.

Povišane vsebnosti arzena v okolju so lahko posledica naravnih in/ali antropogenih virov. Med pomembnejše antropogene vire spadajo izpusti topilnic, izgorevanje fosilnih goriv in uporaba pesticidov. Strupenost arzena je odvisna od kemijske zvrsti. Anorgansko vezan arzen je bolj strupen. Povezujejo ga s povečanim tveganjem za raka kože in pljuč (Cegnar et al., 2016). Pomemben vir težkih kovin v Zasavju je v preteklih letih predstavljalo zgorevanje premoga v termoelektrarni Trbovlje (TET). Pri zgorevanju premoga se sproščajo predvsem arzen, molibden, živo srebro, selen in antimon (Nriagu, 1989). Raziskave onesnaženosti okolja v Zasavju (Ribarič-Lasnik, 2001) so pokazale, da so posledice mokrega in suhega depozita iz zraka prekomerno onesnažena tla v Zasavju, med drugimi so povišane tudi vrednosti arzena, kadmija in svinca. Zavod za zdravstveno varstvo Ljubljana je leta 2008 izdelal elaborat »Zdravje za Zasavje«, v katerem navajajo, da je populacija v Zasavju nenehno izpostavljena prekomernim emisijam prašnih delcev iz več virov (kot največja vira sta navedena termoelektrarna Trbovlje in cementarna v Trbovljah (Lafarge Cement d.o.o.), sledita jima Steklarna Hrastnik d.d. in TKI Hrastnik d.d. (Vudrag, 2008)). V preteklosti je na severnem robu doline Kotredeščice deloval manjši rudnik antimonita, ki je del rudonosnega območja Trojane-Znojile. V prvi polovici 20. stoletja so na tem območju rudarili antimonit (Herlec & Žorž, 2006). Poleg antimonita so v rudišču prisotni tudi arzenovi minerali (Grafenauer, 1964; Herlec & Žorž, 2006) zato so tudi v jalovini, ki je ostala po rudarjenju, povišane vsebnosti antimona in arzena.

Namen raziskave je bil opredeliti morebitne negativne vplive opuščenega rudnika antimonita in drugih možnih virov na povišane vsebnosti arzena in antimona v okolju,



Sl. 1. Poenostavljena litološka karta preiskanega območja (po Buserju, 2009) z označenimi lokacijami vzorčenja.
Fig. 1. Simplified lithological map of researched area (after Buser, 2009) with marked sampling locations.

predvsem v sedimentih in vodah, na območju doline Kotredeščice in Zagorja ob Savi. Na podlagi dostopnih poročil, arhivskih podatkov in drugih virov smo določili lokacije nekdanjih pridobivalnih prostorov in odlagališč odpadkov rudnika antimonita v Znojilah, pregledali dosedanje raziskave stanja okolja v zvezi s povišanimi vsebnostmi arzena v tleh na poplavnih ravnicah in sedimentih na tem območju ter v skladu z ugotovitvami predhodnih raziskav naredili načrt vzorčenja.

Geološka zgradba obravnavanega ozemlja

Obravnavano območje med Trojanami in Zagorjem ob Savi pripada Posavskim gubam, natančneje Trojanski in Litijski antiklinali ter vmesni Laški sinklinali (Kuščer, 1967; Placer, 1999). Najstarejše kamnine na tem območju so karbonski temno sivi do črni skrilavi glinavci in meljevci ter kremenovo-sljudnati peščenjaki in konglomerati (Premru, 1983; Mlakar, 1983). Te kamnine gradijo južna pobočja Čemšeniške planine, na območju med Trojanami in Znojilami. Za glinavce je značilno orudenje z antimonitom (Sb_2S_3), ki so ga v preteklosti pridobivali na več lokacijah. Pojave antimonita spremljajo še drugi minerali: kremen, pirit, arzenopirit, siderit, halkopirit, stibikonit, galenit, itd. Grafenauer (1964) je na območjih nahajališč določil skupno 24 mineralov, katerih mineralizacija je potekala v treh fazah. K raznolikosti mineralne združbe je pripomogla tudi oksidacija rudnih mineralov, ki je bila na območju rudišča Trojane-Znojile zelo močna (Grafenauer, 1964). Nad karbonskimi klastičnimi kamninami ležijo permske grödenske plasti, katerih izdanki pa so redki. Višje vzpetine severno in južno od karbonskih kamnin gradijo predvsem triasni in jurski apnenci ter dolomiti (Premru, 1983). Za nižje ležeča območja oz. jedro Laške sinklinale so značilne klastične oligocenske in miocenske kamnine, ki se razprostirajo v smeri vzhod-zahod (Kuščer, 1967; Premru, 1983). Prisotne so tudi karbonatne kamnine enake starosti (npr. miocenski litotamnijski apnenec). Bogata nahajališča rjavega premoga, ki so ga v preteklosti izkoriščali na območju Zagorja ob Savi, se nahajajo znotraj oligocenske Trboveljske formacije (Placer, 1999), ki so jo prvotno imenovali soteške plasti (Kuščer, 1967). Pod slojem premoga, katerega največja debelina znaša do 30 m (Placer, 1999), ležijo sladkovodne klastične kamnine hudourniškega nastanka, nad premogom pa so se odložili laporovec, laporni apnenec in skrilavi laporovec (Kuščer, 1967; Pavšič & Horvat, 2009). Litološka zgradba ozemlja je shematsko prikazana na sliki 1.

Rudni pojavi antimonita severno od Zagorja

Rudonosno območje leži severno od Zagorja v karbonskih klastičnih kamninah. Antimonit se pojavlja pri Znojilah, zahodno od Znojil sta nahajališči Brezje in Prhovec, najzahodneje pa je bila ruda najdena pri Podzidu pod Trojanami (Duhovnik, 1946; Grafenauer, 1964; Herlec & Žorž, 2006). Pomembnejša rudarska dela so bila pod Trojanami (Kraljev rov, Zinka rov), v rovu pri Prhovcu in pri Znojilah (Mlakar, 1983; Herlec & Žorž, 2006). Skupaj so pridobili okrog 4000 t antimonita (Herlec & Žorž, 2006).

Rudarska dela na tem ozemlju so potekala že v 17. stoletju. Leta 1764 so zaradi pomanjkanja denarnih sredstev dela prenehala. Z rudarskimi deli so nadaljevali šele v 20. stoletju, ko je bila leta 1908 ustanovljena „rudarska družba Trojane“. Družba je delovala le v okolici Podzida na obeh straneh Orehovice, kjer je bilo skupno 8 rovov (Duhovnik, 1946; Mlakar, 1983).

Germovšek in sodelavci (1949) ter Mlakar (1983) v poročilih o podrobnem geološkem kartiranju produktivnega ozemlja med Trojanami in Znojilami navajajo, da se znaki orudenja z antimonitom pojavljajo na ozemlju dolgem 9 km in širokem 2 km. V glavnem so rudni pojavi koncentrirani v okolici Podzida, pri Brezjah in v okolici Znojil. Način pojavljanja rude je relativno enostaven. Antimonit nastopa pretežno v rudnih žilah, skupaj s piritom in kremenom. Orudenje nastopa v skrilavih glinavcih in meljevcih (sl. 1). Debelina orudenih žil je od 2–10 cm (Duhovnik, 1946; Mlakar, 1983; Herlec & Žorž, 2006). Običajno se debelina čistega antimonita, ki doseže v lečastih odebelitvah debelino nekaj deset cm, zelo spreminja. Antimonit je na površju oksidiran v stibikonit. Rudonosne kremenove žile leže tako konkordantno kot diskordantno s plastmi karbonskega skrilavega glinavca (Germovšek et al., 1949).

Pri Podzidu in pri Brezjah, kjer so potekala stara rudarska dela, so našli malo izdankov antimonita. Večja rudarska dela so se vršila še v bližini Brezij, med Brezjami in Prhovcem ter pri kmetiji Križnik. Na tem mestu je bilo v času raziskav leta 1949 še opaziti sledove rova in jaška (Germovšek et al., 1949). Večja rudarska dela so se vršila še v kraju Znojile v dolini Kotredeščice. Tu so se dela vršila v letih 1928–30 in kasneje okoli leta 1935. Na odvalu rudniške jalovine pred zasutim rovom so Germovšek in sodelavci (1949) opazili precej velike kose rude pomešane s kremenom. Po ustnem poročilu rudarjev naj bi se nahajala nekaj metrov od vhoda žila antimonita debela 20 cm. Spodnji rov iz leta 1935 je bil delno zasut, zato je bilo možno raziskati le približno 30 m rova. Po podatkih rudarjev je bil rov, s katerim so presekali le eno žilo, dolg približno 60 m. Višje ležečih izdankov proti vasi Znojile niso opazili. Vse karte in zapiski iz obdobja med prvo in drugo svetovno vojno so bili v času druge svetovne vojne uničeni (Germovšek et al., 1949).

Spomladi 1999 so v Bukovju pri Znojilah ob potoku Kotredeščica, nad območjem rudarjenja, v plasteh črnih karbonskih skrilavih glinavcev odkrili kremenovo žilo, v kateri so se nahajali kristali kremena in rudni minerali z arzenopiritom in skoroditom (Rečnik & Daneu, 2007). Glede na vse zapisano lahko sklepamo, da se v orudenih žilah kremena poleg antimonita (sl. 2), pirita in nekaterih drugih mineralov, pojavljata, vsaj v sledovih, tudi arzenopirit in skorodit (sl. 3), ki sta nosilca arzena (As).

Sl. 2. Fotografija žarkovitega antimonita iz rudišča Trojane-Znojile. Velikost fotografirane površine je približno 0,5 × 0,5 cm (foto: Ž. Šparemblek).

Fig. 2. Photograph of radiating antimonite from Trojane-Znojile mine. The image size is approximately 0.5 × 0.5 cm (photo: Ž. Šparemblek).

Sl. 3. Fotografija delno oksidiranega arzenopirita (sivo) in verjetno skorodita (puščica) v kremenovi žili, rudišče Znojile. Dolžina vzorca znaša 7 cm (foto: Ž. Šparemblek).

Fig. 3. Photograph of partly oxidised arsenopyrite (grey) and possibly scorodite (arrow) in quartz vein. The length of sample is 7 cm (photo: Ž. Šparemblek).

Premogovništvo v Zasavju in geokemične značilnosti zasavskih premogov

Značilno za obravnavano območje je tudi premogovništvo. Začetki izkoriščanja rjavega premoga v Zasavju segajo v leto 1755, ko je v Zagorju baron Franc Raigersfeld dobil prvo uradno dovoljenje za pridobivanje oz. lomljenje premoga. Leta 1880 so se zagorski rudniki pridružili Trboveljski premogokopni družbi. Njegov največji porabnik je postala v drugi polovici 19. stoletja železnica. Zagorje je postalo sredi 19. stoletja središče premogovništva in topilniške industrije na Slovenskem. Zgraditev Južne železnice je prinesla razcvet premogovništva (Rozina, 2005). Za razvoj Zasavja in širšega območja je pomembna tudi Termoelektrarna Trbovlje (TET), ki je premog uporabljala za proizvodnjo električne energije. Leta 1968 so se vsi trije zasavski premogovniki (Trbovlje, Zagorje, Hrastnik) združili v eno organizacijo - Zasavski premogovniki Trbovlje. Leta 1985 so se Zasavski premogovniki Trbovlje preimenovali v Rudnike rjavega premoga Slovenije (RRPS). Leta 1995 RRPS preneha z delovanjem in nastanejo štiri nova podjetja: Rudnik Trbovlje-Hrastnik in tri družbe v zapiranju – Rudnik Kanižarica, Senovo in Zagorje. Z odločitvijo države leta 1995, da se Rudnik Zagorje zapre, so v nekdanjem vhodnem rudniškem jašku uredili in opremili rudarski muzej. Leta 2000 je bil objavljen Zakon o postopnem zapiranju Rudnika Trbovlje-Hrastnik in razvojnem prestrukturiranju regije. Zakon je predvideval pridobivanje energetskega premoga do leta 2007 in postopno zapiranje rudnika do leta 2012, oziroma po spremembah in dopolnitvah imenovanega zakona, pridobivanje energetskega premoga do leta 2009 in zapiralna dela do leta 2015 (Rozina, 2005).

Zasavski premogi spadajo v skupino trdih rjavih premogov, ki ležijo v oligocenskih molasnih sedimentih Panonskega bazena na območju terciarnih sinklinal Posavskih gub osrednje Slovenije. Premogonosno najpomembnejša je Laška sinklinala, v kateri so bili razviti vsi večji zasavski premogovniki in v kateri je razvit le en sloj premoga povprečne debeline okoli 25 m (Kuščer, 1967; Premru, 1983; Placer, 1999).

Prvo obsežnejšo anorgansko geokemično karakterizacijo premogov v Sloveniji sta naredila Pirc in Žuža (1989), ki sta objavila tudi rezultate o vsebnostih slednih prvin iz tedaj aktivnih premogovnikov Velenje, Kanižarica, Senovo, Laško, Trbovlje in Zagorje ter območij raziskav Lendava in Globoko. Povprečna vsebnost arzena (As) v pepelu premoga iz Trbovelj (5 vzorcev) je bila 40 µg/g (Pirc & Žuža, 1989). Podobna vsebnost, v razponu 20–33 µg/g, je bila določena v pepelih trboveljskega premoga iz termoelektrarne Trbovlje (Kočevar, 2000). Pomembne raziskave o geokemičnih značilnostih zasavskega premoga je v 90-ih letih izvedel Uhan (1991, 1993, 1996). S preučevanjem geneze premoga v posameznih delih širšega zasavskega prostora, dopolnjevanjem modela strukturnega razvoja posameznih premogišč ter reševanjem tehnoloških problemov pri pridobivanju in uporabi premoga so pričeli leta 1989 (Markič et al., 1993). Kasneje sta se s preučevanjem arzenovih spojin v nizkokakovostnih premogih iz Velenjskega in Trboveljskega premogovnika ukvarjali Šlejkovec in Kanduč (2005). Vsebnost arzena, določena v vzorcih premoga (5 vzorcev iz Velenja in 1 vzorec iz Trbovelj), je v vzorcu iz trboveljskega premogovnika znašala 8,03 µg/g. Ugotovljeno je bilo, da As v Trboveljskem premogu nastopa v anorganski obliki, medtem ko je As v Velenjskem premogu vezan tako na anorganske kot na organske spojine (Šlejkovec & Kanduč, 2005). V premoški snovi so bile visoke vsebnosti As (nad 100 µg/g) v novejšem času ugotovljene v vzorcih drobcev premoga iz neogenskih plasti na območju Panonskega bazena (Markič & Brenčič, 2014; Markič, 2017). Tekom izkoriščanja premoga so jalovinski material odlagali na odlagališču Ruardi severno od Zagorja, ki je prikazan na sliki 1. Pod odlagališčem se razteza v smeri vzhod—zahod slojišče rjavega premoga. Februarja 1987 se je po dolgotrajnem deževju in taljenju snega na odlagališču sprožil plaz širine okrog 250 m in dolžine okrog 150 m. Plaz je zajel le južni del odlagališča jalovine. Odložena jalovina je zdrsnila v smeri proti jugovzhodu po pobočju hriba Ruardi. Širše območje odlagališča v področju jame je bilo od pričetka odkopavanja premoga izpostavljeno vplivom odkopavanja. Posledica so bili dolgotrajni procesi rušenja in morfološke spremembe površja, poslabšanje geomehanskih karakteristik krovninskih hribin in spreminjanje hidroloških pogojev. Plazenje jalovine se je v glavnem umirilo po približno 6 dnevih. V tem času se je čelo plazine premaknilo za okrog 235 m po zoženi grapi nad cesto proti ravninskemu delu pod njo, skoraj do prestavljene struge Kotedreščice (Kuščer et al., 1988). Odlagališče je danes sanirano, na tem območju so zdaj urejena športna igrišča, park ter vzletišče za letala.

Dosedanje raziskave vsebnosti arzena v tleh in sedimentih na območju doline Kotredeščice

Izjemno močne padavine junija 1994, ko je v dveh urah padlo več kot 100 mm padavin, so povzročile veliko manjših in večjih usadov ter plazov, potoki so prestopili bregove, nastopilo je močno erozijsko delovanje, infrastruktura je bila močno poškodovana (Klabus, 1995). Odneslo je tudi del jalovišča, ki je bil ob potoku Kotredeščica. Visoke vode so septembra 2010 ponovno erodirale bregove Kotredeščice. Odplavilo je material iz odlagališča rudarskih odpadkov in ob samodejni zajezitvi struge naplavilo pol metra sipkega drobnega materiala (Grabner et al., 2012).

ERICo Velenje je leta 1998 v svoji raziskavi *Posnetek stanja onesnaženosti tal in rastlinskega materiala na območju Zagorje ob Savi (*Kugonič, 1998) vzorčil tla iz vrtov na naseljenem območju občine Zagorje ob Savi (Zagorje ob Savi, Selo pri Zagorju, Ravenska vas, Loke pri Kisovcu in Izlake), dele vrtnin ter zatravljene površine v Ravenski vasi, Zagorju ob Savi in Kisovcu. V vrtnih tleh so na globini do 20 cm določali vsebnosti Cd, Co, Ni, Pb, Zn, Cr, Tl, As in Sb. V vrtninah, krmi in ozkolistnem trpotcu so določali vsebnosti Cd, Co, Ni, Pb in Zn. Na travniških tleh so ugotavljali onesnaženost tal s Cd, Co, Ni, Pb in Zn na treh globinah. Rezultati so pokazali, da zgornje plasti travniških tal vsebujejo višje koncentracije težkih kovin v primerjavi z vrtnimi tlemi. Vsebnost arzena (As) v vrtnih tleh na eni lokaciji (Zelena trava) je bila višja od mejne imisijske vrednosti (20 mg/kg; Uradni list RS, 2004), sicer pa mejne imisijske vrednosti niso bile prekoračene. V travniških tleh v Zagorju ob Savi so vrednosti za Pb, Zn in Ni presegale opozorilno imisijsko vrednost; v Kisovcu je bila presežena opozorilna imisijska vrednost za Ni ter mejna imisijska vrednost za Co, v Ravenski vasi pa so bile presežene mejne imisijske vrednosti za Cd in Co ter opozorilne vrednosti za Ni (Uradni list RS, 2004). Mejne vrednosti za Cd v vrtninah so bile prekoračene na vseh izbranih vrtovih (Kugonič, 1998).

V projektu *Raziskave onesnaženosti tal Slovenije* (Zupan et al., 2008) so na dveh lokacijah na območju Zasavja določili povišane vsebnosti As v tleh in sicer na lokaciji Ravenska vas (vsebnost As 23,3 mg/kg v globini 0–5 cm in 23,1 mg/kg v globini 5–20 cm) ter na lokaciji Trbovlje (vsebnost As 37,7 mg/kg v globini 0–5 cm in 38,2 mg/kg v globini 5–20 cm). Na obeh lokacijah so kot možen vir onesnaženja navedene emisije iz dimnika TET (Rots, 1999).

V začetku leta 2011 je celjski zavod za zdravstveno varstvo po naročilu občine Zagorje ob Savi izvedel analizo vzorcev tal in pitne vode. Analiza je pokazala, da so vsebnosti arzena v tleh na treh lokacijah vzdolž struge potoka Kotredeščice med Znojilami in Kotredežem, kjer je bil odložen naplavljeni material iz odlagališča rudarskih odpadkov v Znojilah, presegle mejne vrednosti za tla (20 mg/kg), od tega so bile na dveh lokacijah višje od opozorilne imisijske vrednosti (30 mg/kg) (Uršič et al., 2011). Nadaljnje analize, ki jih je opravil Inštitut za ekološke raziskave ERICo (ERICo, 2010), so pokazale, da naplavljeni material ne sodi med nevarne odpadke (Grabner et al., 2012).

V raziskavi, ki jo je izvedel Inštitut za okolje in prostor, je bilo avgusta 2012 iz globine 15-20 cm odvzetih 60 vzorcev tal (Grabner et al., 2012). Določena je bila vsebnost 36 elementov z ICP-MS metodo po postopku 4-kislinskega razklopa (Grabner et al., 2012). Rezultati raziskave so pokazali, da so tla onesnažena predvsem z arzenom. Ugotovili so preseženo mejno imisijsko vrednost na 6 lokacijah, preseženo opozorilno imisijsko vrednost na 20 lokacijah in preseženo kritično imisijsko vrednost, ki znaša 55 mg/kg (Uradni list RS, 2004), na 17 lokacijah. Na najbolj onesnaženi lokaciji je bila kritična imisijska vrednost za arzen prekoračena za faktor 3. Povišane vsebnosti arzena so bile ugotovljene predvsem v zgornjem toku potoka Kotredeščica, med Znojilami in Kotredežem. Vzdolž struge Kotredeščice v Zagorju ob Savi ni bila presežena kritična imisijska vrednost na nobeni lokaciji. Predlagana je bila začasna prepoved uporabe krme in pridelkov na območjih s preseženo kritično vrednostjo. Določene so bile tudi nekoliko povišane vsebnosti Cu, Ni, Co, Zn in Cd (Grabner et al., 2012). Pri tem je potrebno upoštevati dejstvo, da so povprečne koncentracije prvin v vzorcih izluženih z metodo 4-kislinskega razklopa višje kot pri izluževanju z zlatotopko (Šajn & Gosar, 2003). V naši zakonodaji (Uradni list RS, 2004) je za ugotavljanje onesnaženosti tal predvideno določanje težkih kovin po izluževanju z zlatotopko.

V oktobru 2012 je Zavod za zdravstveno varstvo Ljubljana po naročilu Občine Zagorje ob Savi vzorčil solato in korenje znotraj obravnavanega območja. Prekomernih vsebnosti arzena v analiziranih vrtninah ni bilo (Juričič et al., 2013).

Decembra 2012 je Zavod za zdravstveno varstvo Maribor, Inštitut za varstvo okolja, v poročilu *Preiskave tal na poplavnih območjih doline Kotredeščice* (Ivanoš et al., 2012), podal oceno stanja obremenitev tal/zemljine, krme in kmetijskih pridelkov (krompirja). Ugotovili so, da je območje doline Kotredeščice med naselji Rove in Znojile obremenjeno z arzenom in antimonom. Najvišje vsebnosti v tleh so določili na območju Jesenovega kot posledica poplav v letu 1994. Območje Jesenovega v poplavah 2010 ni bilo prizadeto, saj so bila po letu 1994 na potoku izvedena hidrotehnična – regulacijska dela. Na lokacijah Znojile, Rove in Kotredež so bile ugotovljene nižje vsebnosti arzena in antimona, saj se je po poplavah leta 1994 že erodirani material premeščal in razredčeval z materialom erodiranim iz drugih površin (Ivanoš et al., 2012). Izmerjene vsebnosti arzena v tleh na lokaciji Kotredež so bile pod mejno imisijsko vrednostjo, na lokacijah Rove in Znojile nad opozorilno, a pod kritično imisijsko vrednostjo ter na lokaciji Jesenovo nad kritično imisijsko vrednostjo. Ocenjeno je bilo, da je vsebnost arzena okrog 15 mg/kg značilna za širše geografsko območje (Ivanoš et al., 2012). Na podlagi vrednosti pH tal (pH=6-8) in pričakovane oksidacije pri stiku z atmosferskim kisikom so avtorji sklepali, da so pričakovane mineraloške oblike v vodi slabo topni železovi arzenati (V) in da se obremenitve z arzenom na vegetaciji lahko pričakujejo zaradi površinske vključitve mineralnih delcev v celične strukture rastlin. Vsebnosti arzena v suhi krmi na lokacijah Jesenovo (0,38 mg/kg) in Kotredež (0,097 mg/kg) ter ječmenu namenjenemu za krmo (<0,10 mg/kg) na lokaciji Kotredež niso presegale mejne vrednosti za arzen v krmi (2 mg/kg). Mejna vrednost je bila blago presežena v silažni krmi na lokaciji Znojile (2,6 mg/kg). Vsebnost arzena v krompirju na lokaciji Rove je bila <0,020 mg/kg (Ivanoš et al., 2012).

Na podlagi vseh pridobljenih rezultatov je tedanji Inštitut za varovanje zdravja RS februarja 2013 izdelal oceno tveganja za zdravje ljudi na prizadetem območju (Perharič, 2013). Na podlagi meritev vsebnosti arzena v 178 vzorcih vrtnin (solate in korenja) na področju občin Zagorje, Trbovlje in Hrastnik, ki jih je za potrebe svojega projekta naročil Zavod za zdravstveno varstvo Ljubljana (ZZV Ljubljana, 2012) so ocenili nekoliko povečano tveganje za zdravje malčkov pri dolgotrajni izpostavljenosti arzenu iz prehranskih virov. Vzorci so bili odvzeti na širokem področju od Kandrš in Save na zahodu ter Trojan na severu, do Podkuma na jugu (desni breg Save) in Dola pri Hrastniku oz. Radeč na vzhodu. Na področju vzdolž Kotredeščice je bilo odvzetih 18 vzorcev, in sicer v Znojilah 2, v Kotredežu 4, v Jesenovem 2, v Selu pri Zagorju 2 in v Ravenski vasi 8. Predlagali so ukrepe za zmanjšanje izpostavljenosti, za bolj natančno opredelitev izpostavljenosti pa izvedbo humanega biomonitoringa. Rezultate vzorcev iz doline Kotredeščice so obdelali ločeno od ostalih rezultatov iz občine Zagorje. Rezultati analize vzorcev korenja so pokazali, da je bila vsebnost arzena v korenju tako v dolini Kotredeščice kot v preostalih delih občine Zagorje od tri do štirikrat višja kot v občinah Trbovlje in Hrastnik. Vsebnost arzena je bila tudi v solati v občini Zagorje dvakrat višja kot v občinah Trbovlje in Hrastnik, vendar je bila vsebnost v solati v vzorcih iz doline Kotredeščice nižja kot v ostalih vzorcih iz občine Zagorje. Koncentracije arzena v odvzetih vzorcih pitne vode so bile po navedbah Zdravstvenega inšpektorata v skladu z veljavnim pravilnikom, to je do 10 µg/l (Perharič, 2013).

Koncentracije arzena izmerjene v vrtninah (korenje in solata) pridelanih v dolini Kotredeščice ter tudi v drugih predelih občine Zagorje so bile statistično značilno višje kot v sosednjih občinah, zato so na Inštitutu za varovanje zdravja podali mnenje, da je potrebno natančneje opredeliti vir arzena v vrtninah. Zaključili so, da povišane koncentracije arzena v tleh in v vrtninah v dolini Kotredeščice niso samo posledica preteklega rudarjenja v Znojilah in poplav, ampak tudi posledica geološke sestave (Perharič, 2013), kar so sklepali po podatkih preteklih raziskav tal (Gosar & Šajn, 2005; Zupan et al., 2008).

Da bi preverili prvotno oceno tveganja, ugotovili še druge morebitne vire izpostavljenosti arzenu ter ocenili potrebo po nadaljnjih ukrepih za zmanjšanje izpostavljenosti in spremljanju tveganja za zdravje, je Nacionalni inštitut za javno zdravje (NIJZ) aprila 2016 izvedel epidemiološko presečno raziskavo, v kateri so izpostavljenost arzenu ocenili z določanjem arzena v urinu (Perharič et al., 2017). V pomladnem in jesenskem vzorčenju so zbrali 154 vzorcev urina. Z raziskavo niso potrdili povečanega tveganja za zdravje 3 – 5 letnih otrok, zato so ocenili, da dodatni ukrepi za zmanjševanje tveganja niso potrebni. Na podlagi ponovne ocene vnosa anorganskega arzena z vodovodno vodo, krompirjem in zelenjavo so na NIJZ podali mnenje, da priporočila iz leta 2013, da naj malčki v občini Zagorje ob Savi uživajo čim manj doma pridelanih vrtnin, ni potrebno upoštevati. Delež vnosa anorganskega arzena iz teh virov je na podlagi bolj realnih podatkov precej manjši, kot je bilo ocenjeno v predhodni raziskavi (Perharič et al., 2017).

Materiali in metode

Vzorčenje in priprava vzorcev

Poleti 2017 smo v dolini Kotredeščice in v dolini Medije vzorčili sedimente na 13 lokacijah. Sedem vzorcev je bilo odvzetih vzdolž struge Kotredeščice, med Znojilami in Zagorjem ob Savi. Dva vzorca sta bila odvzeta vzdolž Orehovice (1 nad vasjo Orehovica in 1 v Izlakah, pred izlivom Orehovice v Medijo), ki drenira orudeno območje pod Trojanami. Štirje vzorci so bili odvzeti iz Medije, med Izlakami in Zagorjem ob Savi. Odvzeli smo približno 1,5 kg najdrobnejšega sedimenta. Izvedli smo kompozitno vzorčenje in tako sediment odvzeli na vsaj 5 vzorčnih podlokacijah. Litološka karta ozemlja in lokacije vzorčnih točk so prikazane na sliki 1. Koordinate vzorčnih mest so podane v tabeli 1.

Vzorce smo najprej posušili v sušilniku pri temperaturi do 35°C in nato presejali na frakciji <0,125 in <0,063 mm. Obe frakciji sta bili poslani na kemijsko analizo. Narejena je bila tudi granulometrična analiza vzorcev. S suhim sejanjem smo določili deleže proda (>2 mm), debelo (2–0,63 mm), srednje (0,63–0,2 mm) in drobnozrnatega (0,2–0,063 mm) peska ter mulja (<0,063 mm). Vsakič smo sejali od 100 do 200 g vzorca.

Iz dveh vzorcev frakcije <0,063 mm (SS-KO-01 iz zgornjega toka Kotredeščice in SS-KO-13 iz zgornjega toka Orehovice) sta bili s težkotekočinsko separacijo z bromoformom gostote 2,89 g/cm^3 pripravljeni frakciji težkih mineralov, ki so bili analizirani z vrstično elektronsko mikroskopijo v kombinaciji z energijsko disperzijsko spektroskopijo rentgenskih žarkov (SEM/EDS).

Na lokacijah, kjer smo vzorčili sediment, smo odvzeli tudi vzorce vode iz Kotredeščice, Medije in Orehovice. Vzorci vode so bili prefiltrirani preko filtra <0,45 µm in shranjeni v 60 ml HDPE plastenke, ki so bile predhodno dvakrat izprane z vzorčeno vodo. Ob odvzemu filtriranih vzorcev vode smo sočasno merili pH in temperaturo vode, električno prevodnost, količino raztopljenega kisika in Eh. Odvzeti vzorci vode so bili takoj shranjeni na hladno (8-10 °C) in prepeljani v laboratorij.

Kemijske analize vzorcev sedimentov in vod

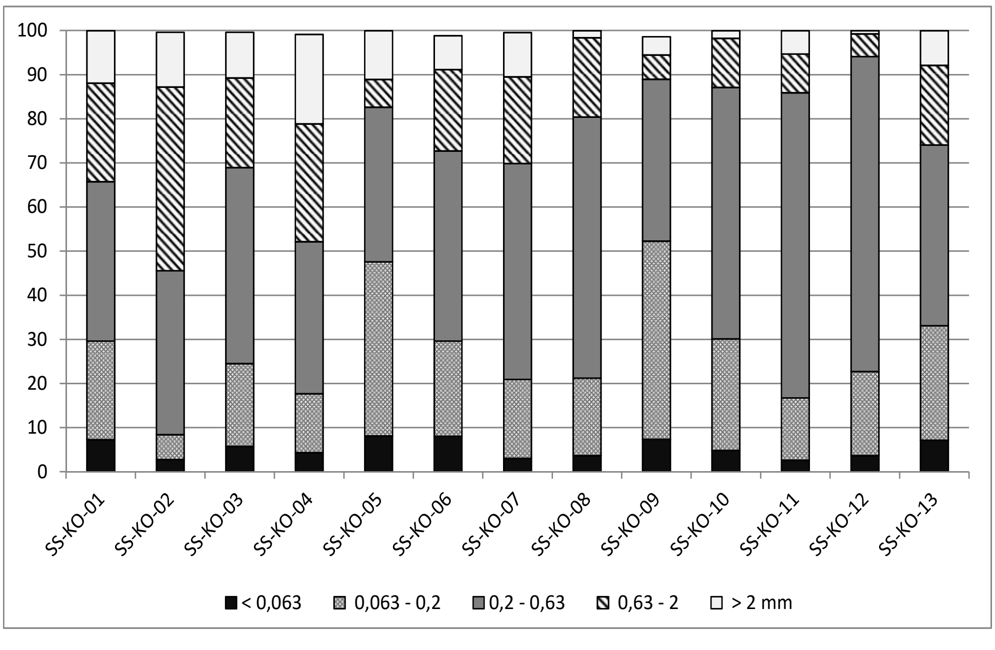
Kemijska analiza vzorcev potočnih sedimentov je bila opravljena v laboratoriju Bureau Veritas Mineral Laboratories, v Vancouvru v Kanadi. Za določitev vsebnosti 12 elementov (As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Zn) je bilo 15 g vzorca prelitega z zlatotopko (mešanica HCl, HNO_3 in H_2O v razmerju 1:1:1), eno uro segrevano

Tabela 1. Osnovni podatki o vzorčnih lokacijah.
Table 1. Basic information about sampling locations.

Oznaka točke/ Sample label	Y	X	Nad. višina (m)/ Altitude (m)	Vodotok/ Stream
SS-KO-01	499909	115031	488	Kotredeščica
SS-KO-02	498594	114423	385	Kotredeščica
SS-KO-03	498111	113843	361	Kotredeščica
SS-KO-04	498407	112814	345	Kotredeščica
SS-KO-05	500664	111484	287	Kotredeščica
SS-KO-06	500810	110601	270	Kotredeščica
SS-KO-07	500582	109715	258	Kotredeščica
SS-KO-08	500013	108634	236	Medija
SS-KO-09	499998	109458	239	Medija
SS-KO-10	498683	110801	261	Medija
SS-KO-11	496078	111713	292	Medija
SS-KO-12	494971	111884	306	Orehovica
SS-KO-13	493461	113963	351	Orehovica

na 95 °C in potem primerno razredčeno z destilirano vodo. Vsebnost prvin v raztopini so nato določili z induktivno sklopljeno plazemsko spektroskopijo (ICP-MS ali ICP-ES). Kakovost analitike je bila zagotovljena s ponovitvama dveh vzorcev in uporabo standardov OREAS-45e, OREAS-45d in OREAS-151b. Srednja vrednost analiziranih prvin v standardih v povprečju odstopa za manj kot 15 % od priporočenih vrednosti. Večje odstopanje (18 %) je bilo ugotovljeno samo za Cd. Natančnost analitike, izračunana kot relativna razlika med pari analiziranih vrednosti istega vzorca, je bila dobra. Edino za Hg je bilo izračunano odstopanje večje od 15 % in je znašalo 27 % za frakcijo <0,063 mm oz. 35 % za frakcijo <0,125 mm.

Vzorci vode so bili takoj po vzorčenju poslani na kemijsko analizo v laboratorij Activation Laboratories Ltd. (Actlabs) v Kanadi. V laboratoriju so bili vzorci najprej zakisani z ultra čisto dušikovo kislino na pH <2 za nekaj dni, da so se morebiti oborjeni elementi ponovno raztopili. Nato so bili analizirani z induktivno sklopljeno plazemsko (ICP) masno spektrometrijo (MS) in optično emisijsko spektrometrijo (OES). Kakovost analitike je bila zagotovljena s ponovitvama dveh vzorcev in uporabo standarda IV-STOCK-1643 (ICP/MS). Izračunano odstopanje srednje vrednosti analiziranih prvin v standardih od priporočenih vrednosti znaša med 1,85 % in 11,4 %.



Sl. 4. Razmerje deležev proda, debelo, srednje in drobnozrnatega peska ter mulja v vzorcih sedimentov.

Fig. 4. Granulometric composition of the samples (ratio between coarse sand, medium sand, fine sand and silt).

SEM/EDS analiza trdnih faz v sedimentih

Težki minerali pridobljeni s težkotekočinsko separacijo vzorcev SS-KO-01 iz zgornjega toka Kotredeščice in SS-KO-13 iz zgornjega toka Orehovice so bili analizirani s SEM/EDS z namenom kemično-mineraloške opredelitve trdnih pojavnih oblik potencialno škodljivih elementov (PHE), predvsem As in Sb, ter določitve splošne mineralne sestave. Vzorca sta bila potresena na ogljikov trak, naprašena z ogljikom in analizirana s SEM/EDS pri pospeševalni napetosti 20 kV, delovni razdalji 10 mm in času zajema spektra 30 s. Mineralna sestava delcev je bila ocenjena iz atomskih razmerij sestavnih elementov in s primerjavo s podatkovno bazo mineralov (Anthony et al., 2009; Barthelmy, 2010). SEM/EDS analiza je bila opravljena na Geološkem zavodu Slovenije.

Rezultati in diskusija

Granulometrična analiza

V večini vzorčenih sedimentov prevladujeta drobno in srednjezrnati pesek (0,063–0,2 mm in 0,2–0,63 mm), sledi grobozrnati pesek, najmanj pa je proda in mulja, saj vzorci vsebujejo od 2,6 do 8,1 % mulja (<0,063 mm) in 0,7 do 20 % proda (>2 mm). Sortiranost je večinoma dobra. Zrnavostna sestava vzorcev je prikazani na sliki 4.

Tabela 2. Mejne in kritične vrednosti v tleh in sedimentih (Uradni list RS, 2004) (*ker za Ba in Sb ni podane mejne in kritične vrednosti za tla v Sloveniji, smo ju privzeli po »The New Duch list« (Vrom, 2000)).

Table 2. Limit and critical values for soil and sediments (Official Gazette RS, 2004) (*limit and critical values for Ba and Sb were taken from »The New Duch list« (Vrom, 2000), because they are not given in Slovenian legislation).

Element	mejna vrednost/ limit value (mg/kg)	kritična vrednost/ critical value (mg/kg)
As	20	55
Ba*	160	625
Cd	1	12
Cr	100	380
Co	20	240
Cu	60	300
Pb	85	530
Mo	10	200
Ni	50	210
Hg	0,8	10
Zn	200	720
Sb*	3	15

Vsebnosti potencialno škodljivih elementov (PHE) v sedimentih

Vsebnosti 12 potencialno škodljivih elementov (PHE) (As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Zn) v obravnavanih vzorcih sedimentov za obe analizirani frakciji so podane v tabelah 3 in 4.

Za Cd, Cu, Ni, Pb, Zn, Cr, Hg, Co, Mo in As so v Uredbi o mejnih, opozorilnih in kritičnih imisijskih vrednostih nevarnih snovi v tleh (Uradni list RS, 2004) podane normativne vrednosti (tabela 2). V raziskavi uporabljamo te vrednosti za ovrednotenje naših rezultatov, saj v Sloveniji zakonodaja za sedimente ne obstaja. **Mejna imisijska vrednost** je gostota posamezne nevarne snovi v tleh, ki pomeni takšno obremenitev tal, da se zagotavljajo življenjske razmere za rastline in živali, in pri kateri se ne poslabšuje kakovost podtalnice ter rodovitnost tal. Pri tej vrednosti so učinki ali vplivi na zdravje človeka ali okolje še sprejemljivi. **Opozorilna imisijska vrednost** je gostota posamezne nevarne snovi v tleh, ki pomeni pri določenih vrstah rabe tal verjetnost škodljivih učinkov ali vplivov na zdravje človeka ali okolje. **Kritična imisijska vrednost** je gostota posamezne nevarne snovi v tleh, pri kateri zaradi škodljivih učinkov ali vplivov na človeka in okolje onesnažena tla niso primerna za pridelavo rastlin, namenjenih prehrani ljudi ali živali ter za zadrževanje ali filtriranje vode (Uradni list RS, 2004). Opozorilne kritične vrednosti za tla po slovenski uredbi so zelo blizu tudi vrednostim po t.i. nizozemski listi »The New Duch list« (Vrom, 2000), ki je veljala tako za **tla** kot tudi za **sedimente**. V t.i. nizozemski listi so podane tudi mejne vrednosti za barij (Ba) in antimon (Sb), ki v slovenski zakonodaji niso definirane. V tabeli 2 navajamo mejne in kritične vrednosti v skladu z zgoraj omenjeno zakonodajo.

Vsebnosti večine PHE v vzorcih sedimentov ne presegajo mejnih imisijskih vrednosti. Presegajo jih le vsebnosti arzena (As) in antimona (Sb), v enem vzorcu pa je močno povišana tudi vsebnost svinca (Pb). Glede na to, da vsebnosti Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb in Zn ne presegajo normativnih vrednosti za tla oz. sedimente in zaradi ugotovljenega preteklega onesnaženja z As kot posledica rudarjenja ter naravno povišanih vsebnosti Sb in As zaradi orudenja, v nadaljevanju podrobneje obravnavamo le vsebnosti As in Sb.

Ugotovljene vsebnosti As v vzorcih sedimenta se gibljejo med 10,9 in 99,7 mg/kg v frakciji <0,125 mm in med 12,8 in 101,9 mg/kg v frakciji <0,063 mm (tabeli 3 in 4, sl. 5). V obeh frakcijah znaša

Tabela 3. Vsebnosti As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb in Zn (v mg/kg) v vzorcih sedimentov (frakcija <0,125 mm) Kotredeščice, Medije in Orehovice in primerjava z mediano obravnavanih elementov v potočnem sedimentu Slovenije in Evrope (Min = minimum, Max = maksimum, Md = mediana).

Table 3. Contents of As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb and Zn (in mg/kg) in sediment samples (<0.125 mm) from Kotredeščica, Medija and Orehovica and comparison to elemental median in stream sediments of Slovenia and Europe Min = minimum, Max = maximum, Md = median).

Oznaka točke/ Sample label	As	Ba	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Sb	Zn
SS-KO-01	99,7	59,1	0,2	14,7	9,1	27,4	0,1	0,6	32,4	22,2	15,9	88,5
SS-KO-02	77,2	57,6	0,2	12,2	9,2	27,7	0,1	0,5	30,4	20,7	11,0	70,6
SS-KO-03	74,9	74,2	0,2	13,3	9,3	28,9	0,2	0,5	31,7	22,0	11,7	94,5
SS-KO-04	52,1	73,7	0,2	11,2	9,4	28,1	0,2	0,5	27,1	21,1	8,5	81,1
SS-KO-05	35,0	58,3	0,2	8,1	8,1	19,7	0,1	0,5	19,1	19,5	6,4	68,8
SS-KO-06	29,5	56,0	0,3	8,8	8,4	21,5	0,1	0,7	21,9	19,3	5,8	74,0
SS-KO-07	36,0	67,0	0,2	8,5	9,1	20,5	0,1	0,8	21,4	21,4	5,3	75,0
SS-KO-08	20,8	31,8	0,2	6,4	8,0	17,4	0,1	0,6	15,9	93,6	6,1	67,1
SS-KO-09	10,9	38,5	0,3	5,5	10,5	22,8	0,1	0,5	15,1	592,5	5,5	131,8
SS-KO-10	11,4	39,2	0,2	6,3	9,6	20,0	0,1	0,4	15,5	19,4	5,5	58,0
SS-KO-11	14,0	78,5	0,3	8,2	11,6	35,8	0,1	0,5	17,9	16,6	5,7	59,0
SS-KO-12	25,6	30,9	0,4	11,0	11,5	34,5	0,4	0,6	23,7	21,1	11,6	88,7
SS-KO-13	27,2	22,6	0,2	12,5	10,3	32,3	0,4	0,5	29,5	20,8	20,0	96,1
Min	10,9	22,6	0,2	5,5	8,0	17,4	0,1	0,4	15,1	16,6	5,3	58,0
Max	99,7	78,5	0,4	14,7	11,6	35,8	0,4	0,8	32,4	592,5	20,0	131,8
Md	**29,5**	**57,6**	**0,2**	**8,8**	**9,3**	**27,4**	**0,1**	**0,5**	**21,9**	**21,1**	**6,4**	**75,0**
Slovenija*	7,0						0,09				0,4	
Evropa**	6,0	86,0	/	8,0	21,0	14,0	/	/	16,0	14,0	/	60,0

* Mediana za potočni sediment Slovenije (po Sotlarju, 1995) / Median for stream sediments in Slovenia (after Sotlar, 1995)
** Mediana za potočni sediment Evrope (Salminen et al., 2005) / European median for stream sediment (Salminen et al., 2005)

mediana 29,5 mg/kg. Vsebnost As v sedimentih je najvišja v zgornjem toku Kotredeščice in upada po toku navzdol. Vsebnosti so nekoliko povišane tudi v dveh vzorcih odvzetih ob Orehovici, v Mediji pa se vsebnosti As znižajo na <20 mg/kg in se ponovno nekoliko povišajo v zadnjem vzorcu pred izlivom Medije v Savo, po pritoku Kotredeščice v Medijo. V 10 (frakcija <0,125 mm) oz. 9 (frakcija <0,063 mm) vzorcih od skupno 13, je bila ugotovljena presežena mejna vrednost za As, ki znaša za tla 20 mg/kg, v 3 (frakcija <0,125 mm) oz. 4 (frakcija <0,063 mm) vzorcih pa je presežena kritična vrednost za tla, ki znaša 55 mg/kg (Uradni list RS, 2004). Vsi vzorci sedimenta, v katerih je kritična vrednost za As presežena, so iz zgornjega toka Kotredeščice, med Znojilami in krajem Rove. Na območju Rov vsebnost v frakciji <0,125 mm že pade nekoliko pod kritično vrednost (52,1 mg/kg).

Ugotovljene vsebnosti Sb nihajo med 5,3 in 20 mg/kg, z mediano 6,4 mg/kg v frakciji <0,125 mm, in med 5,2 in 19,7 mg/kg, z mediano 6,2 mg/kg v frakciji <0,063 mm (tabeli 3 in 4, sl. 6). Najvišje vsebnosti Sb so bile ugotovljene v sedimentih zgornjega toka Kotredeščice ter v sedimentih Orehovice. Mejna vrednost za Sb, ki znaša 3 mg/kg (Vrom, 2000) (tabela 2), je presežena v vseh obravnavanih vzorcih sedimenta, v obeh analiziranih frakcijah. Kritična vrednost za Sb, ki znaša 15 mg/kg (Vrom, 2000), je presežena v 2 vzorcih, v sedimentu iz zgornjega toka Kotredeščice pri Znojilah in v vzorcu sedimenta iz Orehovice, ki je bil odvzet nekoliko nad krajem Orehovica. Najnižje določene vsebnosti (med 5 in 7 mg/kg), ki pa še zmeraj presegajo mejne imisijske vrednosti za tla oz. sediment, so bile določene v sedimentih spodnjega toka Kotredeščice in v sedimentih Medije.

Analiza sedimenta potoka Kotredeščica je pokazala, da je večina sedimenta v strugi Kotredeščice med Znojilami in Zagorjem ob Savi še vedno obremenjena z As in Sb, kar prikazujeta sliki 5 in 6 ter grafi na slikah 7 in 8. Stolpci na grafih prikazujejo vsebnosti As in Sb

Tabela 4. Vsebnosti As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb in Zn (v mg/kg) v vzorcih sedimentov (frakcija <0,063 mm) Kotredeščice, Medije in Orehovice in primerjava z mediano obravnavanih elementov v potočnem sedimentu Slovenije in Evrope (Min = minimum, Max = maksimum, Md = mediana).

Table 4. Contents of As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb and Zn (in mg/kg) in sediment samples (<0.063 mm) from Kotredeščica, Medija and Orehovica and comparison to elemental median in stream sediments of Slovenia and Europe Min = minimum, Max = maximum, Md = median).

Oznaka točke/ Sample label	As	Ba	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Sb	Zn
SS-KO-01	101,9	77,8	0,1	16,5	8,7	26,1	0,1	0,6	32,7	3,0	15,5	83,1
SS-KO-02	74,8	71,6	0,3	13,4	9,7	32,9	0,2	0,5	30,1	22,5	9,9	77,2
SS-KO-03	67,4	69,4	0,2	13,0	9,0	27,1	0,2	0,5	27,9	22,0	11,2	75,0
SS-KO-04	55,6	80,9	0,3	13,1	10,5	32,9	0,2	0,5	29,2	25,2	10,4	88,2
SS-KO-05	39,9	76,4	0,3	8,9	8,8	22,4	0,2	0,6	20,7	23,1	6,0	73,1
SS-KO-06	29,5	66,2	0,3	9,6	8,4	23,9	0,2	0,7	22,4	21,4	5,2	76,6
SS-KO-07	34,7	85,3	0,2	8,5	10,9	22,8	0,1	0,9	21,9	26,7	5,4	69,4
SS-KO-08	24,9	46,3	0,2	7,1	9,2	22,1	0,1	0,6	17,6	73,2	6,3	84,7
SS-KO-09	12,8	56,6	0,4	6,8	12,1	32,3	0,3	0,6	17,9	600,5	5,8	154,8
SS-KO-10	13,6	55,5	0,3	8,1	13,5	29,6	0,1	0,5	20,1	23,4	5,8	76,2
SS-KO-11	15,2	103,6	0,3	9,5	15,4	48,9	0,1	0,6	22,4	17,6	6,2	69,1
SS-KO-12	25,5	50,7	0,3	12,8	14,9	48,3	0,2	0,6	28,7	23,4	10,4	108,7
SS-KO-13	22,6	26,4	0,3	12,2	9,7	29,7	0,3	0,4	26,4	22,6	19,7	77,2
Min	12,8	26,4	0,1	6,8	8,4	21,0	0,1	0,4	17,6	3,0	5,2	69,1
Max	101,9	103,6	0,4	16,5	15,4	48,9	0,3	0,9	32,7	600,5	19,7	154,8
Md	**29,5**	**69,4**	**0,3**	**9,5**	**9,7**	**29,6**	**0,2**	**0,6**	**22,4**	**22,6**	**6,2**	**77,2**
Slovenija*	7,0						0,09				0,4	
Evropa**	6,0	86,0	/	8,0	21,0	14,0	/	/	16,0	14,0	/	60,0

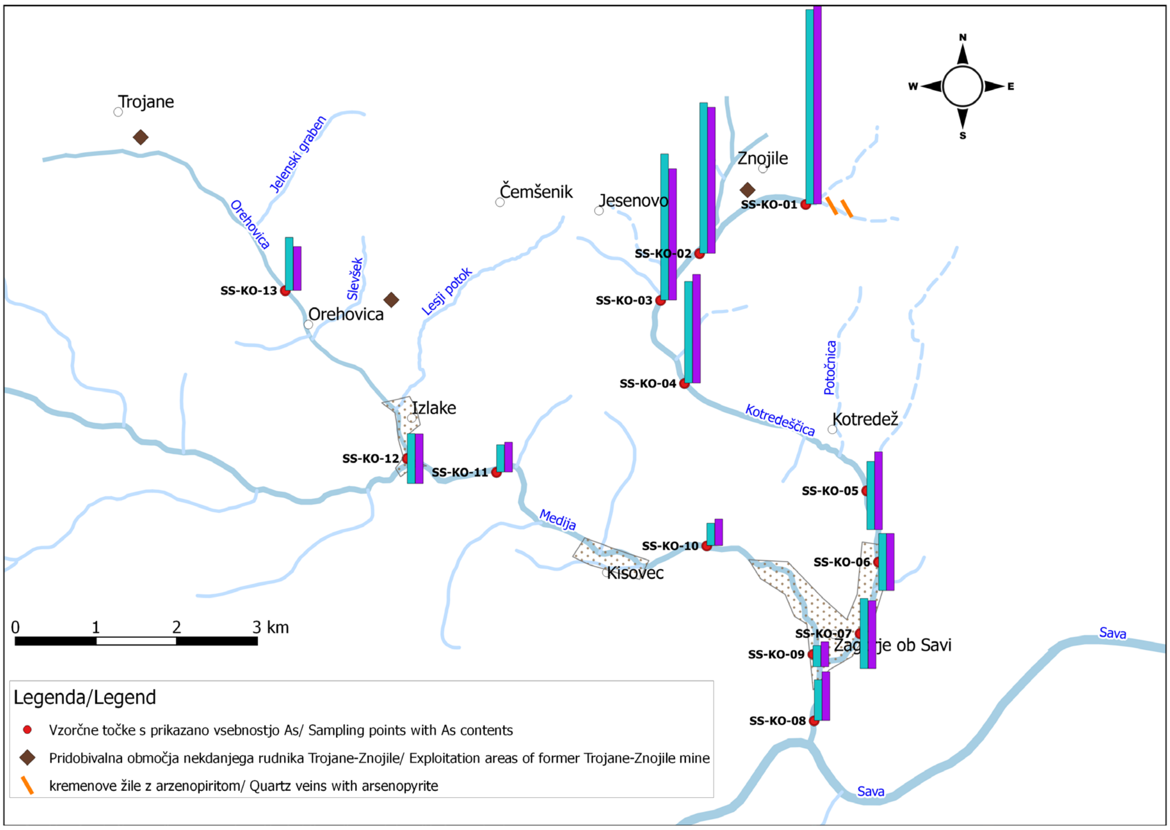
* Mediana za potočni sediment Slovenije (po Sotlarju, 1995) / Median for stream sediments in Slovenia (after Sotlar, 1995)

** Mediana za potočni sediment Evrope (Salminen et al., 2005) / European median for stream sediment (Salminen et al., 2005)

v sedimentih Kotredeščice (sl. 7) ter Orehovice in Medije (sl. 8). Vzorci si v grafih sledijo tako kot vzorčne točke v naravi po toku navzdol. Jasno se vidi, da so vsebnosti v sedimentih Kotredeščice in tudi Orehovice visoke. Vzrok temu so tako spiranje iz odlagališča rudarskih odpadkov kot tudi naravno oz. geogeno povišane vsebnosti obravnavanih prvin na tem območju. Na območju Znojil, nad nekdanjim rudniškim vhodom in nad lokacijo prve vzorčne točke (SS-KO-01), so pogoste večje kremenove žile z vključenim mineralom arzenopiritom, ki je tudi makroskopsko viden. O izdanku kremenovih žil z arzenopiritom na tem območju sta pisala tudi Rečnik in Daneu (2007). Spiranje tega materiala med večjimi nalivi, lahko vpliva na povišanje vsebnosti As v sedimentih Kotredeščice. Med vzorčnima točkama SS-KO-05 in SS-KO-06 leži na desnem pobočju odlagališče Ruardi, kamor so odlagali jamsko jalovino iz pridobivalnih obratov premoga in kjer se je leta 1987 sprožil plaz, kot je opisano v poglavju Premogovništvo v Zasavju. Kljub splazitvi jalovinskega materiala ob kateri je material odnašalo tudi v strugo Kotredeščice, na lokaciji SS-KO-06, ki se nahaja pod odlagališčem, nismo zaznali povišanih vsebnosti As in Sb v sedimentih glede na višje ležečo lokacijo SS-KO-05, kar kaže na to, da odlagališče Ruardi ni imelo vpliva na povišane vsebnosti As in Sb v sedimentih.

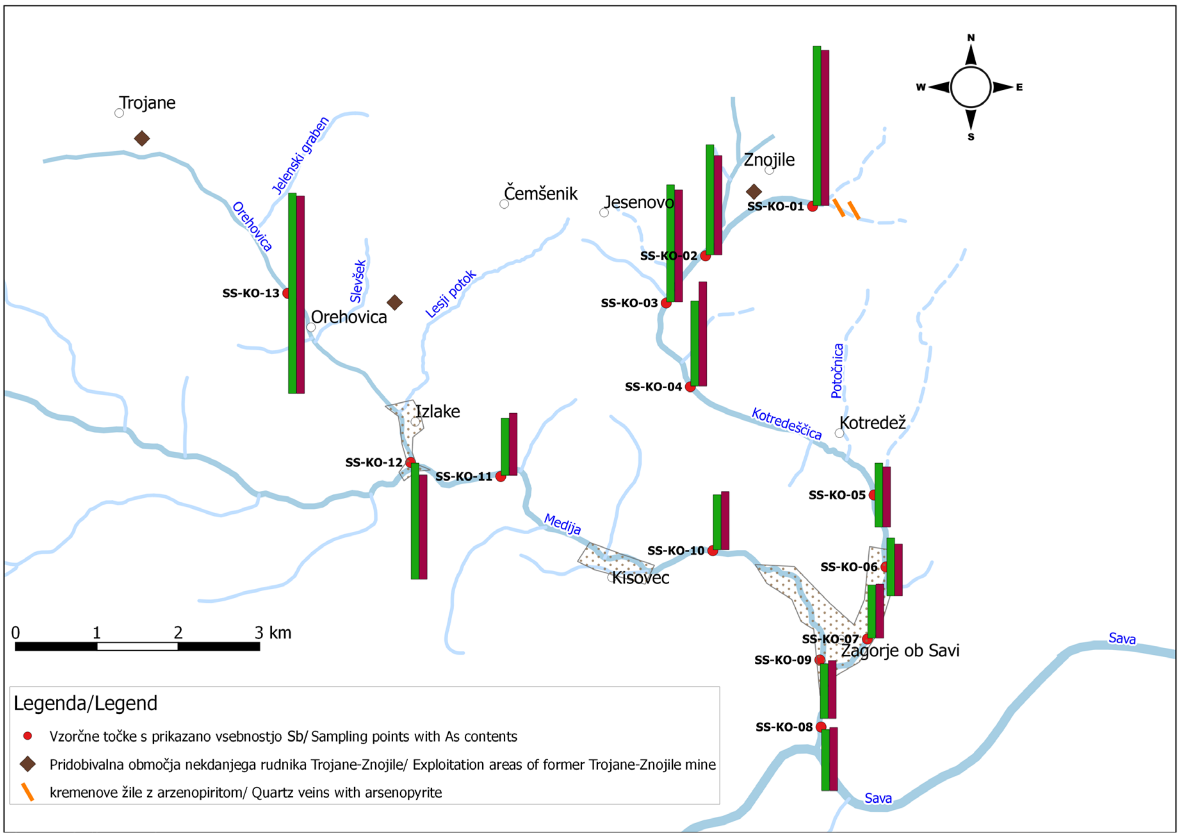
Koncentracije potencialno škodljivih elementov (PHE) v vodah

Fizikalno-kemični parametri vode, kot so pH, temperatura (T), oksidacijsko-redukcijski potencial (Eh), elektroprevodnost (EC) in količina raztopljenega kisika (DO), so osnovni indikatorji kakovosti vode. Pomembno vplivajo na obnašanje trdnih snovi v vodi, tudi tistih, ki vsebujejo PHE, ter na vsebnosti PHE v vodah. Mejne vrednosti osnovnih fizikalno-kemičnih parametrov (pH, T, Eh, EC in DO) v površinskih vodah v uredbah niso posebej predpisane.



Sl. 5. Prikaz vzorčnih mest in vsebnosti arzena (As) v mg/kg v vzorcih sedimentov na vplivnem območju Kotredeščice (levi stolpci prikazujejo vsebnost As v frakciji <0,125 mm, desni v frakciji <0,063 mm).

Fig.5. A display of sampling sites and arsenic (As) contents in mg/kg in sediment samples in the influential area of Kotredeščica (left bars show As content in fraction <0.125 mm, right bars in fraction <0.063 mm).



Sl. 6. Prikaz vzorčnih mest in vsebnosti antimona (Sb) v mg/kg v vzorcih sedimentov na vplivnem območju Kotredeščice (levi stolpci prikazujejo vsebnost Sb v frakciji <0,125 mm, desni v frakciji <0,063 mm).

Fig. 6. A display of sampling sites and antimony (Sb) contents in mg/kg in sediment samples in the influential area of Kotredeščica (left bars show As content in fraction <0.125 mm, right bars in fraction <0.063 mm).

Tabela 5 prikazuje terenske meritve osnovnih fizikalno-kemičnih parametrov vode. Temperatura vode je v času odvzema vzorcev nihala med 13,4 in 20,1 °C, pH vrednost se je gibala med 7,87 in 8,76.

Vrednosti Eh so se gibale med -43,3 in 4,6 mV. Najnižje vrednosti so bile izmerjene v Kotredeščici in Mediji, na vzorčnih mestih SS-KO-07 in SS-KO-08, najvišje pa v Orehovici (SS-KO-13). Elektroprevodnost (EC) se je gibala med 378 in

Tabela 5. Terenske meritve osnovnih fizikalno-kemičnih parametrov vode (pH, Eh, EC, DO in T) na posameznih vzorčnih mestih Kotredeščice, Medije in Orehovice.

Table 5. Field measurements of basic physico-chemical parameters of surface water (pH, Eh, EC, DO, T) at sampling locations from the Kotredeščica, Medija and Orehovica streams.

vzorec/ sample	**pH**	**Eh (mV)**	**EC (µS/cm)**	**DO (%)**	**DO (mg/l)**	**T (°C)**
SS-KO-01	8,44	-25,4	378,4	99,6	9,7	13,4
SS-KO-02	8,57	-32,5	418,7	101,5	9,9	14,3
SS-KO-03	8,6	-34,2	432,6	100,1	9,5	15,6
SS-KO-04	8,56	-31,9	439	103,2	9,9	15,2
SS-KO-05	8,53	-31,1	463,4	100,7	9,5	16,2
SS-KO-06	8,58	-34,2	474,2	103,8	9,6	17,6
SS-KO-07	8,76	-43,3	469,7	112,1	10,1	18,8
SS-KO-08	8,74	-43,3	499,5	114,1	10,2	19,3
SS-KO-09	8,7	-41,1	541,4	110,9	9,9	19,3
SS-KO-10	8,67	-38,8	487,5	110	10,2	17,6
SS-KO-11	8,59	-34,9	468	103,2	9,4	17,9
SS-KO-12	8,17	-12,6	458,9	88,7	7,7	20,1
SS-KO-13	7,87	4,6	428	88,1	8,0	17,7

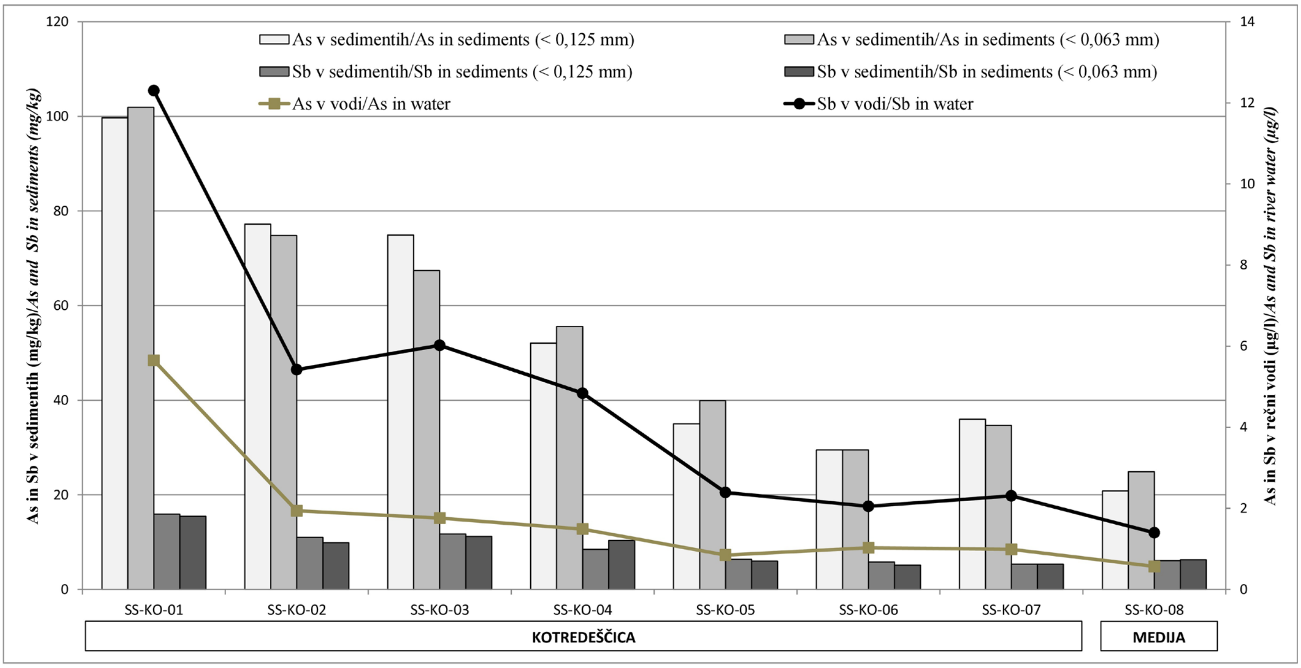
Tabela 6. Vsebnosti As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb in Zn (v µg/l) v vodah Kotredeščice, Medije in Orehovice ter primerjava z zakonodajnimi vrednostmi.

Table 6. Contents of As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb and Zn (in µg/l) in waters from the Kotredeščica, Medija and Orehovica and comparison with the legislation.

Vzorec/ Sample	Vodotok/ Stream	As	Ba	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Sb	Zn
SS-KO-01	Kotredeščica	5,65	34,0	<0,01	0,012	<0,5	<0,2	<0,2	0,1	<0,3	<0,01	12,30	<0,5
SS-KO-02	Kotredeščica	1,94	25,4	<0,01	0,017	<0,5	0,2	<0,2	0,2	<0,3	0,02	5,42	<0,5
SS-KO-03	Kotredeščica	1,76	23,3	<0,01	0,020	<0,5	<0,2	<0,2	0,2	<0,3	0,01	6,02	0,9
SS-KO-04	Kotredeščica	1,49	23,5	<0,01	0,020	<0,5	<0,2	<0,2	0,2	<0,3	<0,01	4,84	<0,5
SS-KO-05	Kotredeščica	0,85	27,8	<0,01	0,020	<0,5	0,2	<0,2	0,3	<0,3	<0,01	2,39	<0,5
SS-KO-06	Kotredeščica	1,03	26,6	<0,01	0,026	<0,5	0,3	<0,2	0,5	<0,3	<0,01	2,05	<0,5
SS-KO-07	Kotredeščica	0,99	27,9	<0,01	0,026	<0,5	0,3	<0,2	0,5	<0,3	<0,01	2,31	<0,5
SS-KO-08	Medija	0,57	44,3	<0,01	0,032	<0,5	2,2	<0,2	0,7	<0,3	0,09	1,40	0,6
SS-KO-09	Medija	0,45	44,4	<0,01	0,022	<0,5	0,7	<0,2	0,6	<0,3	0,03	1,28	1,0
SS-KO-10	Medija	0,38	37,2	<0,01	0,029	<0,5	0,5	<0,2	0,4	<0,3	<0,01	1,29	0,7
SS-KO-11	Medija	0,37	28,7	<0,01	0,023	<0,5	0,3	<0,2	0,3	<0,3	<0,01	1,38	0,6
SS-KO-12	Orehovica	0,51	15,7	<0,01	0,022	<0,5	0,2	<0,2	0,2	<0,3	<0,01	3,06	1,1
SS-KO-13	Orehovica	0,32	6,8	<0,01	0,017	<0,5	<0,2	<0,2	< 0,1	<0,3	<0,01	6,88	<0,5
Naravno ozadje/ Bacground value (NO/BV; µg/l)[1]		/	/	**0,04**	**0,1**	/	**1,0**	**0,0025**	/	/	/	**0,6**	**4,2**
Površinske vode/ Surface waters (NDK; µg/l)[2]		21	/	≤0,45 +NO[a]	2,8 +NO	160	73+ NO	0,07+ NO	200	34	14	30+ NO	78+ NO[b]
Odpadne vode/ Waste waters (µg/l)[3]		100	5000	25	30	500	500	5	1000	500	500	300	2000
Pravilnik o pitni vodi/ Drinking water (µg/l)[4]		10	/	5	/	50	200	1	/	20	10	5	/

[1,2]Uradni list RS, 2016 (NO = naravno ozadje; NDK = največja dovoljena koncentracija);
[3]Uradni list RS, 2015;
[4]Uradni list RS, 2017([a]velja za vode s trdoto < 40 mg/l $CaCO_3$; [b]velja za vode s trdoto < 50 mg/l $CaCO_3$);

[1,2]Official Gazette RS, 2016 (BV = background value; MPL = maximum permissible level);
[3] Official Gazette RS, 2015;
[4] Official Gazette RS, 2017 ([a] applies to water hardness < 40 mg/l $CaCO_3$; [b] applies to water hardness < 50 mg/l $CaCO_3$).

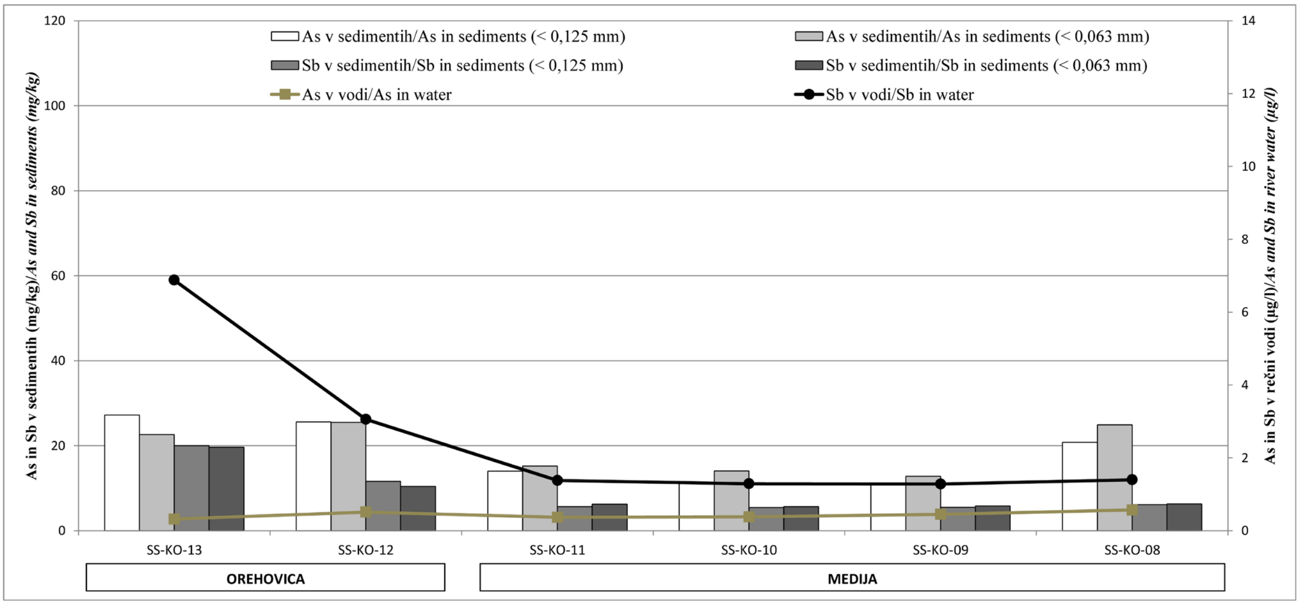


Sl. 7. As in Sb v sedimentih ter vodi na vzorčnih mestih Kotredeščice in Medije.
Fig. 7. As and Sb in sediments and water from Kotredeščica and Medija.

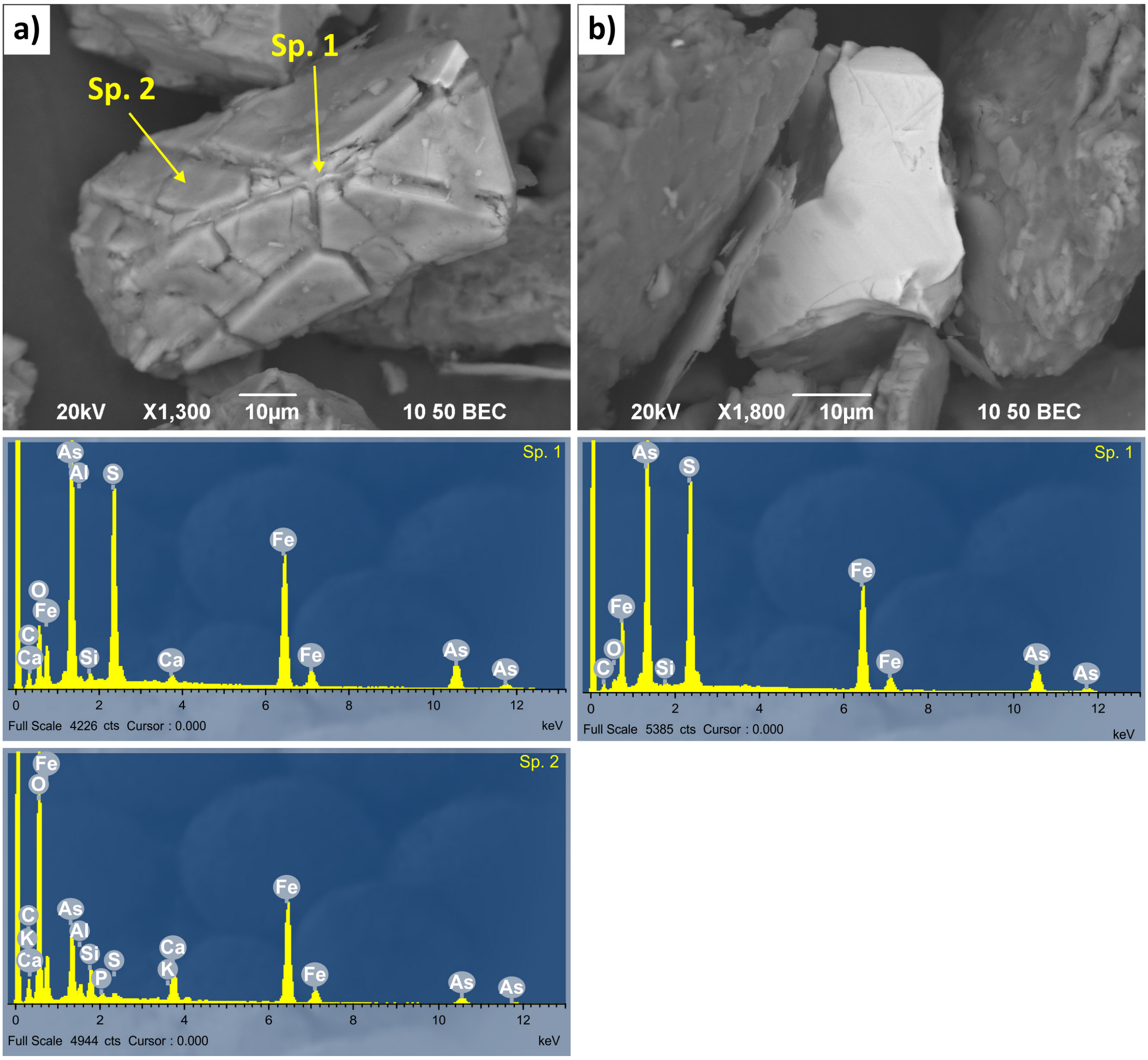
541 µS/cm. Najnižja vrednost je bila izmerjena v Kotredeščici (SS-KO-01), najvišja pa v Mediji (SS-KO-09). Koncentracije v vodi raztopljenega kisika (DO) so se gibale med 7,7 in 10,2 mg/l. Najnižje so bile v Orehovici (SS-KO-12), najvišje pa v Mediji (SS-KO-08 in SS-KO-10).

Glede na izmerjene vrednosti parametrov pH, Eh in DO je okolje v vodah Kotredeščice, Medije in Orehovice nevtralno do rahlo bazično in relativno dobro prezračeno. V takih pogojih so ne-sulfidne PHE vsebujoče oblike vezave (karbonati, oksidi in hidroksidi), večinoma stabilne, medtem ko so sulfidi manj stabilni, zaradi česar se lahko del PHE iz sulfidov izloči v vodo.

Vsebnosti 12 potencialno škodljivih elementov (As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb in Zn) v obravnavanih vzorcih voda so podani v tabeli 6. Za vrednotenje vod na obravnavanih vzorčnih lokacijah smo uporabili mejne vrednosti, določene z Uredbo o stanju površinskih voda (Uradni list RS, 2016), Uredbo o emisiji snovi in toplote pri odvajanju odpadnih voda v vode in javno kanalizacijo (Uradni list RS, 2015 – iztok voda v naravni sprejemnik) ter kot najstrožji



Sl. 8. As in Sb v sedimentih ter vodi na vzorčnih mestih Orehovice in Medije.
Fig.8. As and Sb in sediments and water from Orehovica and Medija.

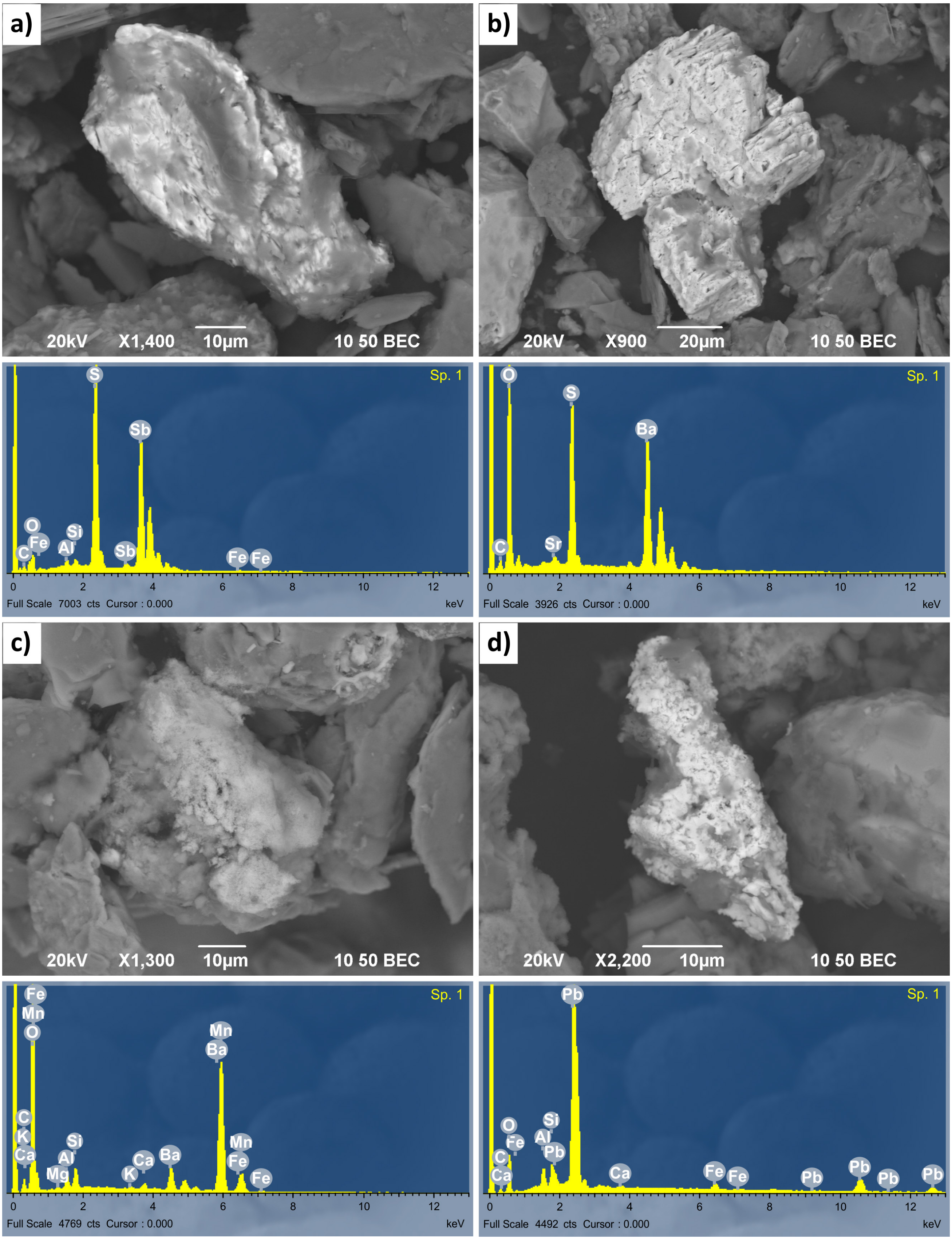


Sl. 9. SEM posnetki in EDS spektri trdnih oblik PHE v težki frakciji sedimentov: a) železov oksihidroksi sulfat z As; b) arzenopirit.

Fig. 9. SEM images and EDS spectra of solid PHE-bearing phases in heavy fraction of sediments: a) iron oxyhydroxy sulphate with As; b) arsenopyrite.

kriterij vrednotenja vod, Pravilnik o pitni vodi (Uradni list RS, 2017). V tabeli 6 so spodaj navedene vrednosti naravnega ozadja (NO), najvišje dovoljene koncentracije za površinske in odpadne vode ter najvišje dovoljene koncentracije za pitno vodo. Vsebnost kadmija (Cd) je v normativu za površinske vode odvisna od trdote vode, ki je razdeljena v pet razredov (r.1 = razred 1: <40 mg $CaCO_3$/l, r.2 = razred 2: 40 do <50 mg $CaCO_3$/l, r.3 = razred 3: 50 do <100 mg $CaCO_3$/l, r.4 = razred 4: 100 do <200 mg $CaCO_3$/l in r.5 = razred 5: ≥200 mg $CaCO_3$/l). Ravno tako je od trdote vode odvisna vrednost cinka (Zn) in je razdeljena v tri razrede: razred e (<50 mg $CaCO_3$/l), razred f (50 do <100 mg $CaCO_3$/l) in razred g (≥100 mg $CaCO_3$/l). Glede na meritve terenskih parametrov in geološko sestavo smo privzeli, da je trdota vode v obravnavanih vzorcih za Cd <40 mg $CaCO_3$/l, s čimer je normativ za Cd ≤0,45 + NO µg/l ter za Zn <50 mg $CaCO_3$/l, s čimer je normativ za Zn 78 + NO µg/l.

Vsebnosti PHE v obravnavanih vzorcih ne presegajo normativov za površinske vode. Analizirane vsebnosti As v vodi znašajo med 0,32 in 5,65 µg/l, z mediano 0,85 µg/l in ne presegajo normativa za pitne vode (10 µg/l) na nobeni vzorčni lokaciji. Koncentracije As so najvišje v zgornjem toku Kotredeščice in upadajo dolvodno do izliva v Medijo, kjer koncentracije ne presegajo 1 µg/l. Tudi v vzorcih iz Orehovice so vsebnosti As <1 µg/l. Vsebnosti As v vodi so najvišje na tistih lokacijah, kjer so povišane tudi vsebnosti



Sl. 10. SEM posnetki in EDS spektri trdnih oblik PHE v težki frakciji sedimentov: a) antimonit; b) barit; c) psilomelan; d) svinčev karbonat/oksid.

Fig. 10. SEM images and EDS spectra of solid PHE-bearing phases in heavy fraction of sediments: a) antimonite; b) barite; c) psilomelane; d) lead carbonate/oxide.

As v sedimentih, to je na lokacijah od SS-KO-01 do SS-KO-07, oziroma na vzorčnih lokacijah v potoku Kotredeščica. Zaznati je tudi rahlo povišanje koncentracije As v točki SS-KO-06, ki se nahaja pod odlagališčem jamske jalovine Ruardi, kar kaže na morebiten vpliv spiranja in raztapljanja jalovinskega materiala oz. splazitve le-tega, na povišane koncentracije As v vodah, vendar je ta vpliv zelo majhen. Vsebnosti Sb nihajo med 1,28 in 12,3 µg/l, mediana je 2,39 µg/l. Koncentracije Sb so prav tako najvišje v zgornjem toku Kotredeščice in upadajo do izliva v Medijo. Vsebnosti Sb so povišane tudi v vzorcih iz Orehovice, najnižje ugotovljene vsebnosti pa so v vzorcih iz Medije, vendar so na vseh vzorčnih lokacijah povišane glede na naravno ozadje (0,6 µg/l). Vsebnosti Sb presegajo normativ za pitne vode (5 µg/l) na 4 vzorčnih mestih, in sicer v 3 vzorcih iz Kotredeščice (SS-KO-01, SS-KO-02 in SS-KO-03) in v 1 vzorcu iz Orehovice (SS-KO-13). Na vseh teh lokacijah so povišane tudi vsebnosti Sb v sedimentih (kritična vsebnost 15 mg/kg presežena na lokacijah SS-KO-01 in SS-KO-13). Zanimivo je, da je v primerjavi z vsebnostjo As v vodah in sedimentih, vsebnost Sb v vodah relativno povišana glede na vsebnost Sb v sedimentih, predvsem v zgornjem toku Kotredeščice in v Orehovici (sl. 7 in 8), kar kaže na relativno dobro raztapljanje trdnih pojavnih oblik Sb v vodi ali na morebiten drug vir Sb v vodi.

Trdne pojavne oblike potencialno škodljivih elementov (PHE) v sedimentih

S SEM/EDS analizo smo v dveh vzorcih težke frakcije sedimentov ugotovili različne trdne oblike potencialno škodljivih elementov (PHE), predvsem As, Sb, Ba, Pb in Cu. **As** se večinoma pojavlja v obliki železovih oksihidroksi sulfatov z manjšimi vsebnostmi As (sl. 9a) in v manjši meri kot mineral arzenopirit (sl. 9b). Zrna železovih oksihidroksi sulfatov z As so velikosti med 60 µm in 70 µm in imajo na površini izrazite izsušitvene razpoke, ki so posledica oksidacije prvotnih železovih sulfidov, iz katerih so nastali. V nekaterih zrnih je ohranjeno jedro prvotnega arzenopirita (sl. 9a, sp. 1), ki postopoma prehaja preko železovih oksihidroksi sulfatov z As v železove oksihidrokside z As (sl. 9a, sp. 2). Železovi oksihidroksidi in železovi oksihidroksi sulfati so lovilci PHE, ki pa predstavljajo izmenljivo frakcijo in se zato ob spremembi naravnih pogojev lahko sprostijo nazaj v vodno okolje. Arzenopirit se pojavlja kot ostrorobi odlomki velikosti okrog 40 µm. **Sb** je vezan v nekoliko porozna mineralna zrna antimonita (sl. 10a) velikosti okoli 70 µm, sestavljena iz drobnih kristalov v združbi s svinčevim karbonatom/oksidom. Trdne pojavne oblike **Ba** zajemajo minerala barit (sl. 10b) in psilomelan (sl. 10c). Zrna barita, velikosti okrog 73 µm, so zelo porozna in tudi korodirana ter vsebujejo manjše vsebnosti Sr. Psilomelan pa tvori okrog 50 µm velike porozne agregate in prevleke iz zelo drobnih kristalov na površini drugih mineralov. **Pb** se pojavlja kot okoli 20 µm velika porozna polikristalna zrna svinčevih karbonatov/oksidov (sl. 10d). **Cu** je vezan v železove oksihidroksi sulfate z manjšimi vsebnostmi Cu, ki tvorijo okrog 50 µm velika zrna z izsušitvenimi razpokami.

Arzenopirit in Fe-oksihidroksi sulfati z As in Cu v danih pogojih v vodah niso obstojni zato postopoma prehajajo v stabilne Fe-oksihidrokside, pri čemer se As in Cu sproščata v vodno okolje. Prav tako ni stabilen antimonit. Svinčevi karbonati/oksidi, barit in psilomelan so v danih pogojih relativno stabilni. Poroznost in razpokanost povečuje specifično površino mineralov in faz zato so pri spremembi naravnih pogojev (pH, Eh) lahko podvrženi raztapljanju.

Delce z As, Sb, Ba in Cu smo določili le v vzorcu iz zgornjega toka Kotredeščice (SS-KO-01), delci s Pb pa se pojavljajo tudi v vzorcu iz osrednjega toka Orehovice (SS-KO-13). Količine trdnih delcev s PHE v obeh vzorcih so majhne in skupaj zavzemajo do največ 2,5 % vzorca.

Zaključki

Analiza sedimentov potokov Kotredeščica, Orehovica in Medija, na območju med Znojilami, Zagorjem ob Savi in Trojanami, je pokazala, da je sediment v strugi Kotredeščice med Znojilami in Zagorjem ob Savi ter v strugi Orehovice obremenjen z As in Sb, medtem ko so vsebnosti teh elementov v sedimentih struge Medije nižje. Kritična vrednost za As je presežena v 4 vzorcih sedimenta iz potoka Kotredeščica med Znojilami in krajem Rove. Kritična vrednost za Sb je presežena v 2 vzorcih, v vzorcu sedimenta iz Kotredeščice pri kraju Znojile ter v vzorcu sedimenta iz Orehovice v bližini kraja Orehovica. Vzrok povišanim vsebnostim As in Sb v sedimentih Kotredeščice so tako spiranje iz odlagališča rudarskih odpadkov, kot tudi naravno oz. geogeno povišane vsebnosti na tem območju, predvsem As. V sedimentu so namreč prisotni predvsem nestabilni rudni sulfidni minerali in sekundarni minerali, ki so nastali s preperevanjem rudnih mineralov. Domnevamo, da je vzrok za povišane vsebnosti As in Sb v strugi Orehovice prav tako spiranje materiala iz odlagališča rudarskih odpadkov iz nahajališča pod Trojanami.

Za potrditev te domneve bi bilo potrebno odvzeti še dodatne vzorce iz struge potoka Orehovica, bližje samemu nahajališču. V vzorcih vode vsebnosti As ne presegajo normativov za površinske vode. Vsebnosti Sb v vzorcih vode so povišane v zgornjem toku Kotredeščice in upadajo do izliva v Medijo. Vsebnosti Sb so povišane tudi v vzorcih iz Orehovice. Vsebnosti Sb presegajo normativ za pitne vode na 4 vzorčnih mestih, in sicer v 3 vzorcih iz Kotredeščice in v 1 vzorcu iz Orehovice. Glede na predhodne podatke iz literature in glede na naše ugotovitve domnevamo, da premogovništvo ni znatno vplivalo na povišane vsebnosti As in Sb v sedimentih in vodah na raziskovanem območju.

Zahvala

Raziskavo je financiralo Ministrstvo za infrastrukturo, DE-Sektor za energetiko in rudarstvo in Javna agencija za raziskovalno dejavnost v okviru Raziskovalnih programov P1-0020 in P1-0025, ki se izvajata na Geološkem zavodu Slovenije.

Viri in literatura

Anthony, J. W, Bideaux, R. A., Bladh, K. W. & Nichols, M. C. 2009: The handbook of mineralogy. Mineralogical Society of America, Chantilly, VA. Internet: http://www.handbookofmineralogy.org/ (6.12.2017)

Barthelmy, D. 2010: The mineralogy database. Internet: http://webmineral.com/ (6.12.2017)

Buser, S. 2009: Geološka karta Slovenije 1:250.000. Geološki zavod Slovenije, Ljubljana.

Cegnar, T., Dolinar, M., Gjerek, M., Koleša, T., Logar, M., Murovec, M., Paradiž, B., Faganeli Pucer, J., Rode, B., Rus, M., Turšič, J., Žabkar, R., Kukec, A., Otorepec, P., Uršič, A. & Uršič,S. 2016: Kakovost zraka v Sloveniji v letu 2015. Ministrstvo za okolje in prostor, Agencija Republike Slovenije za okolje, Ljubljana: 123p.

Duhovnik, J. 1946: Poročilo o geološkem ogledu nahajališč antimonita pri Zagorju in Trojanah. Poročilo. Ljubljana, Geološki zavod Slovenije.

ERICo, 2010: Poročilo o stanju okolja v Občini Zagorje ob Savi. Poročilo. ERICo Velenje, Inštitut za ekološke raziskave d.o.o.: 119 p.

Germovšek, C., Vozelj D., Tovšak R. & Grad K. 1949: Poročilo o podrobnem geološkem kartiranju produktivnega ozemlja, med Trojanami in Znojilami. Poročilo. Ljubljana, Geološki zavod Slovenije: 35 p.

Gosar, M. & Šajn, R. 2005: Arsenic in the environment: enrichments in the Slovenian soils (Arzen v okolju: vsebnosti v tleh na nekaterih območjih Slovenije). Geologija, 48/2: 253-262, doi: https://doi.org/10.5475/geologija.2005.021.

Grabner, B., Ribarič-Lasnik, C., Žerodnik, N. & Kos, M. 2012: Posnetek stanja in izdelava predloga sanacije onesnaženosti kmetijskih tal v dolini Kotredeščice – Končno poročilo. Celje: Inštitut za okolje in prostor: 35 p.

Grafenauer, S. 1964: Najdišča antimonita v Sloveniji. Rudarsko-metalurški zbornik, 3: 257-269.

Herlec, U. & Žorž, M. 2006: Antimonit med Trojanami in Znojilami. Scopolia, Supl. 3: 68-72. Internet: http://www.zobodat.at/pdf/Scopolia_Suppl_3_0068-0072.pdf (9.1.2018).

Ivanoš, J., Baskar, M., Babič, M., Rep, P. & Lapajne, S. 2012: Preiskave tal na poplavnih območjih doline Kotredeščice-Poročilo. Zavod za zdravstveno varstvo Maribor, Maribor: 20 p.

Juričič, M., Perharič, L., Čakš, T., Zupan, M., Kralj, L., Gorenc, S., Lajovic, J., Erčulj, V. & Tič, I. 2013: Izpostavljenost prebivalcev občine Zagorje ob Savi okoljskim onesnažilom – težkim kovinam v tleh in živilih rastlinskega izvora: poročilo. Ljubljana: Zavod za zdravstveno varstvo.

Klabus, A. 1995: Neurje 28. in 29. junija 1994 v Zasavju. Ujma 9: 24–27. Internet: http://www.sos112.si/slo/tdocs/ujma/1995/24_27.pdf

Kočevar, H. 2000: Vpliv pepela z odlagališča TE Trbovlje na tla in rastline. Influence of ash from ash repository pile of Trbovlje coal fired plant on soil and plants. RMZ – Materials and geoenvironment, 47/3-4: 255-266.

Kugonič, N. 1998: Posnetek stanja onesnaženosti tal in rastlinskega materiala na območju Zagorje ob Savi. Poročilo. ERICo, Velenje: 55 p.

Kuščer, D. 1967: Zagorski terciar. Geologija, 10: 5-85.

Kuščer, D., Sovine, I., Vidic, F. & Vidmar, S. 1988: Plaz v Zagorju vzroki in posledice. Ujma, 2; 20–29.

Markič, M. 2017: High arsenic (As) content in coals from Neogene deposits of the Pannonian Basin in Slovenia. = Visoka vsebnost arzena (As) v premogih iz neogenskih plasti Panonskega bazena na območju Slovenije. Geologija, 60/2: 173-180, doi: https://doi.org/10.5474/geologija.2017.012.

Markič, M. & Brenčič, M. 2014: High arsenic (As) content in the Upper Miocene coal matter from TER-1/03 borehole (Terbegovci

– Sveti Jurij ob Ščavnici, NE Slovenia) = Visoka vsebnost arzena (As) v drobcih zgornjemiocenskega premoga iz vrtine TER-1/03 (Terbegovci – Sveti Jurij ob Ščavnici, SV Slovenija). Geologija, 57/1: 15-26, doi: https://doi.org/10.5474/geologija.2014.002.

Markič, M., Uhan, J. & Jelen, B. 1993: Litološke, geokemične in paleobotanične značilnosti zasavske premogovne plasti v profilih Neža in Lopata. Rudar.-metal. 33. skok čez kožo - povzetki predavanj, Ljubljana: 2-4.

Mlakar, I. 1983: Metalogenetske študije za območje Slovenije (3. faza). Geološki zavod Ljubljana: 174 p.

Nriagu, O. J. 1989: Natural versus anthropogenic emissions of trace metals to the atmosphere. In: Pacyna, J.M. & Ottar, B. (ur.): Control and Fate of Atmospheric Trace Metals. NATO ASI Series, 268, Dordrecht, Boston, London, Kluwer Academic Publishers: 3-13.

Perharič, L. 2013: Arzen v dolini Kotredeščice. Ocena tveganja za zdravje ljudi. Ljubljana, Inštitut za varovanje zdravja Republike Slovenije: 16 p.

Perharič, L., Martinčič, M., Uršič, S., Kukec, A., Zadnik, V., Mazej, D., Šlejkovec, Z., Šter M., France-Štiglic, A. & Eržen, I. 2017: Poglobljena ocena tveganja za zdravje otrok zaradi izpostavljenosti arzenu v občini Zagorje ob Savi. Ljubljana, Nacionalni inštitut za javno zdravje: 98 str. Internet: http://www.nijz.si/ (4.1.2018)

Pirc, S. & Žuža, T. 1989: Sledne prvine v premogih v SR Sloveniji. Rudarsko-metalurški zbornik, 36/2: 161-172.

Pavšič, J. & Horvat, A. 2009: Eocen, oligocen in miocen v osrednji in vzhodni Sloveniji. In: Pleničar, M., Ogorelec, B. & Novak, M. (eds.): Geologija Slovenije = The Geology of Slovenia. Geološki zavod Slovenije, Ljubljana: 385-387.

Placer, L. 1999: Structural meaning of the Sava folds (Strukturni pomen Posavskih gub). Geologija, 41: 191-221, doi: https://doi.org/10.5474/geologija.1998.012.

Premru, U. 1983: Tolmač za list Ljubljana. Osnovna geološka karta SFRJ 1 : 100 000. Zvezni geološki zavod Beograd: 75 p.

Rečnik, A. & Daneu, N. 2007: Kristali kremena in arzenopirita z Znojil pri Trojanah. In: Rečnik A. (ed.): Nahajališča mineralov v Sloveniji. Ljubljana: 140–151.

Ribarič-Lasnik, C., Pačnik, L., Savinek, K., Poličnik, H., Bienelli-Kalpič, A., Plut, D., Bole, M., Kugonič, N., Beričnik-Vrbovšek, J., Al Sayegh-Petkovšek, S., Pokorny, B., Glasenčnik, E., Pavšek, Z. & Kopušar, N. 2001: Onesnaženost okolja in naravni viri kot dejavniki razvoja v Zasavski regiji modelni pristop: končno poročilo. ERICo, Velenje: 140 p.

ROTS, 1999: Projekt Raziskave onesnaženosti tal Slovenije v letu 1999. Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za agronomijo, Center za pedologijo in varstvo okolja. Internet: http://soil.bf.uni-lj.si/rots/index.php?page=rots/proj (4.1.2018).

Rozina, R. 2005: Zadnji šiht: 250 let rudnika Zagorja. Zagorje: Regionalni center za razvoj: 119 p.

Salminen, R., Batista, M.J., Bidovec, M., Demetriades, A., De Vivo, B., De Vos, W., Duris, M., Gilucis, A., Gregorauskiene, V., Halamić, J., Heitzmann, P., Lima, A., Jordan, G., Klaver, G., Klein, P., Lis, J., Locutura, J., Marsina, K., Mazreku, A., O'Connor, P.J., Olsson, S.A., Ottesen, R., Petersell, V., Plant, J.A., Reeder, S., Salpeteur, I., Sandström, H., Siewers, U., Steenfelt, A., Tarvainen, T. 2005: Geochemical Atlas of Europe, Part 1, Background Information, Methodology and Maps. Geological Survey of Finland, Espoo: 1-525.

Sotlar, K. 1995: Potočni sediment kot vzorčno sredstvo za izdelavo geokemične karte Slovenije, diplomsko delo. Univerza v Ljubljani, Naravoslovnotehniška fakulteta, Oddelek za geologijo: 1-114.

Šajn, R. & Gosar, M. 2003: Primerjava določitve vsebnosti kemičnih prvin v tleh in podstrešnem prahu po pripravi z različnima kislinskima postopkoma. Geologija, 46/2: 273–280, doi: https://doi.org/10.5474/geologija.2003.024.

Šlejkovec, Z. & Kanduč, T. 2005: Unexpected arsenic compounds in low-rank coals. Environmental Science & Technology, 39: 3450–3454.

Uhan, J. 1991: Geokemične značilnosti premogove plasti v trboveljsko-ojstrški strukturni enoti. Magistrsko delo, Univerza v Ljubljani: 90 p.

Uhan, J. 1993: Geokemična tipomorfnost zasavskega premoga. Rudarsko-metalurški zbornik, 40: 45-58.

Uhan, J. 1996: Metodološki prispevek h geokemični razčlenitvi premogovih plasti = Methodological contribution to geochemical subdivision of coal seams. Geologija, 37/38 (1994/95): 305-319.

Uradni list RS 2004: Uredba o mejnih, opozorilnih in kritičnih imisijskih vrednostih nevarnih snovi v tleh. Uradni list RS, št. 68/96 in 41/04 – ZVO-1.

Uradni list RS 2015: Uredba o emisiji snovi in toplote pri odvajanju odpadnih voda v vode in javno kanalizacijo. Uradni list RS, št. 64/12, 64/14 in 98/15.

Uradni list RS 2016: Uredba o stanju površinskih voda. Uradni list RS, št. 14/09, 98/10, 96/13 in 24/16.

Uradni list RS 2017: Pravilnik o pitni vodi. Uradni list RS, št. 19/04, 35/04, 26/06, 92/06, 25/09, 74/15 in 51/17.

Uršič, A., Bošnjak, K., Zagajšek, A., Gobec, M. & Goličnik, B. 2011: Analiza vzorcev tal in pitne vode na prisotnost arzena: Poročilo.

Vrom, 2000: Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milie = The Ministry of Housing, Spatial Planning and the Environment. Dutch Target and Intervention Values, (the New Dutch List). Internet: https://www.esdat.net/Environmental%20Standards/Dutch/annexS_I2000Dutch%20Environmental%20Standards.pdf (19.9.2017)

Vudrag, M. 2008: Od podrobnejše analize okolja in zdravja v zasavski regiji do odpravljanja razlik v zdravju. Elaborat »Zdravje za Zasavje«. Zavod za zdravstveno varstvo Ljubljana: 52 p.

Zupan, M., Grčman, H. & Lobnik, F. 2008: Raziskave onesnaženosti tal Slovenije – ROTS. Agencija RS za okolje, Ljubljana: 68 p.

ZZV (Zavod za zdravstveno varstvo) 2012: Rezultati vzorčenja vrtnin v Zasavju.

GEOLOGIJA 61/1, 25-32, Ljubljana 2018

https://doi.org/10.5474/geologija.2018.002

Quantified joint surface description and joint shear strength of small rock samples

Geometrijske lastnosti površine razpok in strižna trdnost po razpoki za manjše vzorce kamnin

Karmen FIFER BIZJAK & Andraž GERŠAK

Slovenian national building and civil engineering institute, Dimičeva ul. 12, SI-1000 Ljubljana, Slovenia;
e-mails: karmen.fifer@zag.si, andraz.gersak@zag.si

Prejeto / Received 31. 1. 2018; Sprejeto / Accepted 23. 4. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Key words: camera-type 3D scanner, rock mechanics rock joint, roughness of the joints, rock joint shear strength

Ključne besede: 3D skener s kamero, mehanika hribin, hrapavost razpok, strižna trdnost kamnine po razpoki

Abstract

Geotechnical structures in rock masses such as tunnels, underground caverns, dam foundations and rock slopes often have problems with a jointed rock mass. The shear behaviour of a jointed rock mass depends on the mechanical behaviour of the discontinuities in that particular rock mass. If we want to understand the mechanical behaviour of a jointed rock mass, it is necessary to study the deformation and strength of a single joint. One of the primary objectives of this work is to improve the understanding of the frictional behaviour of rough rock joints under shear loads with regard to the roughness of the joint surface. The main problem is how to measure and quantify the roughness of the surface joint and connect the morphological parameters into a shear strength criterion. Until now, several criteria have been developed; however, all of them used large rock samples (20×10×10 cm). It is often not possible to get large samples, especially when the rock is under a few meters thick layer of soil. In this case, samples of rock can only be acquired with investigation borehole drilling, which means that the samples of rock are small and of different shapes. The paper presents the modified criterion that is suitable for calculating the peak shear stress of small samples.

Izvleček

Geotehnični objekti v hribini, kot so predori, podzemni prostori, pregrade in strme brežine, pogosto povzročajo težave zaradi različne razpokanosti hribinskega masiva. Strižno obnašanje celotnega hribinskega masiva je odvisno od razpok in njihovih strižnih lastnosti. Če želimo razumeti mehansko obnašanje hribinskega masiva, je potrebno preiskati strižne trdnostne karakteristike vsakega sistema razpok. Namen predstavljene raziskave je, da se preuči obnašanje razpok pod strižnimi obremenitvami v odvisnosti od hrapavosti površine razpok. Največji problem se pokaže pri meritvah hrapavosti razpok in povezave morfoloških parametrov površine razpoke s strižnimi karakteristikami same razpoke. Do sedaj je bilo predstavljenih že več kriterijev, vendar so bili vsi razviti na osnovi testiranja velikih vzorcev kamnine (20×10×10 cm). V večini primerov pa je velikih vzorcev kamnine nemogoče dobiti, predvsem takrat, ko je kamnina globoko pod več metrov debelo plastjo zemljine. V tem primeru se vzorce hribine lahko pridobi samo z raziskovalnim vrtanjem. Tako dobljeni vzorci pa so malih dimenzij in različnih oblik. V članku je predstavljen modificiran kriterij, ki je uporaben za izračun vrhunske strižne trdnosti v primeru, da imamo za raziskave dostopne samo vzorce manjših dimenzij.

Introduction

Geotechnical structures in rock material such as tunnels, underground caverns, dam foundations and rock slopes often have problems with a jointed rock mass. The shear behaviour of a jointed rock masses depends on the mechanical behaviour of the discontinuities in that particular rock mass. If we want to understand the mechanical behaviour of a jointed rock mass, it is necessary to study the deformation and strength of a single joint. Until now, many experimental and numerical investigations have been carried out on the mechanical behaviour of rock joints (Barton, 1973; 1976; Barton & Choubey, 1977; Grasselli & Egger, 2003; Hoek & Brown, 1980; Hoek & Bray, 1981; Hoek, 2000; Huang et al., 1992; Patton, 1966; Pellet et al., 2013).

The joint surface is one of the parameters that have the highest influence on the shear strength of the rock joint. Many parameters have been proposed over the past 40 years to describe the joint surface. Barton (1973) proposed a joint roughness coefficient (JRC) to quantify the roughness of a rock joint. The roughness profile of the nature rock joint is visually compared with 10 standard profiles suggested by Barton and Choubey (1977). However, the visual comparison method can be subjective without sufficient experience. The JRC has been widely used in rock engineering and is suggested by the International Society for Rock Mechanics (ISRM) as a useful parameter for describing the joint surface. In the last decade, several researchers published that the roughness of the rock joint could be somewhat underestimated (Hong et al., 2008; Lee et al., 2001).

Other methods using the fractal analysis (Kulatilake, et al., 2006; Odling, 1994) or the statistical approach (Reeves, 1985) have been used for identifying the rock joints. For all those methods, the two-dimensional (2D) description of the surface is used, although the joints have a three-dimensional morphology. Nowadays, with the advanced techniques, it is possible to measure and characterise the joint surface in three dimensions. The roughness metric based on the three-dimensional morphology was proposed by Grasselli (2001, 2002). The ATOS scanner was used for the accurate measurement of the joint roughness (Grasselli & Egger, 2003). The procedure of the roughness measurements is quite clear, yet the relationship between the joint mechanical properties and the geometric parameters is still the object of research nowadays. An empirical relation with the shear strength of the rock joints was studied and three-dimensional roughness parameters such as the contact area, the roughness parameter C and maximum dip angle Θ^{*}_{max} were proposed for the calculation (Grasselli & Egger, 2003; Graselli, 2006). All the parameters were determined by morphology functions. However, the anisotropy of rock joint was not considered in this criterion. Further research developed the modified peak shear strength criteria which could reflect the effect of dilatancy (Tang et al., 2014, 2015). The relationship between peak dilatancy angle and three-dimensional morphology characteristics was taken into consideration in these criteria. In the criterion proposed by Xia (2013), the variation law of the dilatancy angle under various normal stresses was not inconsistent with the actual situation. Samples on which the shear tests were performed in all mentioned papers were of large dimensions, at least 200 cm^2. It is often not possible to get large samples, especially when the rock is under a few meters thick layer of soil. In this case, samples of rock can only be acquired with investigation borehole drilling, which means that samples of rock are small and of different shapes.

In the presented paper, the smaller samples from bore hole drilling were used for direct shear testing. For testing, the Robertson shear apparatus was used. That apparatus is limited by the size of the samples and by the height of normal and shear loads. Based on the experiment, a modified peak shear strength criterion was proposed, and a comprehensive criterion was developed for samples with smaller size and lower loads.

Methods

Use of a 3D Scanner

For measuring rock joint roughness, a camera-type digital three-dimensional scanner was used (fig. 1), which is a combined system with photogrammetry and fringe projection. It uses two cameras to capture the same position or asperity and can thus produce three-dimensional images showing the height of the asperity. Photogrammetry can be used for the measurement of sensor coordinates as well as for the global matching of partial views. In fringe projection, the projector illuminates the stripe of the patterned light on an object and two cameras capture the deformed shape of fringe by the object. An accurate roughness profile may be obtained by specific fringe characteristics. Therefore, the roughness underestimation of unevenness can be improved. Although this method requires a merging process because of image overlapping with "multi-viewing", it produces a high resolution image quickly and conveniently (Reich et al. 2000; Lee & Ahn 2004).

While this method can quickly provide the high density cloud point, it is very sensitive to environmental conditions (Fifer, 2010).

The selected system for this study was Advanced Topometric Sensor (ATOS I) which combines photogrammetry and fringe projection. Because this system can yield high density three-dimensional point clouds for each image, it also requires a high computing system. ATOS has been used in the field of engineering

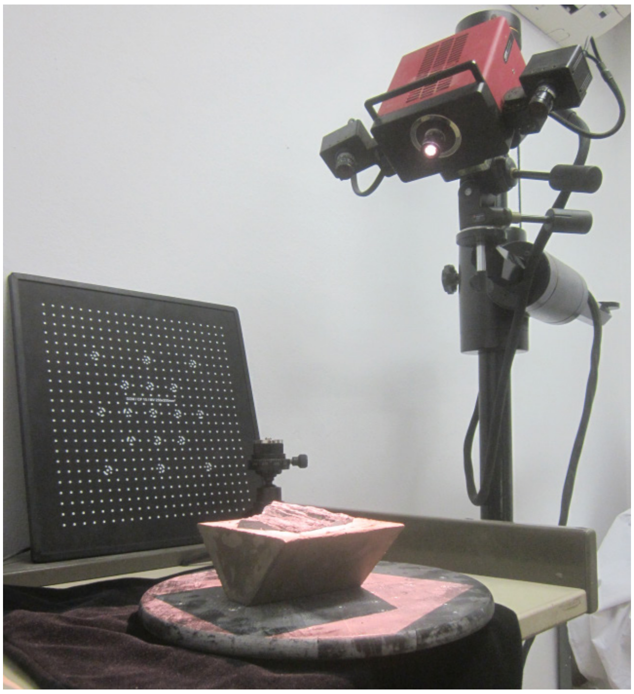


Fig. 1. The ATOS I 3D scanner and the sample.

Table 1. The properties of the optical scanning system ATOS I.

Item	Value
Measured Points	800.000
Measurement Time (seconds)	0.8
Measuring Area (mm²)	125 × 100 - 1000 × 800
Point Spacing (mm)	0.13-1.00
Measuring volume (mm³)	125×100×90 to 1000×800×800
Measuring points per individual scan	1032×776 pixels

for product digitization in industries such as the automotive industry. Details of the selected system are summarized in Table 1. The quality of surface measurements is very important to the estimation of roughness. The accuracy of the morphological model is dependent on the density of measurement points, measurement resolution and the precision with which these points can be located in space.

The camera-type 3D scanner has several advantages:

- the scanning process is fast and the image is accurate,
- the large scale of the specimen can be digitized,
- the scanning process can be performed in the field,
- the rock surface is not damaged during digitizing.

Calculation methods

The morphological parameters which we acquired with the scanning of samples were used for further calculation. The peak shear strength of samples was calculated according to several criteria which have been developed until now.

Grasselli (2001) proposed the apparent dip angle to calculate the three-dimensional morphology parameters (fig. 2). The average inclination angle is used according to the results of his research

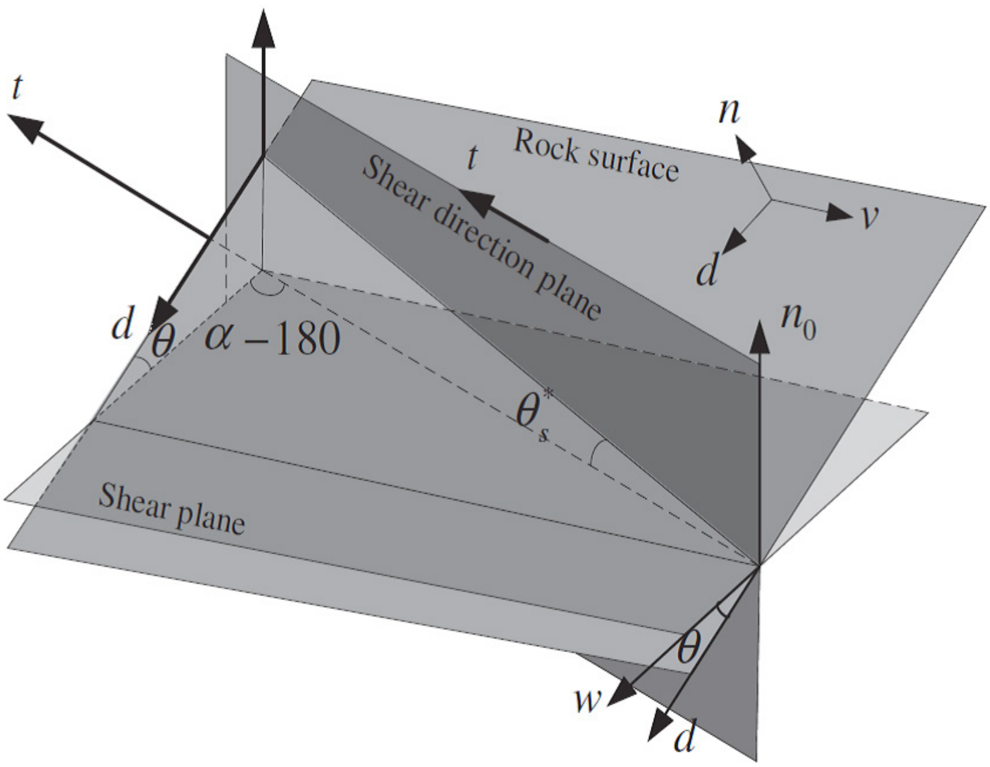


Fig. 2. Calculation of the 3D average angle of the rock joint surface (Grasselli, 2001). Grasselli (2001) proposed the criterion (G01) for calculating the peak shear stress according to the eq. 6.

$$\tan\theta_S^* = \tan\theta\,(-\cos\alpha) \quad (1)$$

$$\cos\theta = \frac{nn_o}{|n||n_o|} \quad (2)$$

$$\cos\alpha = \frac{tn_1}{|t||n_1|} \quad (3)$$

$$\overline{\theta^*} = \frac{tn_1}{|t||n_1|}\frac{1}{m}\sum_{i=1}^{m}\theta_{si}^* \quad (4)$$

where m is the number of triangles, θ^*_{si} is the apparent dip angle of the surface unit, α is the azimuth,   is the tilt angle, $\boldsymbol{t}$ is the shear direction vector, $\boldsymbol{n}$ is the outward normal vector of the triangle, $\boldsymbol{n_0}$ is the outward normal vector of the plane (see Fig. 2) and $\boldsymbol{n_1}$ is the projection vector of $\boldsymbol{n}$. The maximum contact area is calculated as follows:

$$A_0 = \frac{A_l}{A_m} \quad (5)$$

where A_l is the sum of the area facing to the shear direction (θ^*_{si} is greater than zero) and A_m is the actual area of the whole joint surface.

$$\tau_p = \sigma_n * tan(\varphi_r') * \left(1 + exp\left(-\frac{1}{9A_0} * \frac{\theta^*_{max}}{C} * \frac{\sigma_n}{\sigma_t}\right)\right) \quad (6)$$

where s_n is the normal stress, s_t is tension strength of the rock and f_r a residual angle of friction, θ^*_{max} is the maximum apparent dip angle of the surface with respect to the shear direction, C is the roughness parameter, calculated using a best-fit regression function, which characterises the distribution of the apparent dip angles over the surface.

The next version of the same criterion (G06) includes parameter β which is the angle between the plane of schistosity and normal to the sample surface and where f_b is the basic angle of friction got from the direct shear test in laboratory.

$$\tau_p = \sigma_n\left[1 + \exp(-\frac{1}{9A_0} * \frac{\theta^*_{max}}{C} * \frac{\sigma_n}{\sigma_t}\right] * tan\left[\varphi_b + \left(\frac{\theta^*_{max}}{C}\right)^{1{,}18cos\beta}\right] \quad (7)$$

A peak shear strength criterion (X13) with the use of a form of the Mohr-Coulomb equation was developed by Xia (Xia, 2013). The criterion is presented with eq. 8.

$$\tau_p = \sigma_n * tan\left\{\varphi_b + \frac{4 * A_0 * \theta^*_{max}}{C+1}\left[1 + exp\left(-\frac{1}{9A_0} * \frac{\theta^*_{max}}{C+1} * \frac{\sigma_n}{\sigma_t}\right)\right]\right\} \quad (8)$$

With the further use of the laser scanner technology, new criteria were developed (Tang 2014). The proposed shear strength criterion (T14) is capable of predicting the shear strength of rough joints.

$$\tau_p = \sigma_n * tan\left[\varphi_b + 10 * \frac{A_0 * \theta^*_{max}}{(C+1)} * \frac{(\sigma_t/\sigma_n)}{1 + (\sigma_t/\sigma_n)}\right] \quad (9)$$

All criteria are the common parameters A_0, Θ^*_{max} and C, proposed by Grasselli.

All of these criteria are very similar to each other, as they are written according to the equation (7), except for the criterion G01 (equation 6). Common to all of them is , which is multiplied by the tangent of base friction angle to which an additional angle is added, which represents the crushing of the rock teeth of the surface sample and also influence of dilation. The differences between the criteria are actually at this additional angle. It is described with the parameters of the surface, A_0,C, θ^*_{max} .

Test procedure

Samples for direct shear test were taken from different rock formations from the northern part of Slovenia. The types of rock vary from clayey limestone, siltstone to the permo-carboniferous shale rock with very low geomechanical characteristics.

Among many samples, 19 of them were selected for testing. All samples have a natural fracture. The joint surface was scanned by 3D scanner system before the shear test to measure the morphology of the surface (fig. 3). A data processing programme was used to calculate the 3D statistical characterisation parameters.

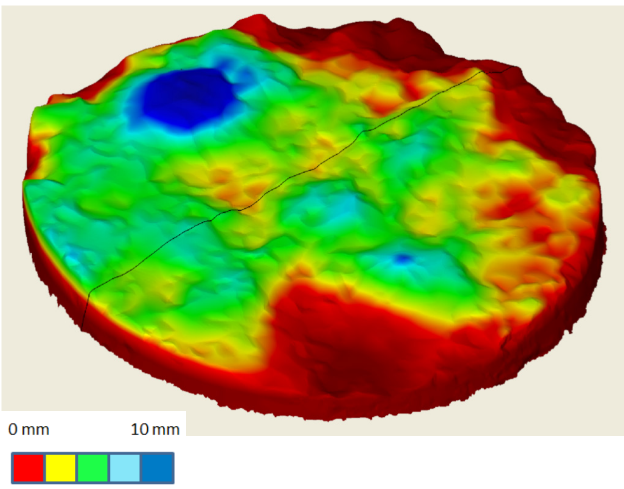


Fig. 3. An example of the scanned sample.

For the direct shear testing, the Robertson apparatus was used. This equipment is very useful for small samples which were acquired with borehole drilling. Shear tests of several rock joint samples under different normal loads have been tested (0.1, 0.2, 0.4 MPa) in order to relate the peak shear strength of a rock joint with the three-dimensional (3D) surface. The test was performed according to the standard ASTM D5607 -08. When the shear displacement reached the post-peak stage and stabilised for a while, the test was stopped. During shearing, normal deformation, horizontal deformation, normal load and shear force of the joint samples were monitored and recorded.

Results

The peak shear strength was calculated for every sample according to the criterion described in the previous chapter. The input data for the calculation are presented in Table 2 and include the input data for the shear peak strength criteria; G01, G06, X13 and T14. The results of the direct shear test and the results of the calculated peak shear strength according to the different criteria are presented in Table 3.

Table 3. Results of peak shear strength calculation under different criteria.

No.	τ_p measured (MPa)	τ_p G01 (MPa)	τ_p G06 (MPa)	τ_p X13 (MPa)	τ_p T14 (MPa)	τ_p X13 mod (MPa)
1	0.401	0.444	0.595	0.459	0.492	0.012
2	0.106	0.087	0.118	0.106	0.126	0.006
3	0.070	0.081	0.119	0.063	0.069	0.169
4	0.064	0.086	0.104	0.061	0.066	0.046
5	0.245	0.327	0.388	0.257	0.269	0.021
6	0.232	0.323	0.410	0.302	0.322	0.165
7	0.115	0.129	0.200	0.138	0.162	0.064
8	0.168	0.130	0.181	0.175	0.177	0.070
9	0.087	0.075	0.098	0.077	0.081	0.225
10	0.276	0.222	0.286	0.267	0.251	0.055
11	0.217	0.280	0.429	0.271	0.307	0.181
12	0.087	0.078	0.102	0.081	0.085	0.056
13	0.278	0.191	0.326	0.357	0.353	0.366
14	0.065	0.085	0.101	0.064	0.068	0.052
15	0.077	0.077	0.092	0.064	0.066	0.239
16	0.219	0.235	0.277	0.232	0.221	0.035
17	0.106	0.067	0.119	0.124	0.156	0.045
18	0.170	0.215	0.309	0.279	0.340	0.411
19	0.328	0.480	0.688	0.465	0.519	0.306

Table 2. Input data for the peak shear strength calculation.

No.	**Lithology**	σ_t (MPa)	σ_n (MPa)	ϕ_b (°)	A_0 (-)	C (-)	θ^*_{max} (°)
1	marly limestone	1.99	0.60	24	0.415	17.03	86.86
2	marly limestone	1.99	0.10	24	0.579	16.99	89.69
3	marly limestone	1.99	0.10	24	0.177	12.87	86.20
4	marly limestone	1.99	0.10	24	0.300	22.04	75.11
5	marly limestone	1.99	0.40	24	0.395	27.92	86.95
6	marly limestone	1.99	0.40	24	0.454	12.20	51.89
7	dolomite	2.17	0.15	25	0.341	11.90	90.00
8	perm. slate	0.30	0.20	24	0.542	15.04	86.21
9	perm. slate	0.30	0.10	24	0.472	9.22	42.93
10	perm. slate	0.30	0.40	24	0.471	9.30	41.42
11	siltstone	2.00	0.40	26	0.200	11.61	87.28
12	claystone	0.30	0.20	20	0.120	19.98	84.74
13	claystone	0.30	0.40	24	0.502	9.40	84.24
14	claystone	1.00	0.10	24	0.366	28.62	89.90
15	claystone	0.30	0.10	24	0.395	24.40	79.72
16	claystone	0.30	0.40	24	0.395	25.60	77.60
17	claystone	0.30	0.10	24	0.511	9.25	89.05
18	siltstone	2.00	0.20	30	0.515	12.46	84.87
19	dolomite	2.49	0.60	28	0.260	12.72	84.31

For all results, the average estimation error was calculated E_{ave} (Kulatilake et al., 1995), which is presented in Table 4.

$$E_{ave} = \frac{1}{m}\sum_{i=1}^{m}\left|\frac{\tau_{test} - \tau_{cal.}}{\tau_{test}}\right| * 100\% \qquad (10)$$

Table 4. Average estimation error for every criterion.

τp G01 (%)	τp G06 (%)	τp X13 (%)	τp T14 (%)	τp X13 mod (%)
23	45	16	23	13

According to the results, a small correction was used to get a better correlation between the measured and calculated peak shear strength for the criterion X13. For the testing with the Roberston apparatus, the samples have to be smaller and with the small change of the equation, better correlation was achieved and modified criterion (X13mod) is presented in eq 11.

$$\tau_p = \sigma_n * tan\left\{\varphi_b + \frac{4{,}9 * A_0 * \theta^*_{max}}{C+1}\left[1 + exp\left(-\frac{1}{A_0} * \frac{\theta^*_{max}}{C+1} * \frac{\sigma_n}{\sigma_t}\right)\right]\right\} \qquad (11)$$

Discussion

This paper presented a detailed methodology to evaluate the three-dimensional roughness of joint surfaces in rock material. The presented methodology uses 3D surface measurements, which are becoming more widely available with the increasing availability of commercial optical measuring devices. The advantage of using 3D scanner is in determining the morphological parameters for the whole surface, not only on a single profile. The use of these parameters allows studying the directional micro-mechanical response of the entire sheared joint.

The proposed roughness evaluation methodology was demonstrated by digitizing and analysing the fracture surfaces of 19 specimens. Samples used in the referred studies (Grasselli, 2001, 2006; Xia, 2013; Tang, 2014) have a dimension at least 200 mm × 100 mm x 100 mm and were consolidated under high normal stresses (more than 1 MPa). It is often not possible to get large samples for testing material in a large direct shear test. Borehole samples are smaller and have various shapes and sizes. In this case, samples are usually tested in Robertson direct shear test apparatus.

In our case, the samples were taken from boreholes and were different with regard to their dimension and shape. The samples were tested under low normal load (no more than 0.4 MPa). The peak shear strengths of natural joints obtained experimentally in laboratory tests were compared with the values calculated by Eq. 7, 8, 9 and 10 as listed in Table 3. According to the correlation analysis, the calculated values are slightly larger than the measured values (fig. 4), but the predicted shear strength from criteria is close to the experimental shear strength of natural joints. Hence, it can be deduced that the proposed shear strength criterion is capable of predicting the shear strength of rough joints. For all criteria, the average estimation errors were

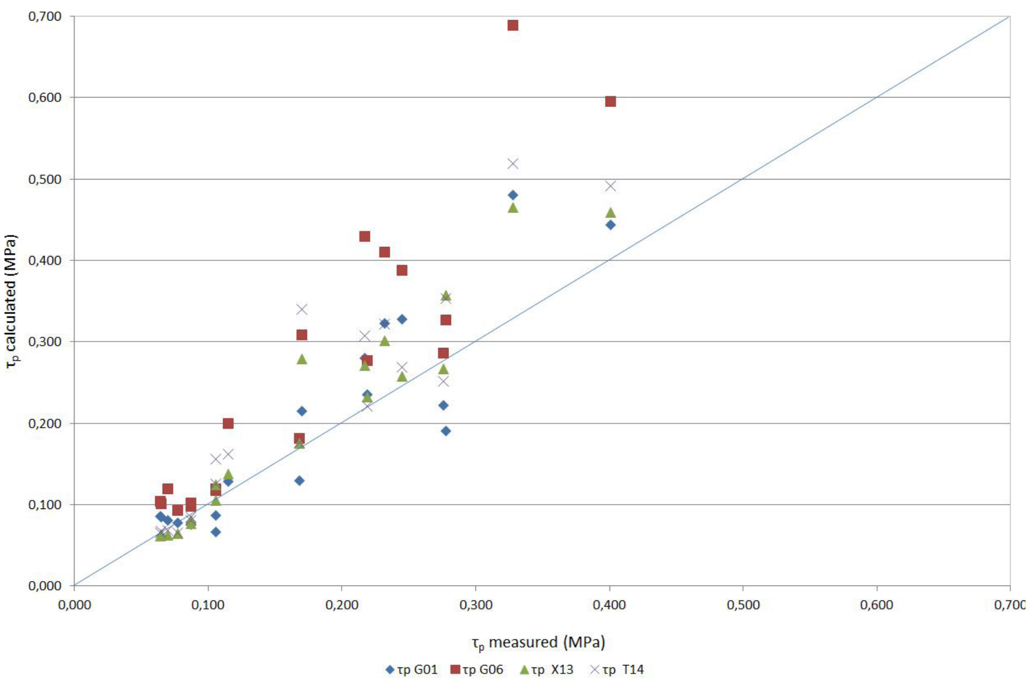


Fig. 4. The comparison between calculated.

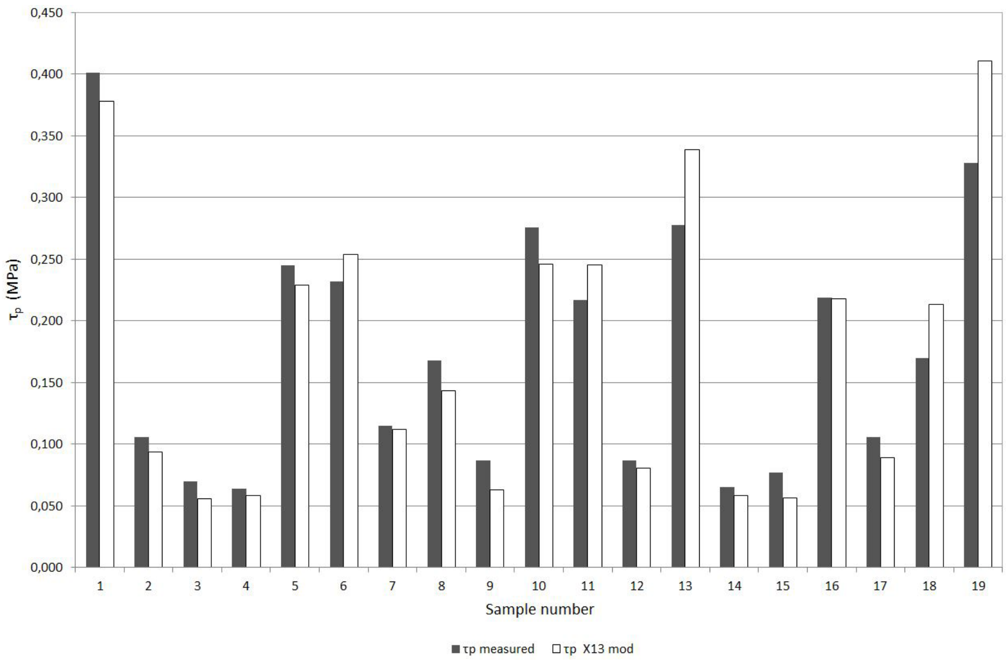


Fig. 5. The comparison between calculated and measured peak shear strength for modified criterion X13mod.

calculated according to the eq. 10. The criterion which fits the best with the measurement data is criterion X-13 with the average estimation error 16 %. To improve the results, we changed the criterion X-13 in a part of the equation where the area A_o is included (Eq. 11), because smaller samples in our research were used. With this small correction, the average estimation error decreases to 13 %. The comparison between calculated and measured peak shear strength for modified criterion X13mod is presented in fig. 5.

For future research, it is necessary to test more samples of the same lithology. The samples tested in our case were very different in the sense of the surface roughness. We could probably get better results if tests were done for every type of rock separately, of course with an adequate number of samples. The size of the samples affected the results and there is probably a reason that the average estimation errors in our research work were not lower for other already known and used criteria.

Conclusions

Shear behaviour of rock joints is investigated with the Robertson apparatus. The shear strength increases with the increasing of normal stress and roughness. The proposed modified criterion can be used as a predictive tool to assess the peak shear strength under the low normal load and if we could only use small samples from the investigation boreholes.

Development of the scanning technology could be used for high-resolution surface characterization in the laboratory, but may also allow joint characterisation in-situ in future research.

Acknowledgement

This paper was prepared from the some results of work carried out within the research project "DESTinationRAIL - Decision Support Tool for Rail Infrastructure Managers" , No. 636285 funded by the European Union, within the scope of HORIZON 2020.

References

Barton, N. 1973: Review of a new shear-strength criterion for rock joints. Eng. Geol., 7/4: 287–332.

Barton, N. 1976: The shear strength of rock and rock joints. Int. J. Rock. Mech. Min. Sci. Geomech. Abstr. 13/9:255–279.

Barton, N. & Choubey, V. 1977: The shear strength of rock joints in theory and practice. Rock Mech 10/1–2:1–54.

Fifer, B.K. 2010: Determining the Surface Roughness Coefficient by 3DScanner. Geologija, 53/2: 147-152, doi: https://doi.org/10.5474/geologija.2010.012.

Grasselli, G. 2001: Shear strength of rock joints based on quantified surface description. PhD Dissertation. Ecole Polytechnique Federale de Lausanne, Lausanne: 126 p..

Grasselli, G. 2006: Shear Strength of Rock Joints Based on Quantified Surface Descripiton. Rock Mechanics and Rock Engineering, 39/ 4: 295-314, doi: https://doi.org/10.1007/s00603-006-0100-0.

Grasselli, G. & Egger, P. 2003: Constitutive law for the shear strength of rock joints based on three-dimensional surface parameters. International Journal of Rock Mechanics and Mining Sciences, 40/1: 25–40, doi: https://doi.org/10.1016/S1365-1609(02)00101-6.

Grasselli, G., Wirth, J. & Egger, P. 2002: Quantitative three-dimensional description of a rough surface and parameter evolution with shearing. International Journal of Rock Mechanics and Mining Sciences, 39/6: 789–800, doi: https://doi.org/10.1016/S1365-1609(02)00070-9.

Hoek, E. 2000: Shear strength of discontinuities. Rock engineering, 61–72, http://www.rocscience.com/hoek/PracticalRockEngineering.asp.

Hoek, E. & Bray, J. W. 1981: Rock slope engineering. Vancouver, CRC Press.

Hoek, E. & Brown, E. T. 1980: Empirical strength criterion for rock masses. Journal of Geotechnical and Geoenvironmental Engineering, 106: 1013–1035.

Hong, E. S., Lee, J. S. & Lee, I. M. 2008: Underestimation of roughness in rough rock joints. International Journal for Numerical and Analytical Methods in Geomechanics, 32: 1385–1403, doi: https://doi.org/10.1002/nag.678.

Huang, S. L., Oelfke, S. M. & Speck, R. C. 1992: Applicability of fractal characterization and modelling to rock joint profiles. International Journal of Rock Mechanics and Mining Sciences & Geomechanics, Abstracts, 29: 89–98.

Kulatilake, P. H. S. W., Balasingam, P., Park, J. & Morgan, R. 2006: Natural rock joint roughness quantification through fractal techniques. Geotechnical & Geological Engineering, 24: 1181–1202, doi: https://doi.org/10.1007/s10706-005-1219-6.

Kulatilake P. H. S. W., Shou G., Huang T. H., Morgan R. M. 1995: New peak shear strength criteria for anisotropic rock joints. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 32/7: 673–697, doi: https://doi.org/10.1016/0148-9062(95)00022-9.

Lee, H. S. & Ahn, K. W, 2004: A prototype of digital photogrammetric algorithm for estimating roughness of rock surface. Geosciences, 8/3: 333-341.

Lee, H. S., Park, Y. J., Cho, T. F. & You, K. H. 2001: Influence of asperity degradation on the mechanical behaviour of rough rock joints under cyclic shear loading. International Journal of Rock Mechanics and Mining Sciences, 38/7: 967–980, doi: https://doi.org/10.1016/S1365-1609(01)00060-0.

Odling, N. E. 1994: Natural fracture profiles, fractal dimension and joint roughness coefficients. Rock Mechanics and Rock Engineering, 27: 135–153.

Patton, F.D. 1966: Multiple modes of shear failure in rock. In: Proceedings of the 1st congress of International Society for Rock Mechanics, 1: 509–513.

Pellet, F. L., Keshavarz, M. & Boulon, M. 2013: Influence of humidity conditions on shear strength of clay rock discontinuities. Engineering Geology, 157: 33–38.

Reeves, M. J. 1985: Rock surface roughness and frictional strength. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 22/6: 429–442, doi: https://doi.org/10.1016/0148-9062(85)90007-5.

Reich, C., Ritter, R. & Thesing, J. 2000: 3-D shape measurement of complex objects by combining photogrammetry and fringe projection. Optical Engineering, 39/1: 224-231, doi: https://doi.org/10.1117/1.602356.

Tang, Z. C., Liu, Q. S. & Huang, J. H. 2014: New criterion for rock joints based on three-dimensional roughness parameters. Journal of Central South University, 21/12: 4653-4659, doi: https://doi.org/10.1007/s11771-014-2473-7.

Tang, Z. C. & Wong, L. N. Y. 2015: New Criterion for Evaluating the Peak Shear Strength of Rock Joints Under Different Contact States. Rock Mechanics and Rock Engineering, 49/4: 1191–1199, doi: https://doi.org/10.1007/s00603-015-0811-1.

Xia, C. C., Tang Z. C., Xiao W. M. & Song, Y.L. 2013: New Peak Shear Strength Criterion of Rock Joints Based on Quantified Surface Description. Rock Mechanics and Rock Engineering, 47/2: 387–400, doi: https//doi.org/10.1007/s00603-013-0395-6.

GEOLOGIJA *61/1*, 33-48, Ljubljana 2018

https://doi.org/10.5474/geologija.2018.003

Klasifikacija zemljin za inženirske namene v Sloveniji – kako naprej?

Soil classification for engineering purposes in Slovenia – how to proceed?

Matej MAČEK, Jasna SMOLAR & Ana PETKOVŠEK

Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo, Katedra za geotehniko, Jamova 2, SI-1000 Ljubljana, Slovenija; e-pošta: matej.macek@fgg.uni-lj.si; jasna.smolar@fgg.uni-lj.si, ana.petkovsek@fgg.uni-lj.si

Prejeto / Received 31. 1. 2018; Sprejeto / Accepted 18. 6. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Ključne besede: Atterbergove meje plastičnosti, klasifikacija, identifikacija, indeksna lastnost, drobna zrna, zemljina

Key words: Atterberg plastic limits, classification, description, fines, identification, soil

Izvleček

Članek obravnava načela inženirske klasifikacije zemljin, uveljavljene v Sloveniji po letu 1948 in jih analizira v luči načel novih evropskih standardov. Predstavljene so bistvene razlike v terminologiji, simbolih in merodajnih indeksnih kazalnikih lastnosti. V razpravo je predložen predlog nove, z evropskimi standardi usklajene slovenske inženirske klasifikacije zemljin, podprt s praktičnimi primeri rabe.

Abstract

Principles of engineering soil classification used in Slovenia since 1948 are analysed and compared with the newly accepted European soil classification principles. The main differences in terminology, symbols and index properties are emphasised. New Slovenian classification symbols and terminology are proposed and supported by practical examples of its use.

Uvod

Inženirska klasifikacija zemljin je razvrščanje nepregledne množice zemljin, zdrobljenih kamnin in materialov iz umetnih nasutij v manjše število skupin zemljin (angl. group) s podobnimi kazalniki inženirskih lastnosti. Na osnovi klasifikacije ocenjujemo trdnostno deformacijsko in hidravlično obnašanje zemljin v različnih pogojih inženirske rabe, kot so: temeljenje objektov, gradnja nasipov, presoja stabilnosti brežin, ocenjevanje zmrzlinske varnosti, potenciala likvifakcije (utekočinjenja), nevarnosti notranje erozije in drugje. Klasifikacijo izvajamo z uporabo rezultatov laboratorijskih raziskav, upoštevaje kriterije za izbrane indeksne kazalnike lastnosti: zrnavostno sestavo (npr. Skaberne, 1980), Atterbergove meje plastičnosti ter vsebnost organskih primesi.

Identifikacija in opisovanje zemljin je, v nasprotju s klasifikacijo, sklop postopkov za ocenitev vrste in stanja zemljine. Izvajamo jo na osnovi vizualnega pregleda, identifikacijskih preiskav in/ali kombinacije obojega. V opis in identifikacijo so poleg klasifikacije vključeni opisi gostotnih in konsistenčnih stanj, barve, vonja, mineralne sestave, geometrijskih značilnosti zrn in druge posebnosti. V praksi potekata opisovanje in identifikacija zemljin v dveh korakih. Zemljino najprej okvirno opišemo na osnovi vizualnega pregleda, končni opis pa izdelamo potem, ko so znani rezultati relevantnih terenskih in/ali laboratorijskih raziskav.

Prve osnutke inženirske klasifikacije zemljin je za potrebe gradnje cest pripravil Karel Terzaghi med delom na MIT (Massachusetts Institute of Technology) v letih 1927 – 1929. Za začetnika inženirske klasifikacije zemljin pa velja Artur Casagrande, Terzaghijev sodelavec na MIT in kasneje profesor na Harvardu, ki je za potrebe načrtovanja letališč med 2. svetovno vojno razvil tako imenovano AC (Airfield Classification System) klasifikacijo. Z manjšimi modifikacijami AC je leta 1952 nastala USCS klasifikacija (Unified Soil Classification System), prvič vključena v ameriški standard ASTM D 2487 leta 1966. AC/USCS klasifikacijo so različna strokovna združenja v osnovni ali lastnim potrebam prilagojeni obliki sprejela v nacionalne standarde, npr. Švica (SN 670 008), Nemčija (DIN 18196), Velika Britanija (BS 5930), nekdanja Jugoslavija (JUS U.B1.001).

Na ljubljanski univerzi je prva predavanja iz predmeta Mehanika tal pripravil profesor Lujo Šuklje konec štiridesetih. Vključevala so tudi MIT in AC klasifikacijo. Prvi Šukljetov univerzitetni učbenik z AC klasifikacijo je izšel leta 1957. V nekdanji skupni Jugoslaviji je bila raba AC klasifikacije določena s Pravilnikom o tehničnih normativih za temeljenje (1974) ter nato dodatno obrazložena v knjigi Objašnjenja k pravilniku (Šuklje, 1979). Zadnji skupni jugoslovanski standard za klasifikacijo zemljin, JUS U.B1.001:1990 je prevzel USCS klasifikacijo. Ta je v Sloveniji še vedno v široki rabi.

Tehnični komite ISO/TC 182 (Geotehnika) je v sodelovanju s CEN/TC 341 (Geotehnične raziskave in testiranja) izdal evropski standard za identifikacijo in klasifikacijo zemljin EN ISO 14688. Ta sestoji iz dveh delov, EN ISO 14688-1:2002 (Prepoznavanje in razvrščanje) in EN ISO 14688-2:2004 (Načela za razvrščanje). EN ISO 14688-2:2004 načela za klasificiranje so drugačna od ACS/USCS načel, uvajajo drugačne simbole in ne podajajo enovitih kriterijev za razvrščanje, kar je sicer primer starejših klasifikacij, kot so AC/USCS, DIN 18196, BS 5930 ali JUS U.B1.001.

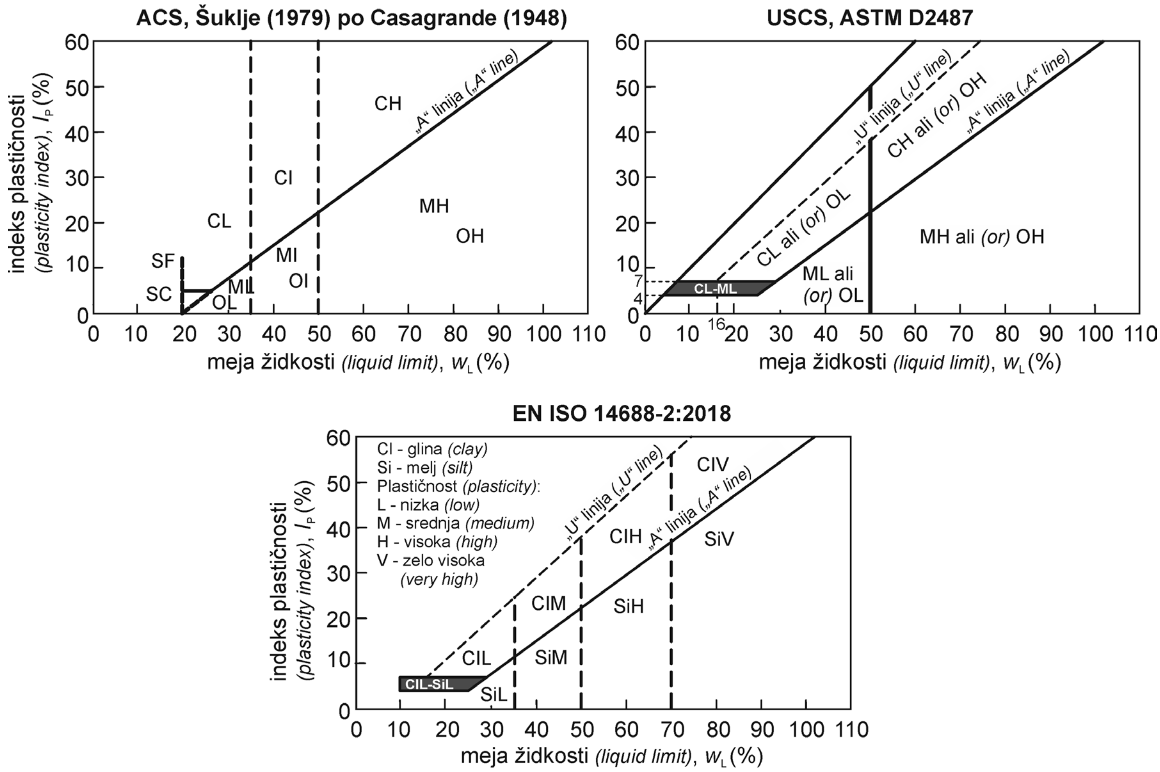
Po prvi izdaji leta 2004, je bil SIST EN ISO 14688-1 kar trikrat dopolnjen oz. spremenjen (leta 2008, 2013 in 2018), SIST EN ISO 14688-2 pa dvakrat (leta 2013 in 2018). SIST EN ISO 14688 iz leta 2018 je vsebinsko prenovljen in se v številnih pogledih vrača k AC načelom klasificiranja.

V okviru CEN/TC 396 Zemeljska dela (angl. Earthworks) nastaja nov evropski standard, prEN 16907-2:2015. V njem so opredeljeni kriteriji za klasifikacijo zemljin, uvedene so tudi nove skupine, t.i. vmesnih (angl. intermediate) zemljin, ki jih starejše klasifikacije ne poznajo. Te zemljine vsebujejo 15 % do 35 % drobnih zrn. prEN 16907-2:2015 razvršča zemljine v 30 skupin, kar je 2 × več kot pri USCS klasifikaciji.

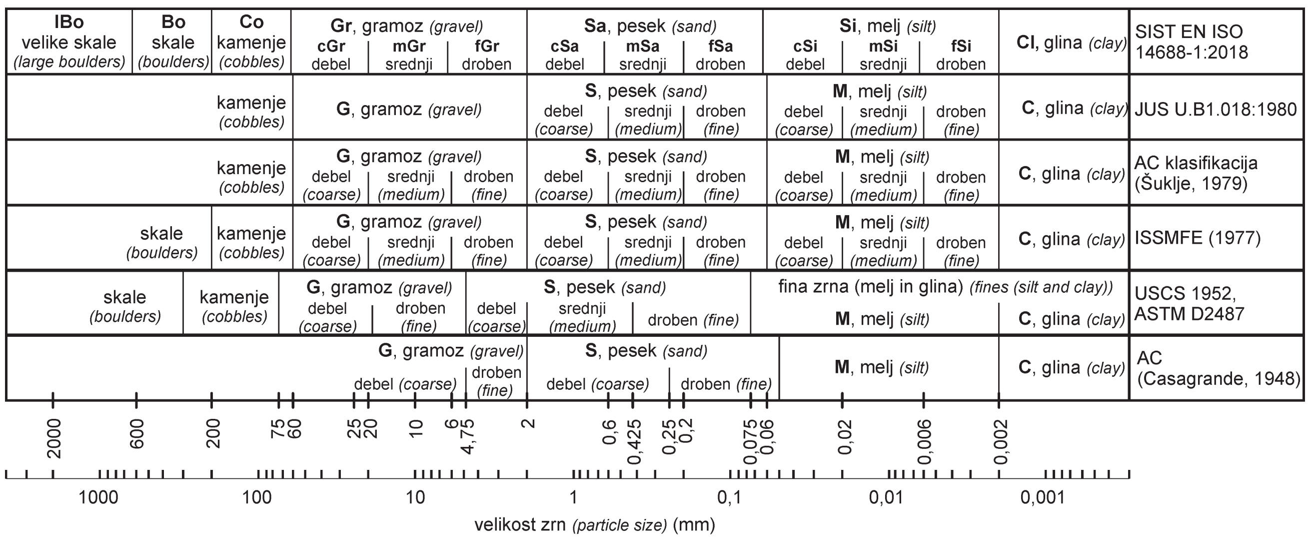
S Pravilnikom o mehanski odpornosti in stabilnosti objektov (2005) so v Sloveniji stopili v obvezno rabo evropski standardi za projektiranje – Evrokodi, med njimi standard za geotehnično projektiranje SIST EN 1997-1, bolj znan kot Evrokod 7 ter z njim povezana standarda EN ISO 14688-1 in EN ISO 14688-2, čeprav ne omogočata klasificiranja vseh skupin zemljin.

Petnajst let po sprejetju evropskih standardov za identifikacijo in klasifikacijo zemljin in 9 let po uveljavitvi Evrokod, v Sloveniji še ni prišlo do široke uveljavitve rabe nove EN ISO 14688 klasifikacije niti pri operativnem inženirskem delu niti pri formalnem prenosu le-te v druge nacionalne tehnične specifikacije. V tem »prehodnem« obdobju so se postopoma razrahljala tudi tradicionalna pravila AC/USCS klasifikacije, tako da je v sedanjem stanju, na področju opisovanja in klasificiranja zemljin precejšen nered. Razloge zato je treba iskati v kombinaciji vzrokov: (1) množica novo sprejetih evropskih in slovenskih standardov po metodi platnice po letu 2000 postaja vse manj pregledna, standardi se nenehno dopolnjujejo, so dragi in nedosegljivi za večino mladih in majhnih podjetij; (2) zaradi krize v gradbeništvu so razpadla močna strokovna jedra v gradbenih podjetjih in raziskovalnih ter inženiring inštitucijah, ki so v preteklosti skrbela za prenose novih znanj na nivoju pristojnih ministrstev in direkcij; (3) z razpadom velikih in nastankom številnih malih podjetij je nastala vrzel v prenosu znanj, mladi inženirji pa so po pravilu tisti, ki izvajajo popise, terensko identifikacijo in klasifikacijo zemljin, ne da bi bili poučeni o formalnem in tehničnem pomenu pravilne klasifikacije; (4) geološko geotehnične raziskave in zemeljska dela nimajo za seboj industrije, kot je to na primer pri asfaltih in betonih, kjer so zahteve proizvajalcev, uporabnikov in trga po uveljavitvi harmoniziranih oznak proizvodov drugačne; (5) tudi za redke preostale slovenske inštitucije z izkušenimi inženirji je evropski standard EN ISO 14688 za klasifikacijo in identifikacijo zemljin premalo dorečen in nujno potrebuje nacionalno dopolnitev oz. razširitev.

Ta prispevek smo pripravili z namenom, da bi osvežili zgodovinski spomin na razvoj in tradicijo rabe zemljinske klasifikacije v Sloveniji, ponovno zapisali strokovna načela klasificiranja, opozorili na vrzeli, nastale po sprejemu EN ISO klasifikacije in v razmislek in razpravo predlagali enostavne nacionalne dopolnitve k EN ISO klasifikaciji tako, da bo ta zaživela v široki rabi in v duhu že skoraj pozabljene dobre inženirske prakse.



Sl. 1. Razvoj rabe AC diagrama plastičnosti ($w_L – I_P$) za klasifikacijo drobno zrnatih zemljin.
Fig. 1. The development of the use of AC plasticity chart ($w_L – I_P$) for the classification of fine grained soils.



Sl. 2. Delitev zemljin po različnih klasifikacijah glede na velikost zrn.
Fig. 2. Grain size scales based on different soil classification systems.

AC klasifikacija

Po AC klasifikaciji (Nonveiller, 1963; Šuklje, 1957, 1967, 1984, 1979; Pravilnik, 1974) se zemljine klasificirajo na osnovi porazdelitve velikosti zrn (zrnavostne sestave) in Atterbergovih meja plastičnosti. Zemljine se delijo na debelozrnate in drobnozrnate. Debelozrnate zemljine so gramozi (G) in peski (S), drobnozrnate so melji (M), gline (C) in organske zemljine (O). V posebno skupino spadata kamenje, ki je brez simbola in sestoji iz zrn premera > 60 mm ter šota (Pt).

Debelozrnate zemljine uvrstimo med gramoze (G), če prevladujejo zrna 2/60 mm in med peske, če prevladujejo zrna 0,06/2 mm. Drobnozrnate zemljine razvrščamo s pomočjo AC diagrama na osnovi preiskave Atterbergovih meja plastičnosti (sl. 1. levo zgoraj, sl. 2).

Zemljine označujemo z dvema simboloma (velikima črkama). Prvi simbol označuje eno od 6 glavnih skupin zemljin, drugi pa pomaga pri nadaljnji delitvi vsake od skupin na podskupine, glede na porazdelitev velikosti zrn (zastopanost frakcij in obliko poteka krivulje zrnavosti) in glede na značaj plastičnosti. Glavne vrste zemljin so:

G – gramoz (angl. gravel),
S – pesek (angl. sand),
M – melj (angl. silt, šved. mjala),
C – glina (angl. clay),
O – organski melj, organska glina (angl. organic silt, organic clay),
Pt – šota (angl. peat).

Debelozrnate zemljine (G in S) razvrščamo v 5 podskupin z naslednjimi oznakami:

W – dobra porazdelitev zrnavosti (angl. well graded). Krivulja zrnavosti poteka preko širokega območja zrnavosti, ne da bi prevladovala zrna določene velikosti oz. frakcije. Vsebnost drobnih zrn je majhna.
P – slaba porazdelitev zrnavosti (angl. poorly graded). Izrazito je pomanjkanje določene frakcije. Vsebnost drobnih zrn je majhna.
U – enolična oz. enotna porazdelitev zrnavosti (oz. dobra sortiranost zrn) (angl. uniformly graded). Prevladujejo zrna ozkega intervala zrnavosti. Vsebnost drobnih zrn je majhna.
C – dobra porazdelitev zrnavosti z glinastim vezivom (angl. clay binder).
F – slaba porazdelitev zrnavosti z znatno količino drobnih zrn (angl. fines) in dobra porazdelitev zrnavosti s preobilno količino drobnih zrn. To skupino razdelimo dalje na: Fs, če pripadajo drobna zrna melju (S) in Fc, če pripadajo drobna zrna glini (C).

Drobnozrnate zemljine (M), (C) in (O) razvrščamo v tri podskupine z naslednjimi oznakami:

L – malo stisljive zemljine (angl. low compressibility) z mejo židkosti $w_L < 35$ %.
I – srednje stisljive zemljine (angl. intermediate compressibility) z mejo židkosti 35 % $< w_L <$ 50 %.
H – visoko stisljive zemljine (angl. high compressibility) z mejo židkosti $w_L > 50$ %.

Izraz stisljivost (angl. compressibility) se v AC nanaša na zemljino, stiskano iz začetne poroznosti pri vlagi blizu meje židkosti. Tega izraza zato ne smemo istovetiti z deformabilnostjo zemljine v naravnem stanju. Nonveiller (1963) že uporablja izraz »plastičnost« namesto izraza stisljivost.

Šotnih vrst zemljin ne razvrščamo na podskupine.

Po AC je za razvrščanje debelozrnatih zemljin na voljo 10 oz. 12 simbolov (GW, GP, GU, GC, GF (GFs, GFc), SW, SP, SU, SC, SF (SFs, SFc)), za razvrščanje drobnozrnatih zemljin pa je na voljo 9 simbolov (ML, CL, MI, CI, MH, CH, OL, OI, OH) ter simbol za šoto, skupaj torej 22 vrst zemljin ter dodatno kamenje. Če se pri AC klasifikaciji ne moremo odločiti samo za enega od simbolov, lahko zemljino označimo z dvojnim simbolom, npr. GC/GFc, MI/CI, GW/GC ipd.

Šuklje (1979) je v povezavi s klasifikacijo poudarjal pomen identifikacije gostotnih in konsistenčnih stanj zemljine in jih povezal z mejnimi vrednostmi indeksa konsistence (I_C) in nedrenirane trdnosti (c_u).

USCS klasifikacija

USCS je modificirana različica AC klasifikacije. Zemljine razporeja na zelo debelozrnate (skale in kamenje), debelozrnate (gramoze in peske), drobnozrnate (melje in gline) in organske zemljine ter šoto. Po USCS je zemljina debelozrnata, če preizkušanec po odstranitvi zrn velikosti nad 75 mm, vsebuje več kot 50 % zrn debelejših od 0,075 mm. Delitev na peske in gramoze je odvisna od tega, ali v debelih frakcijah zrn velikosti nad 0,075 mm prevladujejo zrna velikosti nad 4,75 mm (gramozi) ali zrna velikosti pod 4,75 mm (peski).

Pri razvrščanju debelozrnatih zemljin na peske in gramoze nekatere nacionalne klasifikacije, npr. JUS, BS, DIN odstopajo od USCS klasifikacije (ASTM D 2487). Razlika je v referenčni velikosti sita, ki se v JUS/BS standardu nanaša na sito 2 mm, v USCS pa na sito No. 4 oz. 4,75 mm. Pri kriteriju razvrščanja zemljin na drobnozrnate in debelozrnate, DIN postavlja mejo pri 40 % vsebnosti drobnih zrn velikosti pod 0,063 mm.

Oznaka drobna zrna (angl. fines) se nanaša na vsa zrna, ki padejo skozi sito 0,074 mm ali 0,063 mm.

Za podrobno razvrstitev debelozrnatih zemljin so v USCS uvedeni trije kriteriji:

- koeficient enakomernosti (Cu),
- koeficient zrnavosti, tudi koeficient ukrivljenosti (Cc),
- relativna količina drobnih zrn, ki so padla skozi sito 0,075 mm (5 % in 12 %).

Koeficient enakomernosti (Cu) je opredeljen kot razmerje med velikostjo zrn pri 60 % presejku (d_{60}) in velikostjo zrn pri 10 % presejku (d_{10}). Koeficient zrnavosti (Cc) je opredeljen kot razmerje med kvadratom velikosti zrn pri 30 % presejku $(d_{30})^2$ in produktom velikosti zrn pri presejku 10 % in 60 % (d_{10}xd_{60}).

Vsako zemljino se v USCS, podobno kot pri AC klasifikaciji, označi z dvema simboloma (velikima črkama). USCS ne pozna debelozrnatih zemljin enovito zrnate sestave (GU in SU) in drobnozrnatih zemljin srednje plastičnosti (CI, MI, OI). Zaradi tega je v USCS klasifikaciji le 15 in ne 22 značilnih skupin zemljin.

Sekundarne oznake za delitev zemljin po USCS so naslednje:

W – dobra porazdelitev zrnavosti (angl. well graded). Vsebnost drobnih zrn mora biti enaka ali manjša od 5 %, vrednost Cu mora biti enaka ali večja od 4 za gramoze in enaka ali večja od 6 za peske, vrednost Cc mora biti med vključno 1-3.

P – slaba porazdelitev zrnavosti (angl. poorly graded). Vsebnost drobnih zrn mora biti enaka ali manjša od 5 %, eden ali oba kriterija Cu oz. Cc ne ustrezata za klasifikacijo W.

M – meljast (angl. silty), vsebnost drobnih zrn je večja od 12 %, drobna zrna se nahajajo pod A linijo v AC diagramu.

C – glinast (angl. clayey), vsebnost drobnih zrn je večja od 12 %, drobna zrna se nahajajo nad A linijo v AC diagramu.

USCS klasifikacija osnovnih skupin zemljin je prikazana v tabeli 1, na sliki 3, 4 in 5 pa so podrobna načela klasifikacije in opisa zemljin.

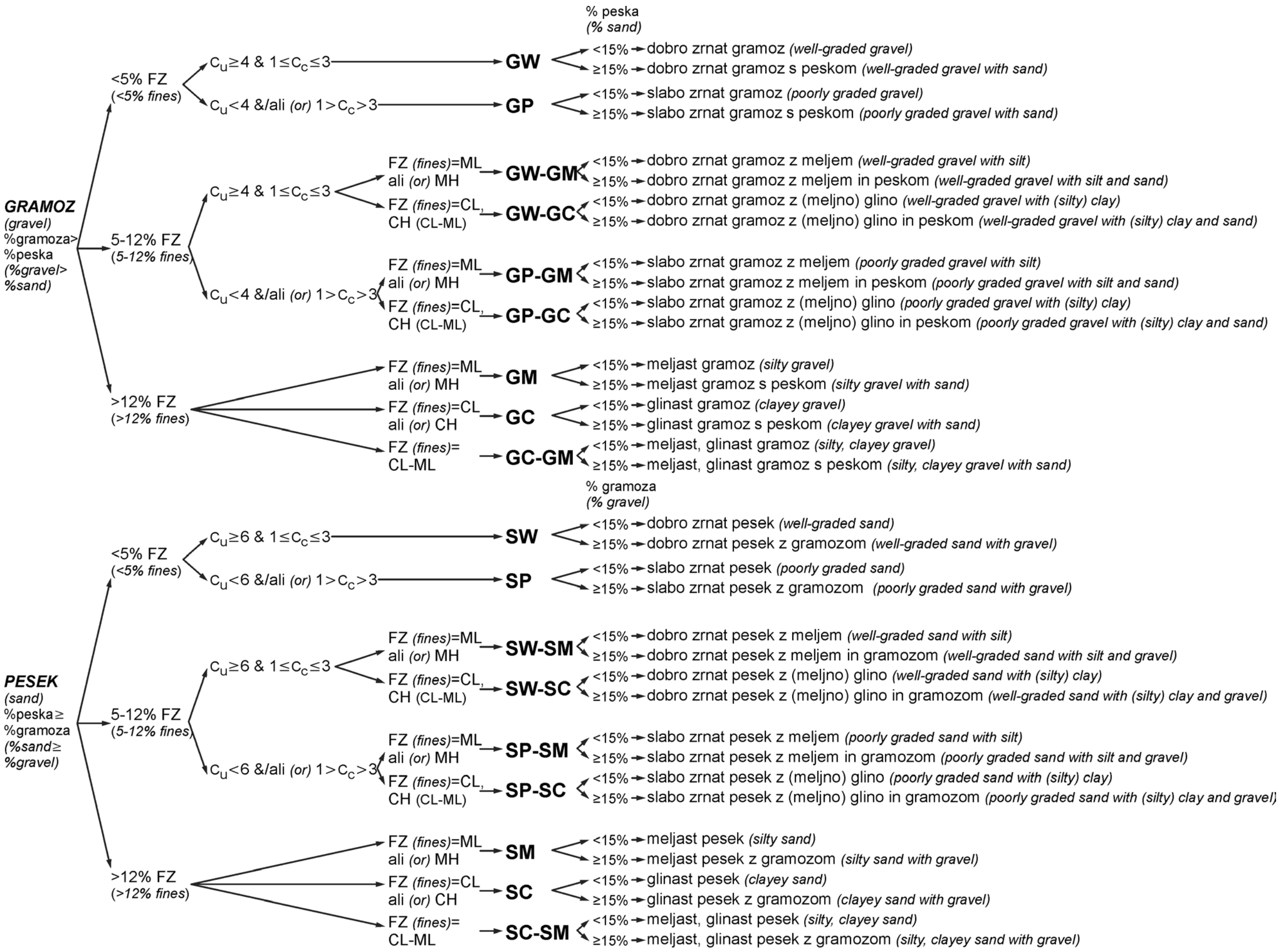
Tabela 1. USCS klasifikacija (ASTM D 2487).
Table 1. USCS classification (ASTM D 2487).

glavna skupina *(major divisions)*	podskupina *(subdivisions)*	simbol *(symbol)*	skupina *(group)*	kriteriji - laboratorijska klasifikacija *(laboratory classification criteria)*	
debelozrnate zemljine *(coarse grained soils)* drobna zrna *(fines)* (0,074 mm) < 50%*	gramoz *(gravel)* $f_{0,074-4,75\ mm} < f_{4,75-74\ mm}$	**GW**	dobro zrnat gramoz *(well graded gravel)*	< 5% FZ *(fines)*	$C_u \geq 4$ in *(and)* $1 \leq C_c \leq 3$
		GP	slabo zrnat gramoz *(poorly graded gravel)*	< 5% FZ *(fines)*	$C_u < 4$ & / ali *(or)* $1 > C_c > 3$
		GM	meljast gramoz *(silty gravel)*	> 12% FZ *(fines)*	drobna zrna ML ali MH *(fines classify as ML or MH)*
		GC	glinast gramoz *(clayey gravel)*	> 12% FZ *(fines)*	drobna zrna CL ali CH *(fines classify as CL or CH)*
	pesek *(sand)* $f_{0,074-4,75\ mm} \geq f_{4,75-74\ mm}$	**SW**	dobro zrnat pesek *(well graded sand)*	< 5% FZ *(fines)*	$C_u \geq 6$ in *(and)* $1 \leq C_c \leq 3$
		SP	slabo zrnat pesek *(poorly graded sand)*	< 5% FZ *(fines)*	$C_u < 6$ & / ali *(or)* $1 > C_c > 3$
		SM	meljast pesek *(silty sand)*	> 12% FZ *(fines)*	drobna zrna ML ali MH *(fines classify as ML or MH)*
		SC	glinast pesek *(clayey sand)*	> 12% FZ *(fines)*	drobna zrna CL ali CH *(fines classify as CL or CH)*
drobnozrnate zemljine *(fine grained soils)* drobna zrna *(fines)* (0,074 mm) ≥ 50%	melj in glina *(silts and clays)* w_L<50%	**ML**	nizkoplastičen melj *(silt)*	$I_P < 4$ ali pod A linijo *(or below A-line)*	
		CL	nizkoplastična glina *(lean clay)*	$I_P > 7$ in na ali nad A linijo *(and on or above A-line)*	
		OL	organski melj in organska glina *(organic silt and organic clay)*	w_L (sušen) (ovendried) / w_L (ne sušen) *(not dried)* < 0,75	
	melj in glina *(silts and clays)* w_L≥50%	**MH**	visokoplastičen melj *(elastic silt)*	pod A linijo *(below A-line)*	
		CH	visokoplastična glina *(fat clay)*	na ali nad A linijo *(on or above A-line)*	
		OH	organski melj in organska glina *(organic silt and organic clay)*	w_L (sušen) *(ovendried)* / w_L (ne sušen) *(not dried)* < 0,75	
šota *(peat)*	organska *(organic)*	**Pt**	visoko organske zemljine *(highly organic soils)*	temne barve in vonj *(dark color and organic odor)*	

* gramozi in peski z vsebnostjo drobnih zrn 5-12 % zahtevajo dvojni simbol *(gravel and sand with 5-12 % fines require dual symbol)*: GW-GM, GW-GC, GP-GM, GP-GC, SW-SM, SW-SC, SP-SM, SP-SC

FZ – drobna zrna *(fines)*

Zaradi preglednosti tabele izraz porazdelitev zrn nadomešča zrnat. *(Slovenian term "porazdelitev zrn" is replaced by "zrnat" to improve the overview in table).*



Zaradi preglednosti diagrama izraz porazdelitev zrn nadomešča zrnat. (*Slovenian term "porazdelitev zrn" is replaced by "zrnat" to improve the overview in flow chart*).

Sl. 3. Klasifikacijski diagram debelozrnatih zemljin – več kot 50 % odsejka na situ 0,074 mm (ASTM D 2487), FZ – drobna zrna.
Fig. 3. Flow chart for classifying coarse grained soils – more than 50 % retained on 0.074 mm sieve (ASTM D 2487).

V ASTM D 2487 so podani tudi vzorčni primeri dodatnih opisov zemljine, ki lahko vključujejo lokalno ime, značilnosti na terenu (npr. konsistenčno stanje, barvo, reakcijo s solno kislino in opis geološkega okolja).

JUS U.B1.001:1990 je obravnaval USCS klasifikacijo, ne pa tudi načel identifikacije in končnega opisa zemljine. Ta so bila vključena v JUS U.B1.003:1990. Pri opisovanju debelozrnatih zemljin so bili vključeni naslednji opisi: oblika zrn, reakcija z 20 % solno kislino, trdota zrn in stopnja občutljivosti zrn na razpad; za opis drobnozrnatih zemljin pa: preizkus s tresenjem, ocena konsistenčnega stanja, sijaj, suha trdnost, preiskava s kislino in opis barve in vonja.

EN ISO 14688: Prepoznavanje in razvrščanje

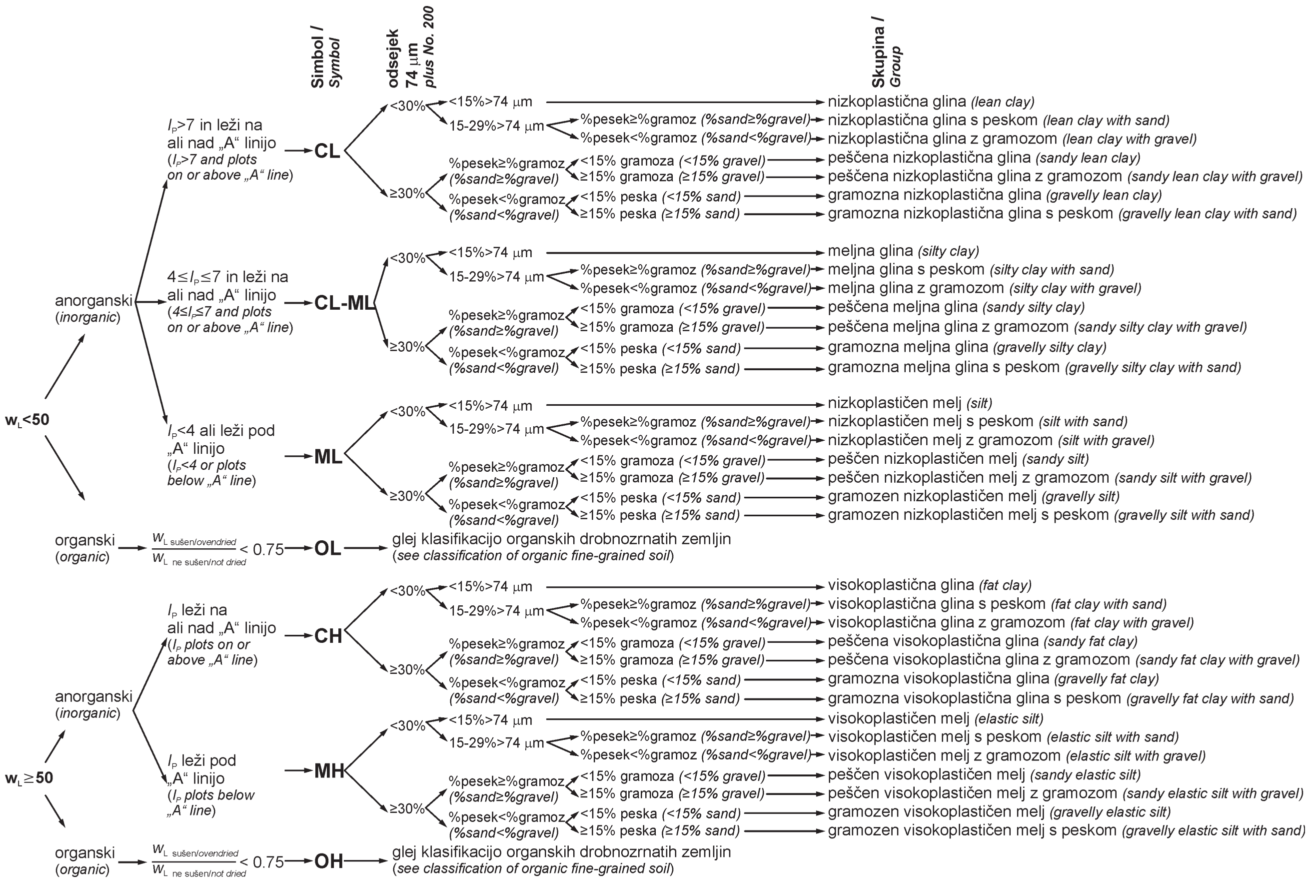
EN ISO standard - Prepoznavanje in razvrščanje zemljin sestoji iz dveh delov:

- EN ISO 14688-1: Prepoznavanje in opisovanje (angl. Identification and description) in
- EN ISO 14688-2: Načela za razvrščanje (angl. Principles for a classification).

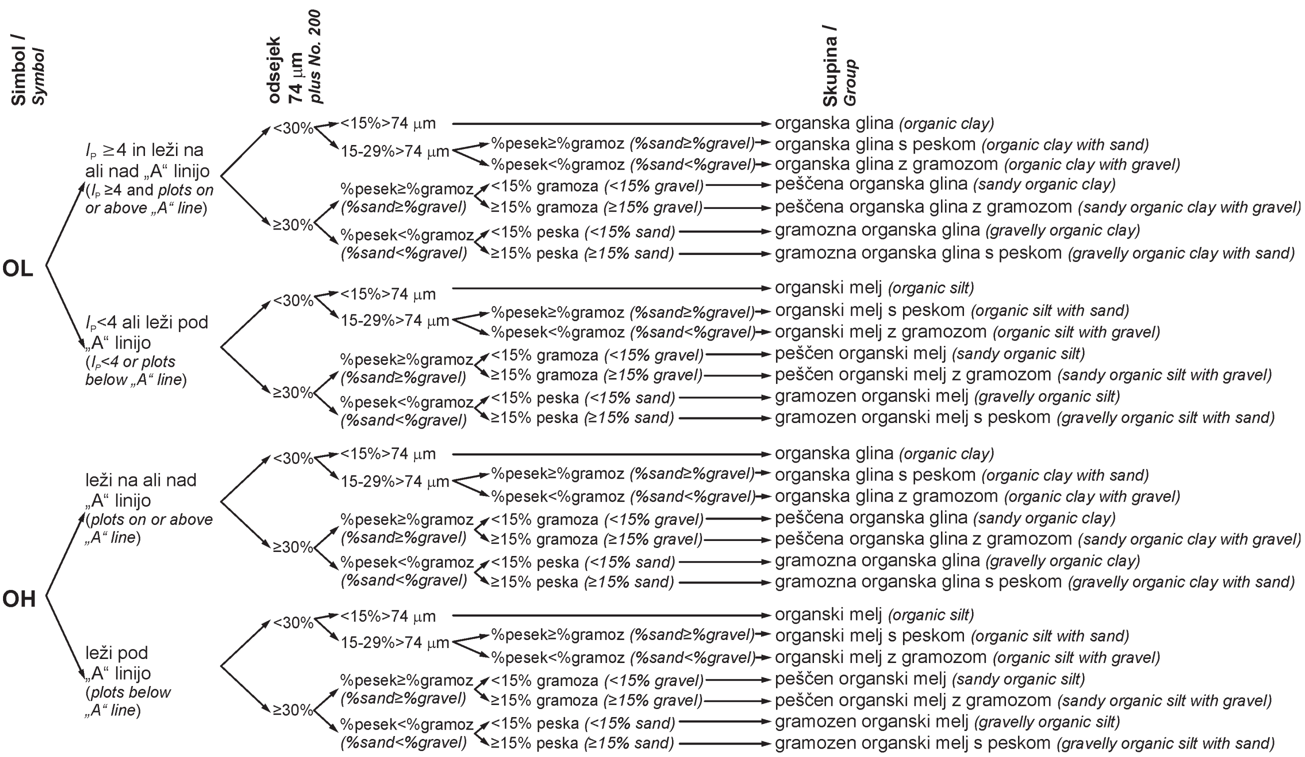
Osnovni EN ISO 14688 se je po zasnovi, vsebini in terminološko razlikoval od zasnov primerjanih standardov (ASTM, BS, JUS, SN) oz. v njih podanih načel klasifikacije. Zadnja izdaja iz leta 2018 pa se ponovno približuje načelom AC/USCS klasifikacije.

Posebnost EN ISO 14688-1 je, da poleg zemljin, vključenih v USCS, ločeno obravnava še načela razvrščanja vulkanskih zemljin ter umetnih nasutij. Umetna nasutja so razdeljena na kontrolirana inženirska nasutja in nekontrolirana nasutja, le ta pa še na nasutja iz geoloških in nasutja iz negeoloških materialov (odpadki, stranski produkti industrije).

Sistem razvrščanja osnovnih skupin zemljin (frakcij) po EN ISO 14688-1 je prikazan v tabeli 2. Namesto uporabe enega simbola (črke) za označevanje glavnih skupin zemljin, EN ISO 14688-1:2018 uporablja dve črki - prvi črki angleškega imena zemljine. Dodane so tudi oznake za



Sl. 4. Klasifikacijski diagram drobnozrnatih zemljin – 50 % ali več zrn manjših od 0,074 mm (ASTM D 2487).
Fig. 4. Flow chart for classifying fine grained soils – 50 % or more passes 0.074 m sieve (ASTM D 2487).



Sl. 5. Klasifikacijski diagram organskih drobnozrnatih zemljin – 50 % ali več zrn manjših od 0,074 mm (ASTM D 2487).
Fig. 5. Flow chart for classifying organic fine grained soils – 50 % or more passes 0.074 mm sieve (ASTM D 2487).

opisno oceno velikosti zrn (c – debel, angl. coarse; m – srednji, angl. medium; f – droben, angl. fine). Glede na osnovno izdajo iz leta 2002 so male črke (c, m, f) zamenjale velike črke (C, M, F). Glavne skupine zemljin so:

Gr – gramoz (angl. gravel), cGr; mGr; fGr
Sa – pesek (angl. sand), cSa; mSa; fSa
Si – melj (angl. silt), cSi; mSi; fSi
Cl – glina. (angl. clay)

Po EN ISO 14688-1:2002 se sekundarna frakcija, ki pomembno vpliva na obnašanje debelozrnatih zemljin, opiše s simbolom iz dveh malih črk, zapisanim pred oznako glavne frakcije, na primer: saGr – peščen gramoz (angl. sandy gravel); siGr – meljast gramoz (angl. silty gravel); clGr – glinast gramoz (angl. clayey gravel) oz. grSa – gramozni pesek (angl. gravelly sand); siSa – meljast pesek (angl. silty sand); clSa – glinast pesek (angl. clayey sand).

Druga sekundarna frakcija, ki lahko vpliva na inženirske lastnosti tal, se prav tako označi z majhno črko, npr: fgrCSa – drobno gramozni debel pesek (angl. fine gravelly coarse sand).

EN ISO 14688-1:2018 ne podaja simbolov za označevanje sekundarnih frakcij, podaja pa opise (npr. peščen GRAMOZ, angl. sandy GRAVEL; debelo peščen droben GRAMOZ, angl. coarse sandy fine GRAVEL).

Po EN ISO 14688-1:2002 se drobnozrnate zemljine, na katerih je moč določiti meje plastičnosti, delijo na nizko in visokoplastične, po EN ISO 14688-1:2018 pa na neplastične, nizko, srednje in visokoplastične. Simboli in kriteriji za razvrščanje teh zemljin so podani v EN ISO 14688-2:2018. Na ta način je prišlo do pomembne dopolnitve standarda iz leta 2004, ki kriterijev razvrščanja ni podajal.

Za identifikacijo in opis organskih zemljin, EN ISO 14688-1:2002 navaja pet različkov: vlaknata šota, psevdo-vlaknata šota, amorfna šota, gitja, in humus, nova izdaja iz leta 2018 pa dodaja še novo skupino »dy« in identificira zemljine nastale z izločanjem koloidov huminskih snovi. Posebnih simbolov za ločevanje organskih zemljin ni.

EN ISO 14688-1:2018 navaja postopke, po katerih se identificirajo in opišejo zemljine. Ti vključujejo: zrnavostno sestavo, obliko zrn, mineralno sestavo zrn, trdnost zrn, vsebnost drobnih zrn, konsistenco, barvo, vsebnosti organskih snovi in karbonatov. Opisani so postopki za identifikacijo stopnje razkroja šote, vulkanskih zemljin in identifikacijo konsistenčnega stanja.

Zrnavost

Pri obravnavi zrnavostne sestave so po EN ISO 14688-1:2018 zelo debelozrnate zemljine razvrščene v tri podskupine, velike skale (veliki bloki), če prevladujejo zrna nad 630 mm, skale (bloki), če prevladujejo zrna med 200 - 630 mm in kamenje, če prevladujejo zrna med 63 – 200 mm (tabela 2, sl. 2).

Za opis porazdelitve zrn se uporabljata koeficienta enakomernosti (C_U = Cu) in zrnavosti – ukrivljenosti (C_C = Cc). EN ISO 14688-2:2004 uporablja štiri (4), EN ISO 14688-2:2018 pa pet (5) kombinacij koeficientov C_U in C_C (tabela 3). Uveden je nov izraz porazdelitev zrnavosti z vrzeljo (angl. gap graded) za krivulje porazdelitve zrnavosti, v katerih manjka prisotnost določene frakcije (bimodalna krivulja zrnavosti). V primerjavi z USCS klasifikacijo, se glede na potek krivulje porazdelitve zrnavosti v EN ISO 14688-2:2004 pojavita, dodatni podskupini: več modalna porazdelitev zrnavosti (angl. multi graded) in srednje porazdeljena zrnavost (angl. medium graded). Podskupino več modalna porazdelitev zrnavosti (angl. multi graded) lahko istovetimo s skupino GW po USCS, le da je kriterij EN ISO strožji (zahteva za $C_U > 15$ in ne $C_U > 4$ kot po USCS).

Podskupine srednje porazdeljena zrnavost (angl. medium graded) ni moč uvrstiti v nobeno od USCS skupin, podskupino enolično porazdeljena zrnavost (angl. even graded) enakovredno opiše oznaka GP, skupino porazdelitev zrnavosti z vrzeljo (angl. gap graded) pa ena od oznak GP, GM ali GC v USCS klasifikaciji.

Kritična analiza kriterijev za klasifikacijo, podanih v EN ISO 14688-2:2004 pokaže, da le ti niso splošno veljavni in ne omogočajo klasifikacije vseh vrst zemljin. Slika 6 kaže, da zemljin s $C_C > 3$; $1<C_C<3$ in $C_U < 15$ ali $C_C<1$ in $C_U > 15$ ni moč razvrstiti v nobeno od novih EN ISO 14688-2:2004 podskupin. Po analogiji z USCS bi te zemljine lahko uvrstili med zemljine s slabo porazdeljeno zrnavostjo (GP oz. GrP). Za porazdelitev zrnavosti z vrzeljo ni kriterijev. Takšne zemljine imajo bimodalno porazdelitev velikosti zrn, ki se na krivulji zrnavosti izraža z značilno grbo (izravnava - prevoj) oz. odsotnostjo določenih frakcij (sl. 7), zanje pa je značilen visok C_U in nizek C_C.

EN ISO 14688-2:2018 odpravlja določene pomanjkljivosti iz prve izdaje leta 2004 in uvaja novo podskupino, enovita porazdelitev zrnavosti (angl. uniformly graded) in boljšo opredelitev podskupine porazdelitev zrnavosti z vrzeljo (angl. gap graded). Prav tako spreminja izraz več modalna porazdelitev zrnavosti (angl. multi graded) v široko uveljavljeni, tradicionalni izraz dobra porazdelitev zrnavosti (angl. well graded).

Tabela 2. Inženirska klasifikacija zemljin – primerjava pristopov.
Table 2. Soil classification – comparison of procedures.

skupina *(soil group)*	AC (Šuklje, 1979)*		ASTM D 2487*		EN ISO 14688-2:2004**		EN ISO 14688-1:2018		
							pod frakcije *(sub-fractions)*	simbol *(symbol)*	D (mm)
zelo debelozrnata *(very coarse grained)*					velike skale *(large boulder)*	**LBo**	velike skale	**lBo**	> 630
			skale *(boulder)*		skale *(boulder)*	**Bo**	skale *(boulder)*	**Bo**	>200–630
	kamenje *(cobble)*		kamenje *(cobble)*		kamenje *(cobble)*	**Co**	kamenje *(cobble)*	**Co**	>63–200
debelozrnata *(coarse grained)*	dobro zrnat gramoz *(well-graded gravel)*	**GW**	dobro zrnat gramoz *(well-graded gravel)*	**GW**	gramoz *(gravel)****	**Gr**	debel gramoz *(coarse gravel)*	**cGr**	>20–63
	slabo zrnat gramoz *(poorly-graded gravel)*	**GP**	slabo zrnat gramoz *(poorly-graded gravel)*	**GP**					
	eno (enovito) zrnat gramoz *(uniform gravel)*	**GU**					srednji gramoz *(medium gravel)*	**mGr**	>6,3–20
	glinast gramoz *(clayey gravel)*	**GC**	glinast gramoz *(clayey gravel)*	**GC**	glinast gramoz *(clayey gravel)*	**clGr**	droben gramoz *(fine gravel)*	**fGr**	>2,0–6,3
			meljast gramoz *(silty gravel)*	**GM**	meljast gramoz *(silty gravel)*	**siGr**			
		GF (GF_S, GF_C)[1]							
	dobro zrnat pesek *(well-graded sand)*	**SW**	dobro zrnat pesek *(well-graded sand)*	**SW**	pesek *(sand)****	**Sa**	debel pesek *(coarse sand)*	**cSa**	>0,63–2,0
	slabo zrnat pesek *(poorly-graded sand)*	**SP**	slabo zrnat pesek *(poorly-graded sand)*	**SP**					
	eno (enovito) zrnat pesek *(uniform sand)*	**SU**					srednji pesek *(medium sand)*	**mSa**	>0,2–0,63
	glinast pesek *(clayey sand)*	**SC**	glinast pesek *(clayey sand)*	**SC**	glinast pesek *(clayey sand)*	**clSa**	droben pesek *(fine sand)*	**fSa**	>0,063–0,2
			meljast pesek *(silty sand)*	**SM**	meljast pesek *(silty sand)*	**siSa**			
		SF (SF_S, SF_C)[2]							
drobnozrnata *(fine grained)*	nizko, srednje in visokoplastičen *(low, mid- plastic and elastic)*	**ML**	nizkoplastičen melj *(silt)* in visokoplastičen melj *(elastic silt)*	**ML**	melj *(silt)*	**Si******	debel melj *(coarse silt)*	**cSi**	>0,02–0,063
		MI					srednji melj *(medium silt)*	**mSi**	>0,0063–0,02
		MH		**MH**			droben melj *(fine silt)*	**fSi**	>0,002–0,0063
	nizko, srednje in visokoplastična *(low, mid and high plasticity fines)*	**CL**	nizkoplastična in visokoplastična glina *(lean and fat clay)*	**CL**	glina *(clay)*	**Cl******	glina *(clay)*	**Cl**	≤0,002
		CI							
		CH		**CH**					
organska *(organic)*	organske zemljine in šota *(organic soil and peat)*	**OL, OI, OH, Pt**	organske zemljine in šota *(organic soil and peat)*	**OL, OH, PT**	organske zemljine in šota *(organic soil and peat)*	**Or (Pt)**			
grajeno tlo *(made ground)*					umetni in naravni materiali *(man-made and relaid natural materials)*	**Mg**			

AC: [1]slabo zrnat gramoz z znatno količino finih zrn oz. dobro zrnat gramoz s preobilno količino finih zrn *(poorly- graded gravel with significant amount of fines or well graded gravel with large amount of fines)*

AC: [2]slabo zrnat pesek z znatno količino finih zrn oz. dobro zrnat pesek s preobilno količino finih zrn *(poorly- graded sand with significant amount of fines or well graded sand with large amount of fines)*

* klasifikacija z dvojnimi simboli (npr. GC-GM, SC-SM, SW-SM, SW-SC,…) – glej tabelo 1 *(dual symbols – see Table 1)*

** EN ISO 14688-2:2004: predlog nadaljnje razvrstitve v podskupine je na sliki 8 *(proposed subdivision – Figure 8)*.

*** več-, srednje-, enovito- zrnat *(multi-, medium-, even- graded)*, zrnavost z vrzeljo *(gap – graded)*

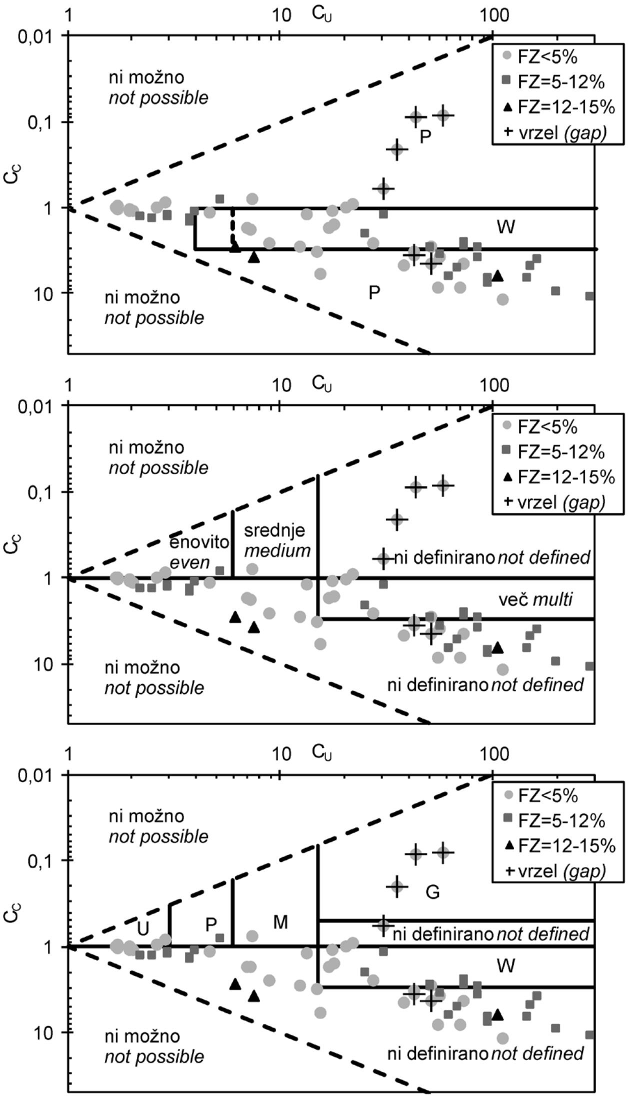
****ne-plastična *(non plastic)*, nizkoplastična *(low plasticity)*, srednjeplastična *(intermediate plasticity)*, visokoplastična *(high plasticity)*

Zaradi preglednosti tabele izraz porazdelitev zrn nadomešča zrnat. *(Slovenian term "porazdelitev zrn" is replaced by "zrnat" to improve the overview in table).*

Tabela 3. Oblika krivulje zrnavosti po EN ISO 14688-2:2004 in EN ISO 14688-2:2018.
Table 3. Shape of grading curve after EN ISO 14688-2:2004 and EN ISO 14688-2:2018.

EN ISO 14688-2:2004	EN ISO 14688-2:2018	C_U	C_C
več zrnata *(multi graded)*	dobro zrnata *(well graded)*	> 15	$1 < C_C < 3$
srednje zrnata *(medium graded)*	srednje zrnata *(medium graded)*	6 - 15	< 1
enolično (enotno) zrnata *(even graded)*	slabo zrnata *(poorly graded)*	3 - 6	< 1
	enovito zrnata *(uniformly graded)*	< 3	< 1
zrnavost z vrzeljo *(gap graded)*	zrnavost z vrzeljo *(gap graded)*	običajno visok *(usually high)* > 15 (EN ISO 14688-2:2018)	katerakoli vrednost (običajno < 0,5) *(any, usually < 0,5)* <0,5 (EN ISO 14688-2:2018)

Zaradi preglednosti tabele izraz porazdelitev zrn nadomešča zrnat. *(Slovenian term "porazdelitev zrn" is replaced by "zrnat" to improve the overview in table).*



Sl. 6. Položaj zemljin v diagramu C_U - C_C in meje za razvrščanje glede na obliko krivulje zrnavosti po JUS U.B1.001:1990 (zgoraj), EN ISO 14688-2:2004 (sredina) in EN ISO 14688-2:2018 (spodaj). (P – slabo, W – dobro, M – srednje, U – enakomerno zrnata zemljina, G – zemljina z vrzeljo zrnavosti; niz vrzeli, gap po kriteriju EN ISO 14688-2:2004).

Fig. 6. Position of soils in C_U - C_C chart and soil classification based on particle size distribution in accordance with JUS U.B1.001:1990, EN ISO 14688-2:2004 and EN ISO 14688-2:2018 (P - poorly, W – well, M – medium, U – uniformly, G – gap graded; series vrzel, gap after criteria given in EN ISO 14688-2:2004).

Plastičnost in vsebnost organskih snovi

EN ISO 14688-2:2018 se vrača k AC načelu razvrščanja. Kriterij za razvrščanje so meje židkosti in indeks plastičnosti, kot je prikazano na sliki 1. V primerjavi z AC klasifikacijo je novost v dodani novi podskupini: ClV in SiV za zemljine z mejo židkosti nad 70 %, to je za zelo visokoplastične. Pri zemljinah z indeksom plastičnosti I_P = 4-7 % in lego nad linijo A v AC diagramu se uporablja dvojni simbol ClL-SiL – meljna glina, podobno, kot je zapisano v USCS.

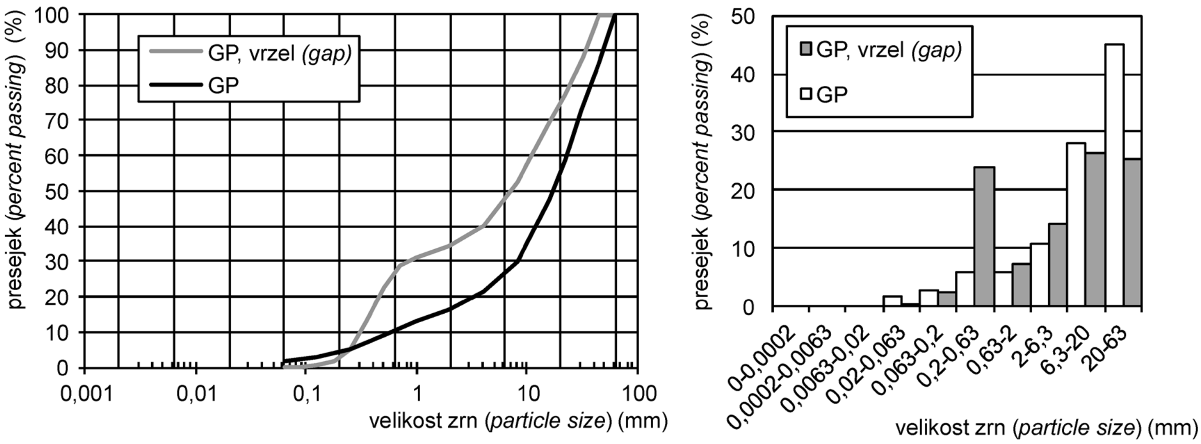
Glede na masno vsebnost organskih primesi v frakciji velikosti pod 2 mm, se zemljine delijo na nizko organske (2 – 6 %), srednje organske (6 – 20 %) in visoko organske (več kot 20 %). Mineralnim organskim zemljinam se k simbolu drobnozrnate zemljine doda oznaka »O«- organska (angl. organic).

Ostali principi (geneza)

Po EN ISO 14688-2 se ob klasifikaciji zemljin opišejo še: zgoščenost, nedrenirana trdnost, občutljivost in indeks konsistence. Za specifične namene rabe se lahko uporabljajo še dodatni opisi, npr. indeks saturacije, nabrekalni indeks, karbonatni indeks itd, vse brez navedbe kriterijev za razvrščanje. EN ISO 14688-2 izrecno dopušča oz. priporoča širitev podanih načel klasifikacije na nacionalni ravni ali na ravni specifičnega projekta.

prEN 16907-2:2015 klasifikacija

prEN 16907-2:2015 je prilagojen klasificiranju zemljin za gradnjo nasipov. Osnovne skupine zemljin iz EN ISO 14688-1, so v prEN 16907-2:2015 nadgrajene z dodatnimi skupinami ter simboli in natančnimi kriteriji za klasifikacijo. Vključene so nove podskupine zemljin: IS – vmesna zemljina (angl. intermediate soil), C – mešana zemljina (angl. composite soil). Umetna tla se razvrščajo na nasutja iz naravnih materialov (FN – angl. fill,



Sl. 7. Primer krivulje zrnavosti slabo zrnatega gramoza brez vrzeli in z vrzeljo (levo) in porazdelitev vsebnosti posameznih frakcij (desno).
Fig. 7. Grading curve of poorly graded gravel without and with gap (left) and the distribution of separate fractions (right).

natural material) in nasutja iz umetnih materialov (FA – angl. fill of manufactured – artificial material). Klasifikacija obravnava 30 podskupin zemljin, posameznim podskupinam so pripisane ocene uporabnosti za običajne zemeljske objekte.

Razprava o formalno veljavni klasifikaciji

Standarda EN ISO 14688-1:2002 ter EN ISO 14688-2:2004 so države članice CEN vključile v nacionalne standarde in standarde za projektiranje Evrokod 7. Standarda EN ISO sta v osnovni izdaji glede na predhodne AC/USCS klasifikacije spremenila simbole za označevanje skupin zemljin, nista podajala kriterijev za razvrščanje glavnih skupin zemljin v značilne podskupine in nista bila splošno veljavna, saj s svojimi parcialnimi kriteriji nista pokrila vseh vrst zemljin. To je pomenilo, da z EN ISO 14688-2:2004 načeli, klasifikacija zemljin formalno ni bila možna. V številnih evropskih državah so ohranili lastne standarde za klasifikacijo zemljin (npr. DIN, SN, BS) in tako z njimi ohranjajo lastne principe klasifikacije, s katerimi nadgrajujejo EN ISO 14688-2:2004 načela. V Sloveniji smo v sredini 1990ih let kratkovidno razveljavili JUS standarde in tako ostali brez ustreznih nacionalnih pravil. S tem smo v 50-letno tradicijo in dobro prakso klasifikacije zemljin vnesli nered, ki ni le formalne oz. terminološke, temveč tudi pomembne vsebinske narave. Na srečo je prenovljena izdaja standarda EN ISO 14688 iz leta 2018 odpravila večino, ne pa vseh pomanjkljivosti iz osnovne izdaje. Največja prednost nove izdaje iz leta 2018 je, da omogoča natančno razvrščanje drobnozrnatih zemljin, pri debelozrnatih zemljinah pa še vedno ostajajo kriteriji nedorečeni. Na nacionalni ravni se bomo morali dogovoriti, kako bomo v prihodnje klasificirali zemljine za inženirsko rabo. Možna sta dva pristopa:

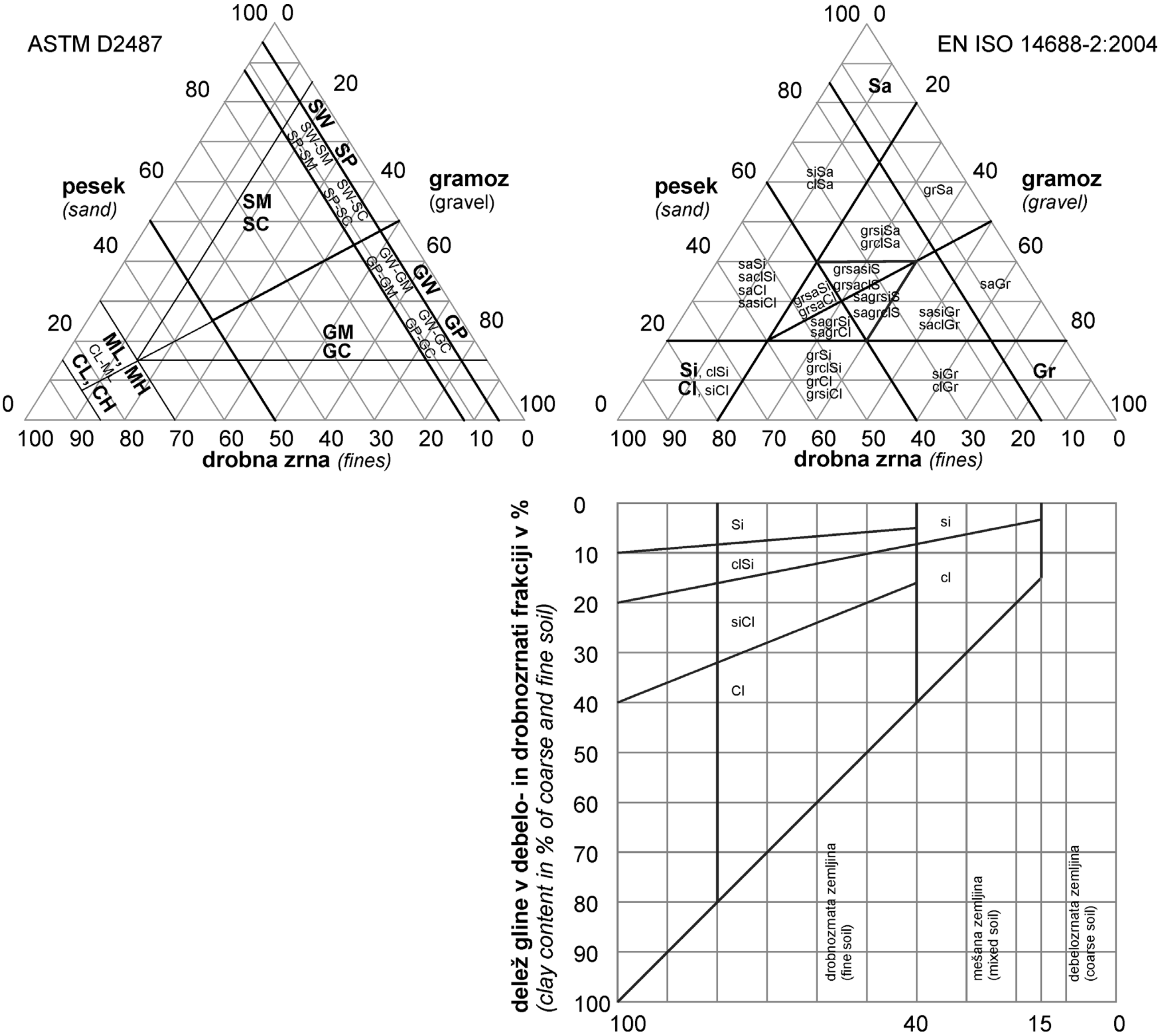
1. Uporabljamo lahko oba pristopa, torej nepopolne oznake in opise po EN ISO 14688-2:2018 in po USCS
2. Načela AC/USCS klasifikacije, uveljavljene v Sloveniji, smiselno povežemo z načeli EN ISO 14688-2:2018 in na ta način ohranimo tradicijo klasificiranja zemljin po slovenski geotehnični šoli, oz. po prof. Luju Šukljetu ter standardu JUS U.B1.001.

V tabeli 2 in na sliki 8 so prikazane primerjave AC, USCS in EN ISO oznak za značilne skupine in podskupine zemljin. Poudariti velja, da razlike niso vezane le na spremembe simbolov, temveč so zelo opazne tudi vsebinske razlike v kriterijih za klasificiranje.

V tabeli 4 je podan predlog nove klasifikacije zemljin, ki smiselno povezuje slovensko tradicijo klasificiranja z načeli in kriteriji EN ISO standardov. Na sliki 9 so prikazani primeri in primerjava nove EN ISO in USCS klasifikacije za značilne izbrane podskupine zemljin.

Pri debelozrnatih zemljinah ohranjamo glavni skupini zemljin G/Gr in S/Sa z naslednjimi podskupinami: GW/GrW, GP/GrP, GM/siGr in GC/clGr ter SW/SaW, SP/SaP, SM/siSa in SC/clSa. Glede na kriterije EN ISO 14688-2:2018 so dodane nove podskupine GrU in GrG ter SaU in SaG, ki bi sicer po USCS klasifikaciji pripadale podskupini GP in SP.

Pri klasifikaciji drobnozrnatih zemljin uporabljamo modificiran AC diagram (sl. 1). Pomembnejša novost je uvedba nove podskupine zelo visokoplastičnih zemljin (ClV, SiV) in pripadajočih podskupin z dodatno oznako »O« npr. ClHO- organska visokoplastična glina, oz. SiLO- organski nizkoplastičen melj. Z novo klasifikacijo tako dobimo: 3 skupine zelo debelozrnatih zemljin (LBo, Bo in Co), 14 skupin debelozrnatih



Sl. 8. Trikotna diagrama za klasifikacijo osnovana na relativni vsebnosti gramoza, peska in drobnih zrn po ASTM D2478 in EN ISO 14688-2:2004.

Fig. 8. Trigons showing classification schemes based on relative percentage of gravel, sand and fines based on ASTM D2478 and EN ISO 14688-2:2004.

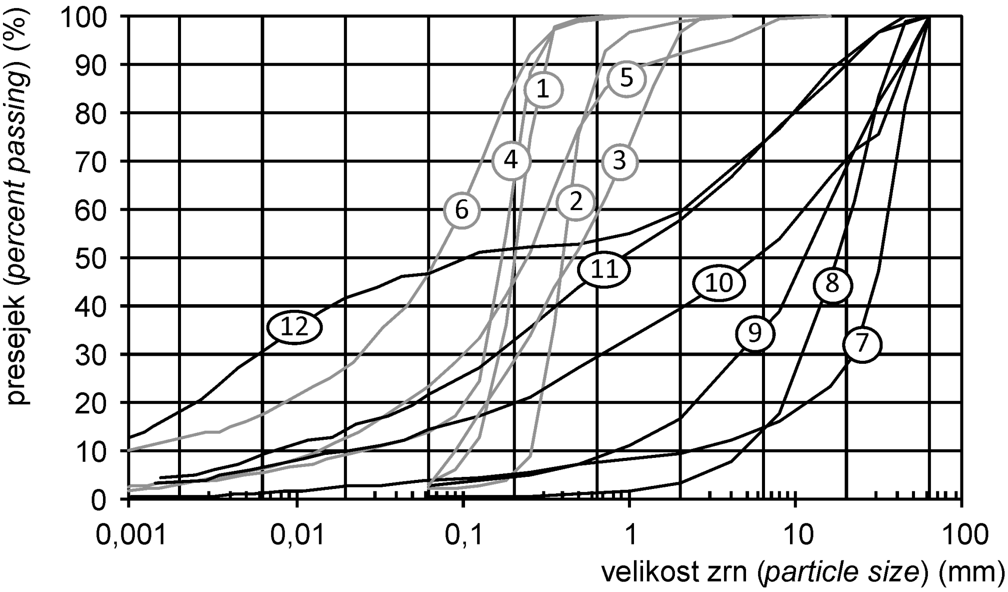
Tabela 4 nadaljevanje

- gramoz z vsebnostjo finih zrn 5 %-12 % opišemo z »dvojnim« simbolom *(gravels with* 5 %-12 % fines *require »dual« symbols)*: GrW-siGr, GrW-clGr; GrP-siGr, GrP-clGr; GrM-siGr, GrM-clGr; GrU-siGr, GrU-clGr; GrG-siGr, GrG-clGr.
- pesek z vsebnostjo finih zrn 5 %-12 % opišemo z »dvojnim« simbolom *(sands with* 5 %-12 % fines *require »dual« symbols)*: SaW-siSa, SaW-clSa; SaP-siSa, SaP-clSa; SaM-siSa, SaM-clSa; SaU-siSa, SaU-clSa; SaG-siSa, SaG-clSa.
- če so v mineralni drobnozrnati zemljini organske primesi, dodamo oznako »O« (npr. ClHO) *(if mineral fine grained soil has organic constituents, add "O" to symbol (e.g. ClHO)).*
- če zemljina vsebuje ≥ 20 % peska, se k opisu (stolpec skupina) pripiše »peščen« in dopiše sekundarna frakcija k simbolu (npr. saGr ali saSi) *(if soil contains ≥ 20 % sand, add »sandy« to a group name and add secondary fraction to a group symbol (e.g. saGr or saSi).*
- če zemljina vsebuje ≥ 20 % gramoza, se k opisu (stolpec skupina) pripiše »gramozen« in dopiše sekundarna frakcija k simbolu (npr. grSa ali grSi) *(if soil contains ≥ 20 % gravel, add »gravelly« to a group name and add secondary fraction to a group symbol, e.g. grSa or grSi).*
- če zemljina vsebuje tako več kot ≥ 20 % peska kot tudi ≥ 20 % gramoza se od leve najprej zapiše sekundarna frakcija z manjšim deležem zrn (npr. grsaCl) *(if soil contains both ≥ 20 % gravel and ≥ 20 % sand write secondary fraction with least amount to leftmost position (e.g.grsaCl)).*
- če drobno zrnata zemljina vsebuje ≥ 20 % a < 40 % debelo zrnate frakcije, se k opisu (stolpec skupina) pripiše »peščen« ali »gramozen« in dopiše sekundarna frakcija k simbolu v odvisnosti od prevladujoče debelo zrnate frakcije (npr. grSi ali saCl) *(if fine grained soil contains ≥ 20 % but < 40 % coarse fraction, add »sandy« or »gravelly« to a group name and add secondary fraction to a group symbol whichever is predominant, e.g. grSi or saCl).*

Tabela 4. Predlog klasifikacije po načelih JUS U.B1.001:1990, ASTM D 2487, EN ISO 14688-1:2004, in EN ISO 14688-2:2018.
Table 4. Proposed classification based on principles given in JUS U.B1.001:1990, ASTM D 2487, EN ISO 14688-1:2004 and EN ISO 14688-2:2018.

glavna skupina *(major divisions)*	podskupina *(subdivisions)*	simbol *(symbol)*	skupina *(group)*	kriteriji - laboratorijska klasifikacija *(laboratory classification criteria)*	
debelozrnate zemljine *(coarse grained soils)* drobna zrna *(fines)* (0,063 mm) < 50%	gramoz *(gravel)* $f_{0,063\text{-}2,0\ mm} < f_{2,0\text{-}63\ mm}$	**GrW**	dobro zrnat gramoz *(well graded gravel)*	< 5% FZ	$C_U > 15$ in *(and)* $1 \le C_C \le 3$
		GrP	slabo zrnat gramoz *(poorly graded gravel)*	< 5% FZ	$3 < C_U < 6$ in *(and)* $C_C < 1$ ali *(or)* $C_U < 15$ in *(and)* $C_C > 1$ ali *(or)* $C_U > 15$ in *(and)* $0,5 < C_C < 1$ ali *(or)* $C_U > 15$ in *(and)* $C_C > 3$
		GrM	srednje zrnat gramoz *(medium graded gravel)*	< 5% FZ	$6 < C_U < 15$ in *(and)* $C_C < 1$
		GrU	enakomerno zrnat gramoz *(uniformly graded gravel)*	< 5% FZ	$C_U < 3$ in *(and)* $C_C < 1$
		GrG	gramoz z vrzeljo zrnavosti *(gap graded gravel)*	< 5% FZ	$C_U > 15$ in *(and)* $C_C < 0,5$
		siGr	meljast gramoz *(silty gravel)*	> 12% FZ	FZ – melj ($I_P < I_{PA}$) *(silty fines)*
		clGr	glinast gramoz *(clayey gravel)*	> 12% FZ	FZ – glina ($I_P \ge I_{PA}$ in *(and)* $I_P \ge 4$) *(clayey fines)*
	pesek *(sand)* $f_{0,063\text{-}2,0\ mm} \ge f_{2,0\text{-}63\ mm}$	**SaW**	dobro zrnat pesek *(well graded sand)*	< 5% FZ	$C_U > 15$ in *(and)* $1 \le C_C \le 3$
		SaP	slabo zrnat pesek *(poorly graded sand)*	< 5% FZ	$3 < C_U < 6$ in *(and)* $C_C < 1$ ali *(or)* $C_U < 15$ in *(and)* $C_C > 1$ ali *(or)* $C_U > 15$ in *(and)* $0,5 < C_C < 1$ ali *(or)* $C_U > 15$ in *(and)* $C_C > 3$
		SaM	srednje zrnat pesek *(medium graded sand)*	< 5% FZ	$6 < C_U < 15$ in *(and)* $C_C < 1$
		SaU	enakomerno zrnat pesek *(uniformly graded sand)*	< 5% FZ	$C_U < 3$ in *(and)* $C_C < 1$
		SaG	pesek z vrzeljo zrnavosti *(gap graded sand)*	< 5% FZ	$C_U > 15$ in *(and)* $C_C < 0,5$
		siSa	meljast pesek *(silty sand)*	> 12% FZ	FZ – melj ($I_P < I_{PA}$) *(silty fines)*
		clSa	glinast pesek *(clayey sand)*	> 12% FZ	FZ – glina ($I_P \ge I_{PA}$ in *(and)* $I_P \ge 4$) *(clayey fines)*
drobnozrnate zemljine *(fine grained soils)* drobna zrna *(fines)* (0,063 mm) ≥ 50%	melj in glina *(silts and clays)* $w_L < 35\%$	**SiL**	nizkoplastičen melj *(low plasticity silt)*	$I_P < 4$ ali *(or)* $I_P < I_{PA}$	
		ClL-SiL	nizkoplastična meljna glina *(silty clay)*	$4 \le I_P \le 7$ in *(and)* $I_P \ge I_{PA}$	
		ClL	nizkoplastična glina *(low plasticity clay)*	$I_P > 7$ in *(and)* $I_P \ge I_{PA}$	
	melj in glina *(silts and clays)* $35\% \le w_L < 50\%$	**SiM**	srednjeplastičen melj *(medium plasticity silt)*	$I_P < I_{PA}$	
		ClM	srednjeplastična glina *(medium plasticity clay)*	$I_P \ge I_{PA}$	
	melj in glina *(silts and clays)* $50\% \le w_L \le 70\%$	**SiH**	visokoplastičen melj *(high plasticity silt)*	$I_P < I_{PA}$	
		ClH	visokoplastična glina *(high plasticity clay)*	$I_P \ge I_{PA}$	
	melj in glina *(silts and clays)* $w_L > 70\%$	**SiV**	zelo visokoplastičen melj *(very high plasticity silt)*	$I_P < I_{PA}$	
		ClV	zelo visokoplastična glina *(very high plasticity clay)*	$I_P \ge I_{PA}$	
organska *(organic)*		**Pt**	šota *(peat)*	šota *(peat)*	
umetno tlo (*anthropogenic soil*)		**Mg**	umetni materiali in naravni vgrajeni materiali *(man-made materials and relaid natural materials)*	zahteva se posebna obravnava *(requires special consideration)*	

FZ – drobna zrna *(fines)*, I_{PA} – indeks plastičnosti A – linije pri w_L *(plasticity index on A – line at w_L)*, $C_U = D_{60}/D_{10}$, $C_C = (D_{30})^2/D_{10} \cdot D_{60}$
Zaradi preglednosti tabele izraz porazdelitev zrn nadomešča zrnat. *(Slovenian term "porazdelitev zrn" is replaced by "zrnat" to improve the overview in table).*



Sl. 9. Krivulje zrnavosti zemljin s klasifikacijo po JUS U.B1.001:1990 in po predlogu klasifikacije osnovane po usmeritvah v EN ISO 14688-2:2018 (tabela 4).

Fig. 9. Soils grading curves with classification based on JUS U.B1.001:1990 and a classification proposal adapted after EN ISO 14688-2:2018 (table 4).

krivulja zrnavosti št. *(gradation curve Nr).*	AC/USCS JUS.U.B1.001 (1990)	predlog klasifikacije tega članka *(Proposed classification)*	drobna zrna *(fines)* (<0,063 mm)	peščena frakcija *(sand fraction)* (0,063 -2 mm)	gramozna frakcija *(gravel fraction)* (2–63 mm)	C_U	C_C
1	SP	SaP*	3	97	0	2,03	1,12
2	SP	SaU	2	97	1	1,72	0,97
3	SP	SaM	3	94	4	7,38	0,78
4	SM	siSa	14	86	0	7,54	3,78
5	SM	siSa	24	69	8		
6	SC	clSa	47	53	0		
7	GP	GrP*	3	7	91	15,4	5,96
8	GW	GrP	0	3	96	4,62	1,16
9	GW	GrW	4	13	83	17,8	1,60
10	GM	sasiGr	14	25	61	531	2,00
11	GM	sasiGr	21	36	42		
12	GC	clGr	47	13	40		

* po razširjenem kriteriju slabo zrnatih debelozrnatih zemljin *(based on widened criteria for poorly graded coarse soil)*

zemljin (GrW, GrP, GrM, GrU, GrG, siGr, clGr, SaW, SaP, SaM, SaU, SaG, siSa, clSa), 9 skupin drobnozrnatih anorganskih zemljin (ClL, ClM, ClH, ClV, SiL, SiM, SiH, SiV ter mešano skupino ClL-SiL) ter 9 skupin drobnozrnatih organskih zemljin. Ohranja se oznaka za šoto (Pt), skupaj torej 36 skupin zemljin. Če izločimo zelo debelozrnate zemljine in oznake za organske mineralne zemljine, je skupno število skupin za razvrščanje 24, to je primerljivo število kot v osnovni AC klasifikaciji.

Terminološke zadrege

Geološki terminološki slovar (Pleničar et al., 2006) pod izrazom »zemljina« zapiše, da je izraz zemljina neustrezen in predlaga izraze: preperina oz. sediment, usedlina. Prikazana analiza in kazalo referenčnih dokumentov kažejo, da je izraz zemljina (angl. soil, nem. Boden) zgodovinsko natančno opredeljen na področju inženirske klasifikacije zemljin in je kot tak ustrezen in nezamenljiv. Genetsko pa izraz zemljina pokriva nevezljive in vezljive preperine, sedimente, piroklastične (vulkanske) in antropogene (naravne in umetne) materiale, ki pa jih moramo za inženirske namene razvrstiti v enotne skupine.

V Sloveniji se je pri opisovanju debelozrnatih zemljin v preteklosti uveljavil izraz »grobozrnat« (angl. coarse grained). Izraz »grobozrnat« je pri klasifikaciji in opisu zemljin vsebinsko neprimeren in bi ga morali zamenjati z izrazom »debelozrnat«. Tudi izraz »fina zrna« (angl. fines) bi bilo primerneje nadomestiti z izrazom »drobna zrna«.

Iz tabele 4 vidimo, da bo potrebno opustiti izraze »pust/pusta« in »masten/mastna« pri opisovanju značaja glin in meljev. ASTM uporablja izraz »pust« (angl. lean) za nizkoplastično glino (CL) in izraz »masten« (angl. fat) za visokoplastično glino (CH). Izraza »pust« in »masten« sta bila sicer opuščena že v JUS U.B1.001:1990.

Precejšnjo zadrego prinaša nova podskupina zemljin »gap graded«, za katero težko poiščemo slovenski terminološki ekvivalent. Predlagali smo izpeljanko »porazdelitev zrnavosti z vrzeljo«, čeprav nismo prepričani, da je to pravi izraz. Morda bi izraz bimodalna porazdelitev zrnavosti bolj ustrezal, a je hkrati v inženirski klasifikaciji manj domač.

Zaključek

Evropska standarda za prepoznavanje in razvrščanje zemljin EN ISO 14688-1:2002 in EN ISO 14688-2:2004 sta v osnovni izdaji temeljito posegla v tradicionalna načela prepoznavanja in razvrščanja zemljin, uveljavljena v Sloveniji po letu 1948. Zaradi nedoslednih kriterijev nista bila uporabna za široko rabo in klasificiranje vseh vrst zemljin in se v praksi nista »prijela«. Aprila 2018 je bila sprejeta nova izdaja EN ISO 14688-1:2018 in EN ISO 14688-2:2018, v kateri je večina pomanjkljivosti prve izdaje odpravljenih. V kratkem se pričakuje tudi končni sprejem standarda za klasifikacijo zemljin za zemeljska dela, ki je trenutno na nivoju prEN 16907-2:2015.

Po sprejemu navedenih novih standardov, izgovorov za nespoštovanje načel klasificiranja zemljin za inženirske namene ne bo več. Inženirsko klasifikacijo zemljin bo treba izvajati po evropskih standardih in jo vpeljati tudi v ustrezne tehnične dokumente za gradnjo. Predlagana klasifikacija povezuje tradicionalne pristope klasifikacije zemljin z novimi načeli EN ISO 14688-2:2018 in hkrati omogoča natančno razporejanje zemljin v posamezne skupine po tradicionalnih načelih AC/USCS klasifikacije.

Za objavo prispevka v reviji Geologija smo se avtorji odločili zato, ker so inženirji geologije tisti, ki v veliki večini izvajajo popise zemljin pri raziskovalnih delih na terenu in v laboratoriju in so prav oni tisti, ki lahko največ prispevajo, da se načela pravilnega klasificiranja ponovno vrnejo v operativno rabo v Sloveniji.

Viri in literatura

ASTM D 2487-00: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

BS 5930: 2015: Code of practice for ground investigations.

Casagrande, A. 1948: Classification and Identification of Soils. Transactions of the American Society of Civil Engineers, 113/1: 901-930.

DIN 18196:2006-06: Erd- und Grundbau - Bodenklassifikation für bautechnische Zwecke.

ISSMFE (International society of soil mechanics and foundation engineering) 1979: Subcommittee report on symbols, units, definitions. Proc., 9th Int. Conf on Soil Mechanics and Foundation Engineering, 153-170 (in French).

JUS U.B1.001 1990: Geotehnička ispitivanja, Opšta klasifikacija tla.

JUS U.B1.003 1990: Geomehanička ispitivanja - Terenska identifikacija uzoraka tla.

JUS U.B1.018 1980: Geomehanička ispitivanja - Određivanje granulometrijskog sastava.

Nonveiller, E. 1963: Geomehanika, 1. dio. Sveučilište u Zagrebu, Zagreb: 110 p.

oSIST prEN 16907-1:2016: Zemeljska dela - 1. del: Načela in splošna pravila.

oSIST prEN 16907-2:2015: Zemeljska dela - 2. del: Klasifikacija materialov.

Pleničar, M., Strmole, D., Leder, Z., Pavšič, J., Kralj, P. & Grm, M. 2006: Geološki terminološki slovar, Zbirka Slovarji / Založba ZRC, ZRC SAZU.

Pravilnik o tehničkim normativima za projektovanje i izvođenje radova kod temeljenja građevinskih objekata. Službeni list SFRJ, br. 34-642/1974.

Pravilnik o mehanski odpornosti in stabilnosti objektov. Uradni list RS, št. 101/05 in 61/17 – GZ.

SIST EN 1997-1:2005: Evrokod 7: Geotehnično projektiranje - 1. del: Splošna pravila.

SIST EN 1997-1:2005/AC:2009: Evrokod 7: Geotehnično projektiranje - 1. del: Splošna pravila.

SIST EN 1997-1:2005/A1:2014: Evrokod 7: Geotehnično projektiranje - 1. del: Splošna pravila.

SIST EN 1997-1:2005/A101:2006: Evrokod 7: Geotehnično projektiranje – 1. del: Splošna pravila – Nacionalni dodatek.

SIST EN ISO 14688-1:2004: Geotehnično preiskovanje in preskušanje - Prepoznavanje in razvrščanje zemljin - 1. del: Prepoznavanje in opisovanje (ISO 14688-1:2002).

SIST EN ISO 14688-1:2004/AC:2008: Geotehnično preiskovanje in preskušanje - Prepoznavanje in razvrščanje zemljin - 1. del: Prepoznavanje in opisovanje (ISO 14688-1:2002).

SIST EN ISO 14688-1:2004/A1:2013: Geotehnično preiskovanje in preskušanje - Prepoznavanje in razvrščanje zemljin - 1. del: Prepoznavanje in opisovanje (ISO 14688-1:2002/A1:2013).

SIST EN ISO 14688-1:2018: Geotehnično preiskovanje in preskušanje - Prepoznavanje in razvrščanje zemljin - 1. del: Prepoznavanje in opisovanje (ISO 14688-1:2017).

SIST EN ISO 14688-2:2004: Geotehnično preiskovanje in preskušanje – Prepoznavanje in razvrščanje zemljin – 2. del: Načela za razvrščanje (ISO 14688-2:2004).

SIST EN ISO 14688-2:2004/A1:2013: Geotehnično preiskovanje in preskušanje - Prepoznavanje in razvrščanje zemljin - 2. del: Načela za razvrščanje (ISO 14688-2:2004/A1:2013).

SIST EN ISO 14688-2:2018: Geotehnično preiskovanje in preskušanje – Prepoznavanje in razvrščanje zemljin – 2. del: Načela za razvrščanje (ISO 14688-2:2017).

Skaberne, D. 1980: Predlog klasifikacije in nomenklature klastičnih sedimentnih kamnin, 1. del: Predlog granulometrijske klasifikacije in nomenklature. Rudarsko-metalurški zbornik 27/1: 21-46.

SN 670008: 1970: Klassifikation der Lockergesteine; Laboratoriumsmethode nach USCS.

Šuklje, L. 1967: Mehanika tal. Univerza v Ljubljani, Fakulteta za arhitekturo, gradbeništvo in geodezijo, Ljubljana: 480 p.

Šuklje, L. 1979: Objašnjenje pravilnika o tehničkim normativima za projektovanje i izvođenje radova kod temeljenja građevinskih objekata. Časopis »Izgradnja«, Beograd: 227 p.

Šuklje, L. 1984: Mehanika tal. Univerza Edvarda Kardelja v Ljubljani, Fakulteta za arhitekturo, gradbeništvo in geodezijo, Ljubljana: 359 p.

GEOLOGIJA *61/1*, 49-71, Ljubljana 2018
https://doi.org/10.5474/geologija.2018.004

Lower Jurassic succession at the site of potential Roman quarry Staje near Ig (central Slovenia)

Spodnjejurske plasti na območju morebitnega rimskega kamnoloma Staje pri Igu

Boštjan ROŽIČ[1], Luka GALE[1,2], Rok BRAJKOVIĆ[2], Tomislav POPIT[1] & Petra ŽVAB ROŽIČ[1]

[1]University of Ljubljana, Faculty of Natural Sciences and Engineering, Department for Geology, Privoz 11, SI-1000 Ljubljana, Slovenia;
[2]Geological Survey of Slovenia, Dimičeva ul. 14, SI-1000 Ljubljana, Slovenia
e-mail: bostjan.rozic@ntf.uni-lj.si, luka.gale@ntf-lj.si, rok.brajkovic@geo-zs.si, tomi.popit@ntf.uni-lj.si, petra.zvab@ntf.uni-lj.si.

Prejeto / Received 22. 3. 2018; Sprejeto / Accepted 19. 6. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Keywords: Lower Jurassic, Sinemurian, Dinaric Carbonate Platform, neptunian dyke, microfacies, Roman quarry

Ključne besede: spodnja jura, sinemurij, Dinarska karbonatna platfroma, neptunski dajk, mikrofacies, rimski kamnolom

Abstract

Several locations along the southern margin of the Ljubljana Moor have been proposed as sites of antique Roman quarries, but except for the site in the village of Podpeč, no detailed sedimentological investigations, which would reveal the spectrum of available natural stone, have yet been made. This paper presents a section logged at the potential Roman quarry from the small valley southeast of the village of Staje near Ig. The section is composed of Sinemurian strata dominated by micritic limestone with dissolution voids and bioclastic limestone, mostly wackestone with mollusks. Other facies are rare aggregate-grain/ooidal calcarenite, lumachella, limestone microbreccia, and stromatolitic limestone. Altogether, 21 microfacies types are described. Facies association points to sedimentation in restricted and open marine lagoon repeatedly subjected to emersion, rarely high-energy conditions or events. Previously unrecorded on the Dinaric Carbonate Platform in this area are neptunian dykes that occur as fractures partially filled by calcite cement and partially by intra/bioclastic packstone containing upper Jurassic microfossils. These could potentially serve as a diagnostic feature for recognizing artefacts made from stone quarried at Staje.

Izvleček

Do sedaj je bilo vzdolž južnih obronkov Ljubljanskega barja predlaganih nekaj lokacij kot domnevno rimskih kamnolomov, vendar nobena izmed teh, razen Podpeči, ni bila detajlno sedimentološko raziskana. Spekter dostopnega naravnega kamna tako ostaja dokaj slabo poznan. V tem prispevku predstavljamo profil, ki je bil posnet na območju morebitnega rimskega kamnoloma v majhni dolini jugovzhodno od vasi Staje pri Igu. Profil sestavljajo spodnjejurske, natančneje sinemurijske plasti, v katerih prevladujejo mikritni apnenci z dvema generacijama korozijskih votlinic in bioklastični apnenci, večinoma tipa wackestone z mehkužci. Ostali faciesi so redki kalkareniti z agregatnimi zrni ali ooidi, lumakela in apnenčeva mikrobreča. V raziskanem zaporedju izdvajamo 21 mikrofaciesnih tipov. Faciesna združba kaže na sedimentacijo v zaprti in občasno odprtomorski laguni, ki je bila podvržena ponavljajočim se okopnitvam, redko pa tudi višjeenergijskim razmeram ali dogodkom. Raziskane plasti ustrezajo predhodno opisanemu spodnjejurskemu zaporedju širšega območja, ki kaže postopno odpiranje iz hettangijskega medplimskega sedimentacijskega okolja v pliensbachijsko razgibano laguno. Pomemben element profila Staje so tudi neptunski dajki, ki do sedaj niso bili poznani v kamninah Dinarske karbonatne platfrome tega območja. Pojavljajo se v obliki razpok, zapolnjenih deloma s kalcitnim cementom, deloma pa s sedimentom tipa intra/bioklastični packstone, ki vsebuje zgornjejurske fosile. Le ti bi kot specifična značilnost lahko služili pri razločevanju artefaktov narejenih iz naravnega kamna pridobljenega iz območja Staj.

Introduction

The large alluvial fan of the Iška River at the southern outskirts of the Ljubljana Moor has been populated since pre-history (Velušček, 2004, 2010). During the first centuries AD the settlements from the Iška alluvial fan supplied the evolving colony of Emona (Šašel Kos, 2009) and left rich archaeological evidence, including numerous sepulchral monuments (roman tombstones) (Šašel, 1959; Ragolič, 2016; Veranič & Repanšek, 2016).

At Marof near Ig, the archaeological site was discovered in the year 2014, which included a pit with stone monuments from the Roman period (Ragolič, 2016). The majority of these monuments are made of limestone, for which a local origin has been presumed (Žvab Rožič et al., 2016). Proof of Roman use of natural stone comes to us from depictions on stone monuments (stelae), which indicate that the Roman-era inhabitants of the Ig area were involved in quarrying, forestry, and metalworking (Šašel, 1959). Ramovš (in Šašel Kos, 1997) mentions four locations of possible quarries from the Roman period along the southern outskirts of the Ljubljana Moor: Sveta Ana, Podpeč, Staje and Skopačnik (listed moving from west to east). The only proven roman quarry is that known in the village of Podpeč (Ramovš, 2000; Djurić & Rižnar, 2017), because during the archaeological excavations by B. Djurić in 2017 remains of Roman-age architecture were found inside the quarry (Djurić, pers.comm.). In this locality grey, dark grey and almost black Pliensbachian limestone with abundant ooids and bioclasts is exposed (Buser & Debeljek, 1995; Gale, 2014, 2015; Kramar et al., 2015). However, as pointed out already by Žvab Rožič and co-workers (2016), facies of analysed artefacts from Marof differ from the Podpeč limestone. Nor does it correspond to the Lower Triassic limestone of the potential ancient quarry near the Skopačnik farm that was described by Mušič (1990). Until now, there was no detailed lithological data from the other two sites (Sveta Ana and Staje) of potential ancient quarries.

This paper is the result of geological research of the Lower Jurassic succession from the village of Staje, i.e. the proposed site of the Roman quarry that was located closest to the above-mentioned Marof archeological site (cf. Ramovš - in Šašel Kos, 1997). We provide a detailed sedimentologic and biostratigraphic description of the limestone succession from the Staje section from the site where the ancient quarry was most likely situated. This data will serve as the basis for comparison with stone artefacts recovered at Marof and other archaeological sites located close by.

Geological setting

The studied succession is located on the northern edge of the Krim-Mokrec Mountain Range and structurally belongs to the Hrušica Nappe of the External Dinarides (fig. 1) (Placer, 1999; 2008). The main structures of the area are NW-SE oriented strike-slip faults (Buser et al., 1967; Buser, 1968). During the Mesozoic this area belonged to the northern part of the Dinaric (Adriatic) Carbonate Platform; thus, Upper Triassic to Middle Jurassic carbonates prevail (fig. 1). The Upper Triassic begins with a thin succession of coarse-crystalline ("cordevolian") dolomite, part of which could be Middle Triassic in age (Celarc, 2004, 2008). It is followed by a thick peritidal Norian-Rhaetian Main Dolomite Formation. The Lower Jurassic part is dominated by micritic and bioclastic limestones that alternate with ooidal limestone. In the Pliensbachian part of this succession, lithiotid bivalves occur (Buser & Debeljak, 1995; Debeljak & Buser, 1997; Gale 2014, 2015), whereas the Toarcian part is marked by thin-bedded micritic limestone (Dozet, 2009). The Middle Jurassic is composed almost exclusively of ooidal limestone (Miler & Pavšič, 2008). Jurassic limestones are often replaced by dolomite (Buser et al., 1967, Buser, 1968; Miler & Pavšič, 2008). In addition to the described carbonates, Paleozoic clastics and Early Triassic carbonate-clastic succession outcrops to the east of the studied area (Buser, 1968; Mušič, 1990). To the north the described units are covered by Quaternary alluvial fan coarse-clastic sediments, which further north interfinger with lacustrine and marsh deposits (Buser et al., 1967, Buser, 1968).

Methods

The micro-location of the potential Roman quarry was determined using a combination of fieldwork observations and analysis of the digital elevation model based on detailed 1 × 1m Lidar data. In the selected area a detailed sedimentological section (almost 40 m at 1:50 scale) was logged and densely sampled. Logging included measurements of structural elements (orientation and dip of fractures, veins, neptunian dykes). A total of 58 samples were selected; from these, 62 thin-sections were made for microfacies and biostratigraphic analysis. Names of the sample correspond to the stratimetric position of the logged section (sample 7.1 was taken at the 7.1th m of the section). The size of the ooids and aggregate grains, and the number of ooid laminae were measured in at least 30 grains in each thin-section dominated by these grains.

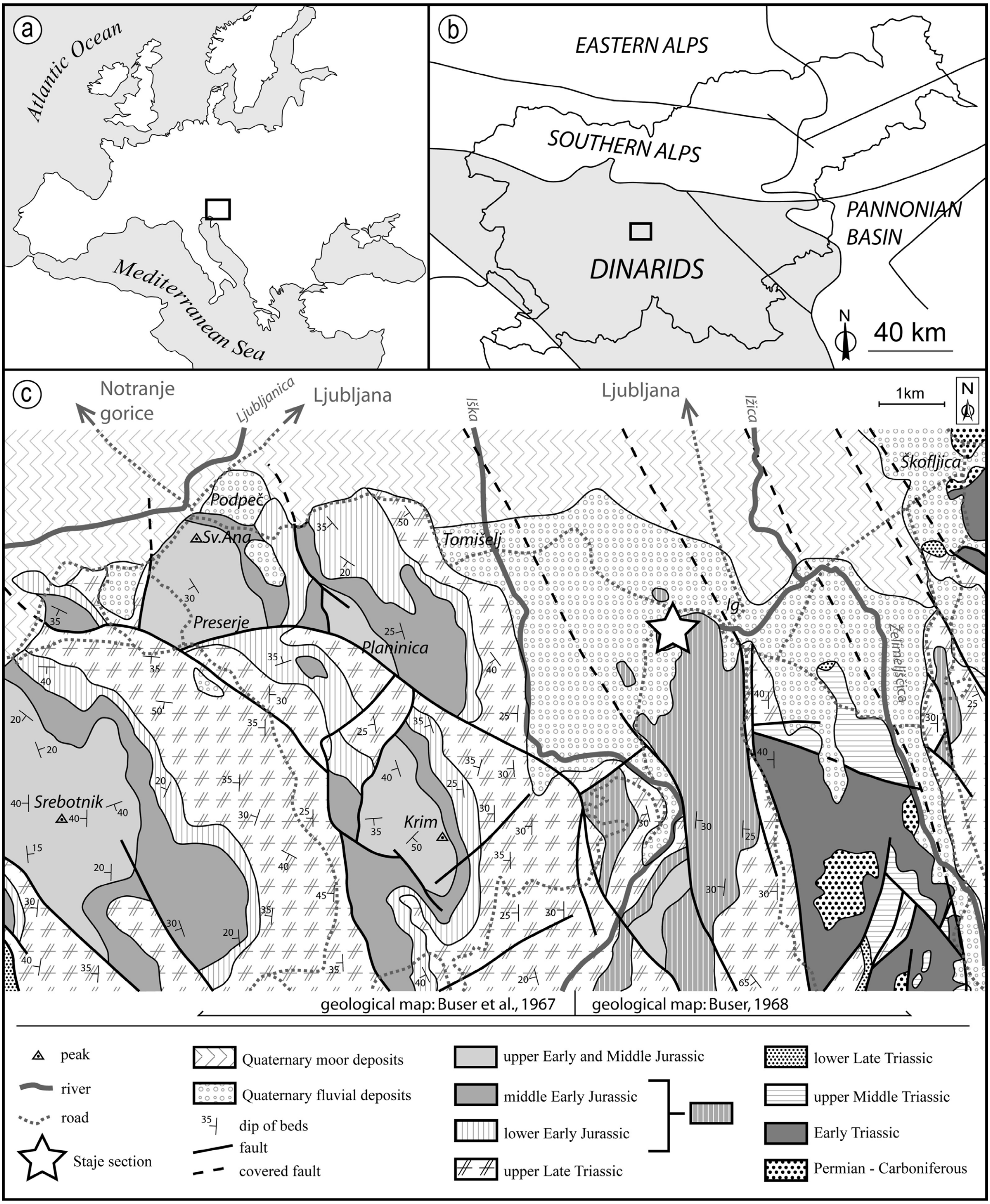


Fig. 1.a) Location of the studied section (boxed area is enlarged to the right). b) Macrotectonic subdivision of Slovenia (after Placer, 1999) with marked position of geological map below. c) Simplified geological map of the southern outskirts of the Ljubljana Moor (compiled from Buser et al., 1967 and Buser, 1968). The star marks the location of the studied section.

Micro-location of the potential Roman quarry

The hilly area south of the village of Staje is composed of Lower Jurassic limestone and subordinate dolomite (fig. 2). This karstic terrain is dominated by dolines and passes into the relatively flat Iška River alluvial fan. On the transitional belt (including the area of Staje and other villages) between the hills and flatland, the gravel-sand sediments also cover geomorphological depressions within outcropping base-rock, such as valleys and larger dolines. Anthropogenic al-

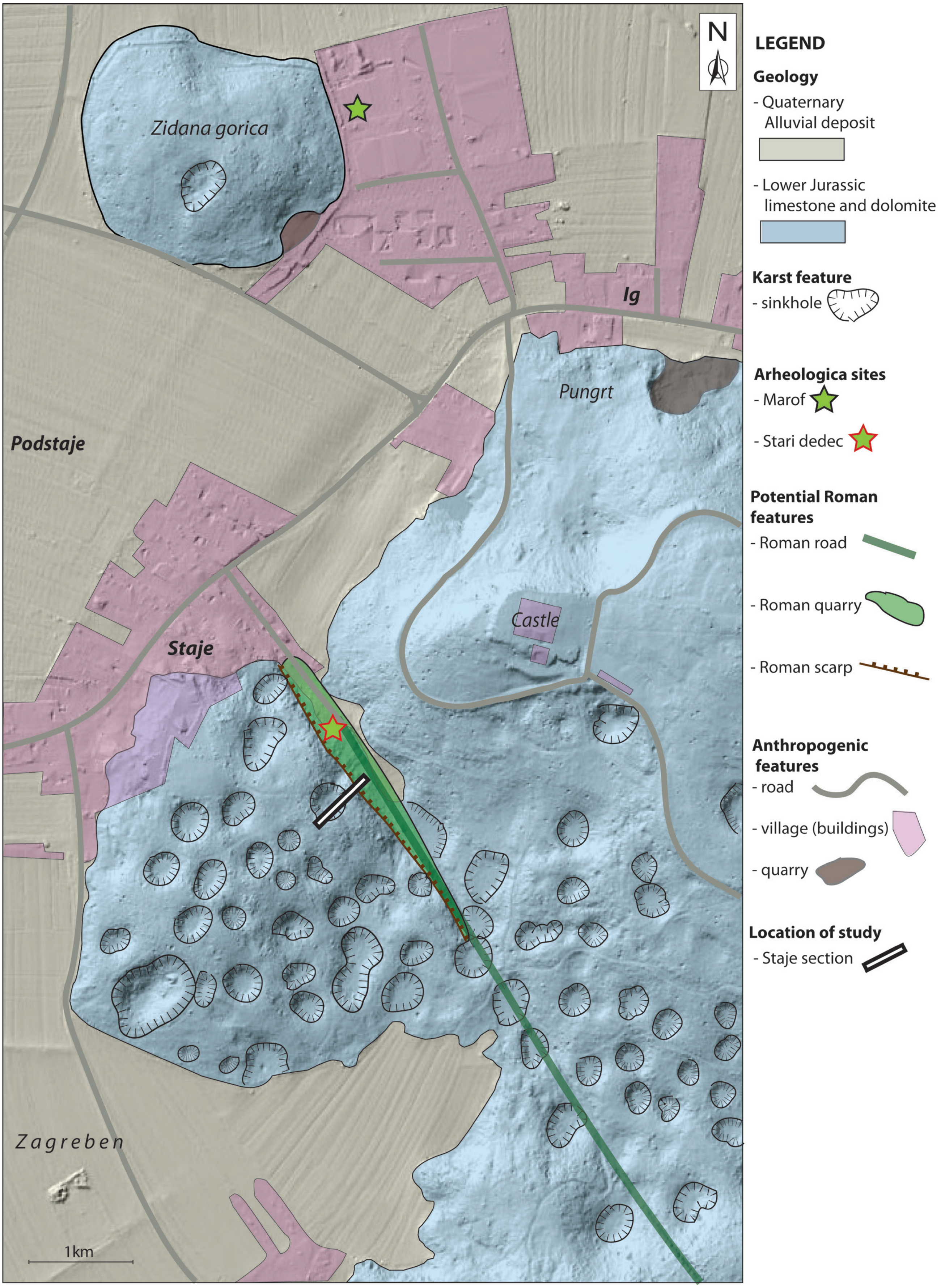


Fig. 2. Geomorphological map of the area of Staje and Marof with marked positions of the logged section (potential roman quarry), "Stari dedec" Roman monument and Marof arheological site.

Fig. 3. a) ”Stari dedec” Roman stela carved into the massive limestone outcrop at the entrance to the valley with potential roman quarry. b) Limestone escarpment at SW bank of the valley that could be of anthropogenic origin. c) Reddish sediment infill of large dissolution void (5. m of the section). d) Bioclastic rudstone deposited above erosional surface (just above 20. m of the section).

terations of the bedrock can be recognized in the area of the villages of Staje and Ig, on the Pungrt hill, where the Ig Castle is situated, and at the SW flank of the flat valley that runs from the village of Staje in the SE direction (figs. 3a, b). The latter shows a straight escarpment, which is in stark contrast to the NE flank of the same valley, which is defined by soft karstic lines (some are probably dolines filled by gravel and sand deposits). The escarpment on the SW flank of valley is a subvertical rock-wall stretching up to 6 m in height. Fractures run parallel to the massive wall surface, whereas rock debris is accumulated at the base of the wall.

As already mentioned by Vuga (2000a, b), this might be the site of ancient extraction of stone blocks that was positioned along the local Roman road that ran SE-ward. The same author proposes that the extraction site was owned by a family of stonecutters that carved the Roman stele (known as “Stari dedec”) into the massive limestone block that stands at the entrance to the same valley; figs. 2, 3a). If this hypothesis is true, the extraction of blocks was likely facilitated by the above-mentioned sub-vertical fractures. Interestingly, it looks is if the road-cut of the potential Roman road (located in the lower right corner of the fig. 2) follows the same fracture zone. On the walls of the road-cut we noticed indices of dextral strike slip movement.

Although the described features point to rock-cutting activities during the Roman period in the Staje area, more precise archaeological research is needed, because rock-extraction and road-construction could easily be of later origin. For example, lime production is reported from the Staje area (Dozet, 2014).

Description of the Staje section

With the Staje section 39.4 stratigraphic meters of Lower Jurassic carbonates were logged. The tentative productive part (main escarpment) of the presumed Roman quarry starts at 4.3 m and ends at 11 m of the section (fig. 3b). It is possible that there is a minor fault at the base of the escarpment (fig. 4).

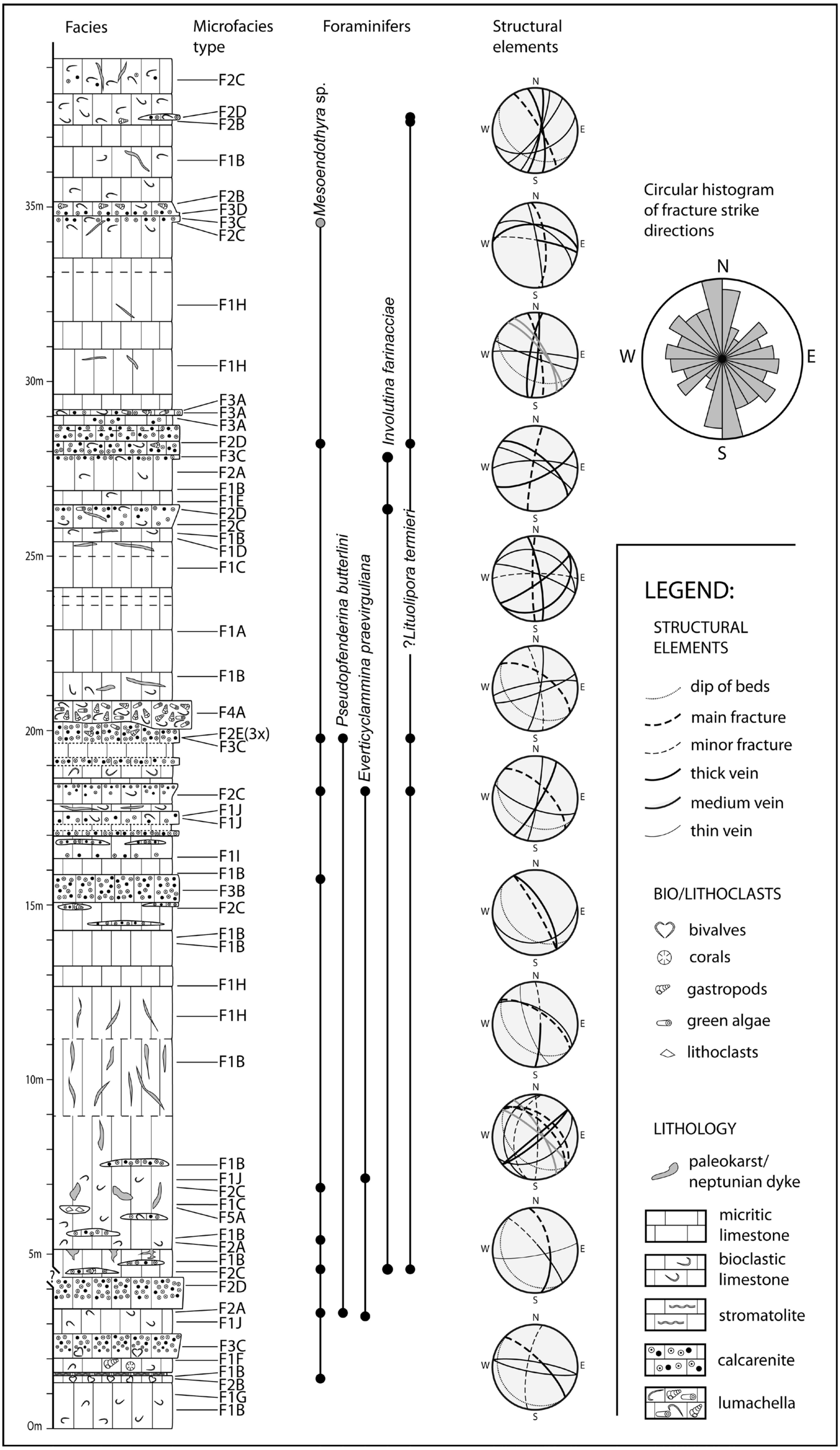


Fig. 4. Staje section with position of microfacies types, time-diagnostic foraminifers and nature of deformation at particular interval of the section (presented as spherical projection; equal-area projection, lower hemisphere and compiled in circular histogram of fracture strike directions).

The predominant facies are grey to dark grey micritic and bioclastic limestones, representing most of the thick beds, including the massive wall of the potential Roman quarry. Micritic limestone (F1) is characterized by small fenestrae. Also present are large dissolution cavities filled with cement and/or reddish, rarely greenish sediment (fig. 3c). Bioclastic limestone (F2) locally contains large (cm-sized) bivalves and subordinate gastropods. A single solitary coral was also spotted. The matrix between large fossils is micritic limestone, locally calcarenite. Besides fragments of mollusks, some beds are rich in other bioclasts: for example, the bed at the 20th m of the section also contains abundant dasycladacean algae. The third facies is grey, thin- to medium-bedded calcarenite (F3) that also occurs in thin lenses within the micritic and bioclastic facies. It is present at the base of the section (from the 2nd to 4th m), becomes more common in the middle part (15th to 20th m) and also occurs in the upper part of the section (28th to 29th and at 35th m).

The next facies type could be described as lumachella (F4) as bioclasts (gastropods, bivalves and dasycladacean algae) are accumulated in a bed at the 20.5th m of the section that shows scour-like depressions at the base (fig. 3d). A thin lens (channel) of limestone microbreccia (F5) was spotted at the 6.3th m of the section within micritic limestone. At the base of the section a thin stromatolite bed (F6) is present (no thin section was made from this facies). Neptunian dykes are present in the form of fractures filled by calcite and sediment.

Microfacies of the Staje section

The greatest diversity of microfacies was found within micritic limestone, as it is also the most common facies. *Mudstone* (F1A) appears in a single thin-section. The most common is *fenestral mudstone/wackestone* (F1B). Apart from sporadic ostracods, it is very poor in fossils. Dissolution voids are usually of two generations. Earlier, smaller (mm-sized) and usually geopetally filled birds-eyes fenestrae. These are followed by larger dissolution cavities, filled with sediment and/or cement (Figs. 5a-c). The following microfacies types are generally similar to the previous one (F1B), but have specific characteristics. In *fenestral laminated mudstone* (F1C) dense, curly laminae are visible. *Fenestral mudstone with clusters of small circular grains* (F1D) shows intense dissolution and microsparite fields that contain small circular microsparite grains (Figs. 5d. e). *Disintegrated laminated mudstone* (F1E) is composed of intraclasts that originated from disintegration of laminated mudstone (fig. 5f).

The following five microfacies are macroscopically defined as micritic limestone, but show transitional characteristics. Fenestral mudstone with large gastropods (F1F) is mudstone that contains rare larger gastropods and already represents transition to bioclastic limestone (fig. 6a). *Fenestral pelletal packstone* (F1G) and *Parallel and low-angle cross-laminated pelletal pack/grainstone* (F1H) are packstones composed of small pellets. The first is non-laminated with two generations of dissolution voids (equal to F1B) (fig. 6b). The second is laminated packstone with fenestrae present only occasionally in the form of small, lamination-parallel birds-eyes (Figs. 6c, d). *Bioturbated intraclastic/pelletal wackestone* (F1I) is wackestone that contains sand-size grains of the same type as encountered in calcarenite (fig. 6e). *Fenestral wackestone with coated grains (oncoids)* (F1J) also shows transitional characteristics to the bioclastic limestone. It generally corresponds to previously described microfacies, but additionally contains large, coated bioclasts (fig. 6f), sometimes in the form of well-developed oncoids.

Bioclastic limestone occurs in form of five microfacies. The first is *Bioclastic wackestone with or without large mollusks* (F2A). Large fossils, when present, are cm-sized (fig. 7a). In some thin sections, the density of large fossils is high and the microfacies is better described as *molluskan floatstone* (F2B) (figs. 7b, c). Two other microfacies types are found within this group. They both have large bioclasts (mostly mollusks), but the matrix between them is grain-supported (figs. 7d, e), in the form of either (partly washed) packstone (*intraclastic, ooidal, pelletal partly-washed packstone with large bivalves and intraclasts* – F2C) or grainstone (*intraclastic, ooidal, pelletal grainstone with large mollusks and intraclasts* – F2D). The last microfacies, *dasycladacean & molluskan pack/floatstone* (F2E) is transitional to ooidal calcarenite, because it contains ooidal, partly-washed packstone as a matrix and large mollusks and dasycladacean algae (fig. 7f).

Calcarenite can be divided into two subgroups according to its composition. In the first, aggregate grains prevail among the constituents (figs. 8a-c). These microfacies types are either poorly sorted, partly-washed packstone that locally contain large bioclasts (*partly washed packstone with aggregate grains* - F3B) or well sorted grainstone (*grainstone with aggregate grains* - F3A). The second subgroup is dominated by ooids (fig.

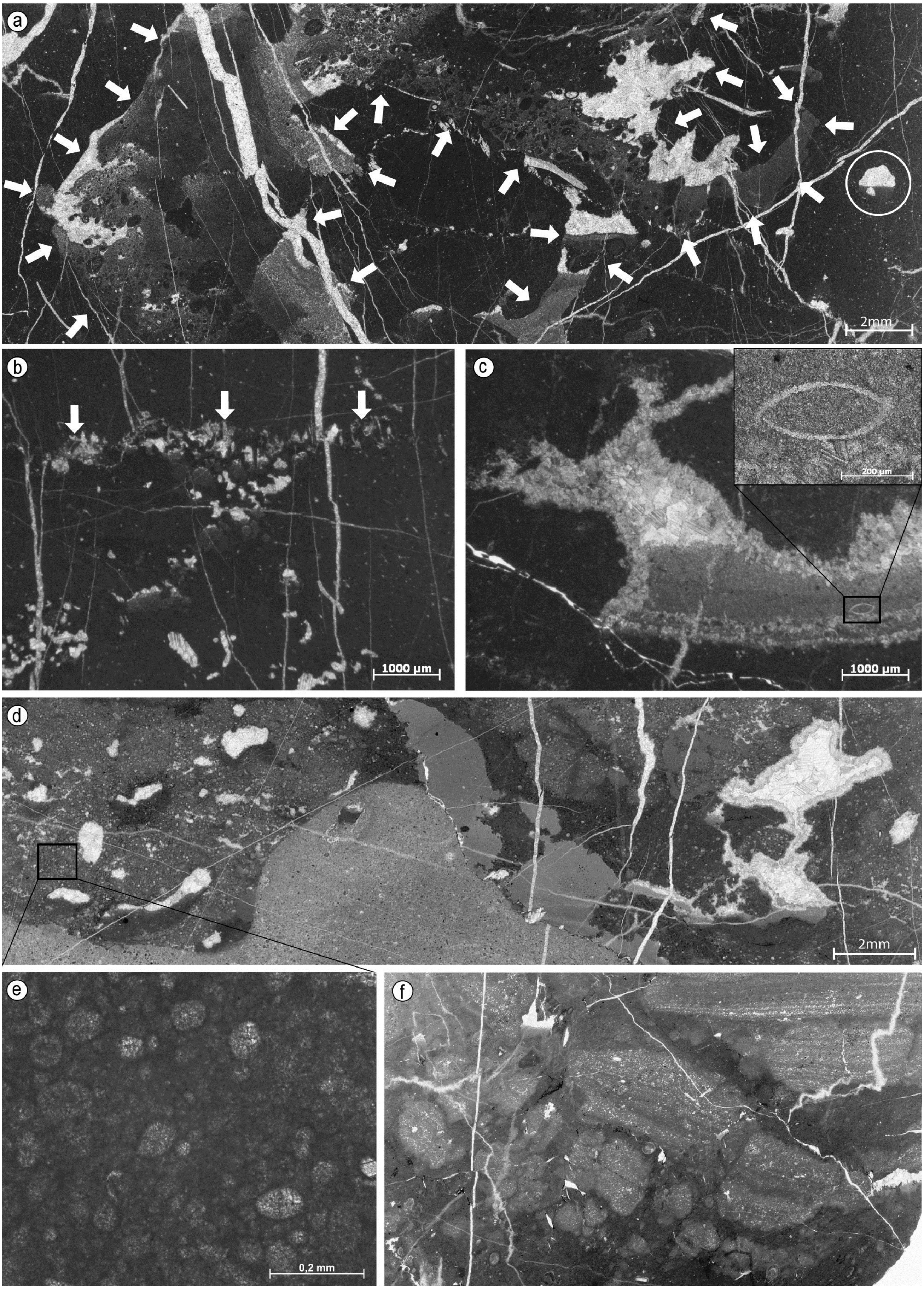


Fig. 5. Microfacies of micritic limestone.

8d), mainly in the form of *ooidal grainstone and subordinate packstone* (F3C). One thin section is *ooidal packstone with fenestrae* (F3D) that shows an intense dissolution of matrix between ooids (fig. 8e).

The last two (micro) facies types appear as coarse-grained accumulations at only two levels (figs. 8f, g). Lumachella is described as *dasycladacean & molluskan rudstone* (F4A) because it consists almost exclusively of large (cm-sized) gastropods, bivalves and dasycladacean algae (fig. 8f). Limestone microbreccia, named *lithoclastic floatstone* (F4A), is composed of diverse, angular lithoclasts and comes from a thin lens (?channel) within micritic limestone (fig. 8g). For a detailed description of microfacies see Table 1.

Biostratigraphy of the Staje section

The foraminiferal assemblage within the investigated succession (fig. 9) is characterized by *Pseudopfenderina butterlini* (Brun), *Mesoendothyra* sp., *Everticyclammina praevirguliana* Fugagnoli and ?*Lituolipora termieri* (Hottinger). The uncertainties in the structure of the wall and the type of aperture prevent us from reliably determining the latter species. The stratigraphic range of *P. butterlini* is from late Sinemurian to Pliensbachian (BouDagher-Fadel & Bosence, 2007; Velić, 2007). Due to the absence of lithiotid bivalves and *Orbitopsella* in the section, we suggest Sinemurian age for the studied succession. *Mesoendothyra* sp. likewise makes its first appearance in Sinemurian (Velić, 2007), whereas *E. praevirguliana* possibly appears already in the latest Hettangian (Velić, 2007) or during the Sinemurian (BouDagher-Fadel & Bosence, 2007). Other associated foraminiferal species, all with long stratigraphic ranges or not considered to be reliable biostratigraphic fossils, are *Duotaxis metula* Kristan, *Siphovalvulina* ex gr. *gibraltarensis* BouDagher-Fadel et al., *Siphovalvulina colomi* BouDagher-Fadel et al. vel *Siphovalvulina variabilis* Septfontaine, *Earlandia dunningtoni* (Elliot), *Involutina farinacciae* Brönnimann & Koehn-Zaninetti, ?*Trocholina umbo* (Frentzen), *Ammobaculites* sp., *Reophax* sp., Textulariidae, undetermined miliolid and lagenid foraminifers.

Neptunian dykes and other structural elements

Neptunian dykes occur in the form of thick extensional fractures with a NW-SE strike and dipping generally perpendicular to the bedding of the host-rock, but other directions are also present. Infilling of fractures vary from: A) completely sediment-filled fractures, B) sediment fill that follows the first generation of cements (usually with crystal growth perpendicular to fracture margin), C) geopetally filled fractures (often after the first generation of cement), and D) fractures filled with calcite and fragments of host-rock. The thick, calcite-filled veins probably belong to the same extensional event. The combinations and vertical alternation of the described subtypes (including thick veins) can be visible in the same thin-section (fig. 10a).

Sediment of neptunian dykes varies from calcisiltite to medium-grained calcarenite; occasionally it even alternates irregularly or in laminae within the same dyke (figs. 10b-d). Most information comes from the dyke at 6.4 m of the section that is filled with coarse calcarenite (Fig. 10d). It is well-sorted medium-grained packstone composed predominantly of bioclasts, intraclasts, pellets and subordinate small, superficial ooids. Among the bioclasts echinoderm fragments prevail. Others are foraminifers, *Tubiphytes*-like grains, fragmented bivalves and fragments of dasycladacean algae. Part of the sparitic grains could also originate from the disintegration of early cements.

Fig. 5. Microfacies of micritic limestone

a) Fenestral wackestone with large void filled by several generations of cement and sediment. Arrows indicate margins between large cavity and host rock. Circle (right side of micrograph) envelops birds-eyes void filled geopetally with ostracod-bearing calcisiltite and drusy-mosaic calcite (mf-type F1B, sample 14.1).

b) Field of small fenestrae (some geopetally infilled) that are divided by a network of thin micritic walls (mf-type F1B, sample 0.5).

c) Geopetal infill of stromatactis with two generations of cement and intermediate sediment infill with calcisiltite. In boxed area an ostracod from calcisiltite is enlarged (mf-type F1B, sample 21.6).

d) Fenestral mudstone with clusters of small circular grains (enlarged in fig. 1e). Early fenestrae tend to form in micrite between these clusters. Later generations of dissolution voids (filled with calcisiltite) are larger and do not follow the preceding texture (mf-type F1D, sample 25.5).

e) Enlarged cluster with small oval microsparitic grains that may be produced through early diagenetic bacterial-induced cementation (mf-type F1D, sample 25.5).

f) Disintegrated laminated mudstone. Downwards, intraclasts tend to decrease in size and oval, mm-sized grains (?pisoids) start to occur between them (mf-type F1E, sample 26.55).

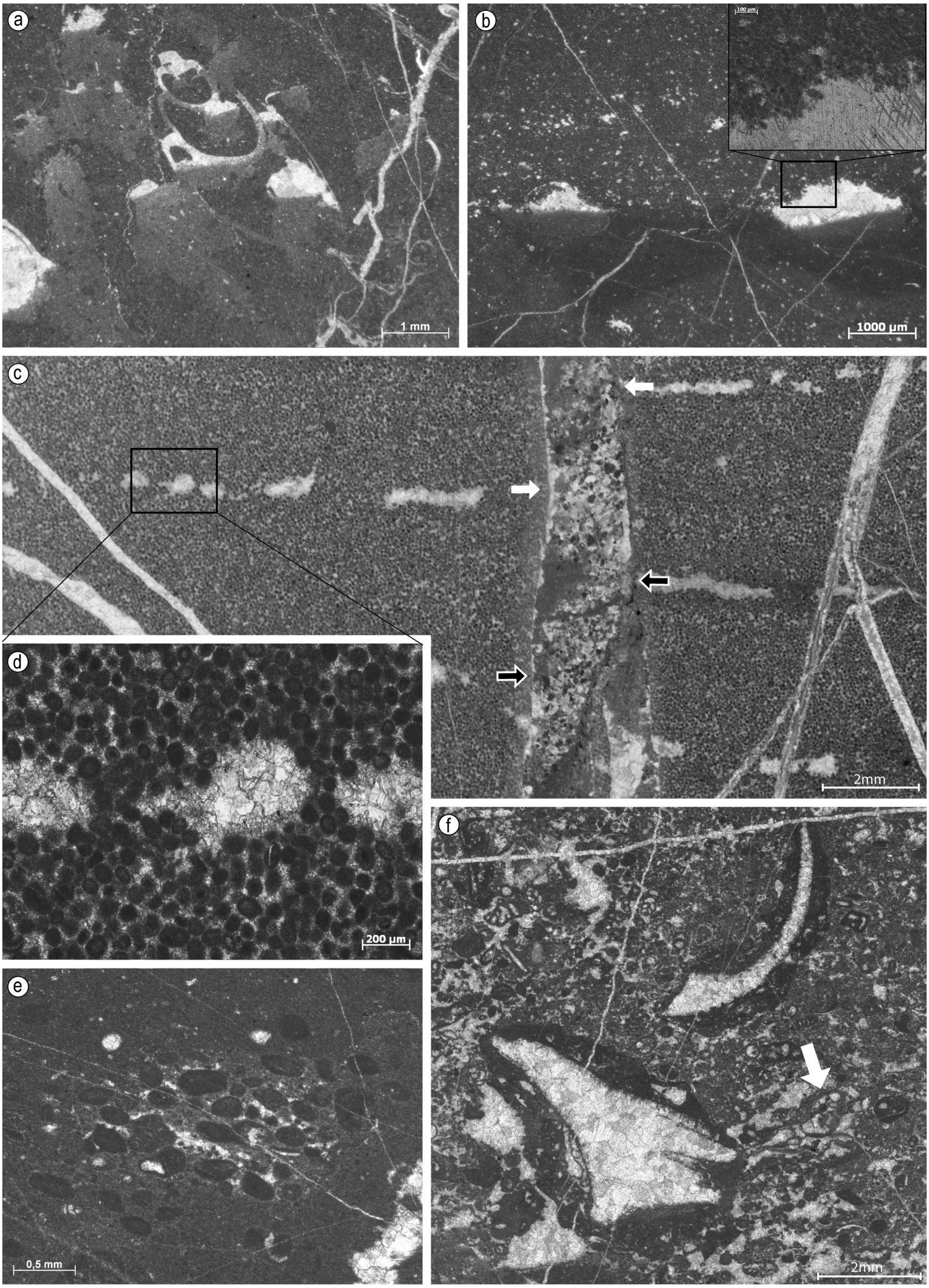


Fig. 6. Transitional microfacies from micritic to other microfacies.

a) Mudstone with gastropod shell involved in formation of fenestrae (mf-type F1F, sample 1.9).

b) Pelletal packstone with fenestrae filled by dense micrite, dissolved again and geopetally refilled. The enlarged box shows that the host-rock is composed of densely packed tiny pellets (mf-type F1G, sample 1.0).

c) Pelletal packstone with fenestrae occurring mostly in distinct laminae (enlarged in Fig. 6d). Fracture is filled with latest Jurassic sediment (neptunian dyke); arrows indicate minor displacement (mf-type F1H, sample 32.2).

d) Birds-eyes laminae within pelletal packstone (enlargement of boxed area from Fig. 6c) (mf-type F1H, sample 32.2).

e) Intraclasts and pellets concentrated in burrow inside wackestone that contains equal grains (mf-type F1I, sample 16.3).

f) Coated bioclasts within fenestral wackestone; arrow indicates Thaumatoporella sp. (mf-type F1J, sample 3.1).

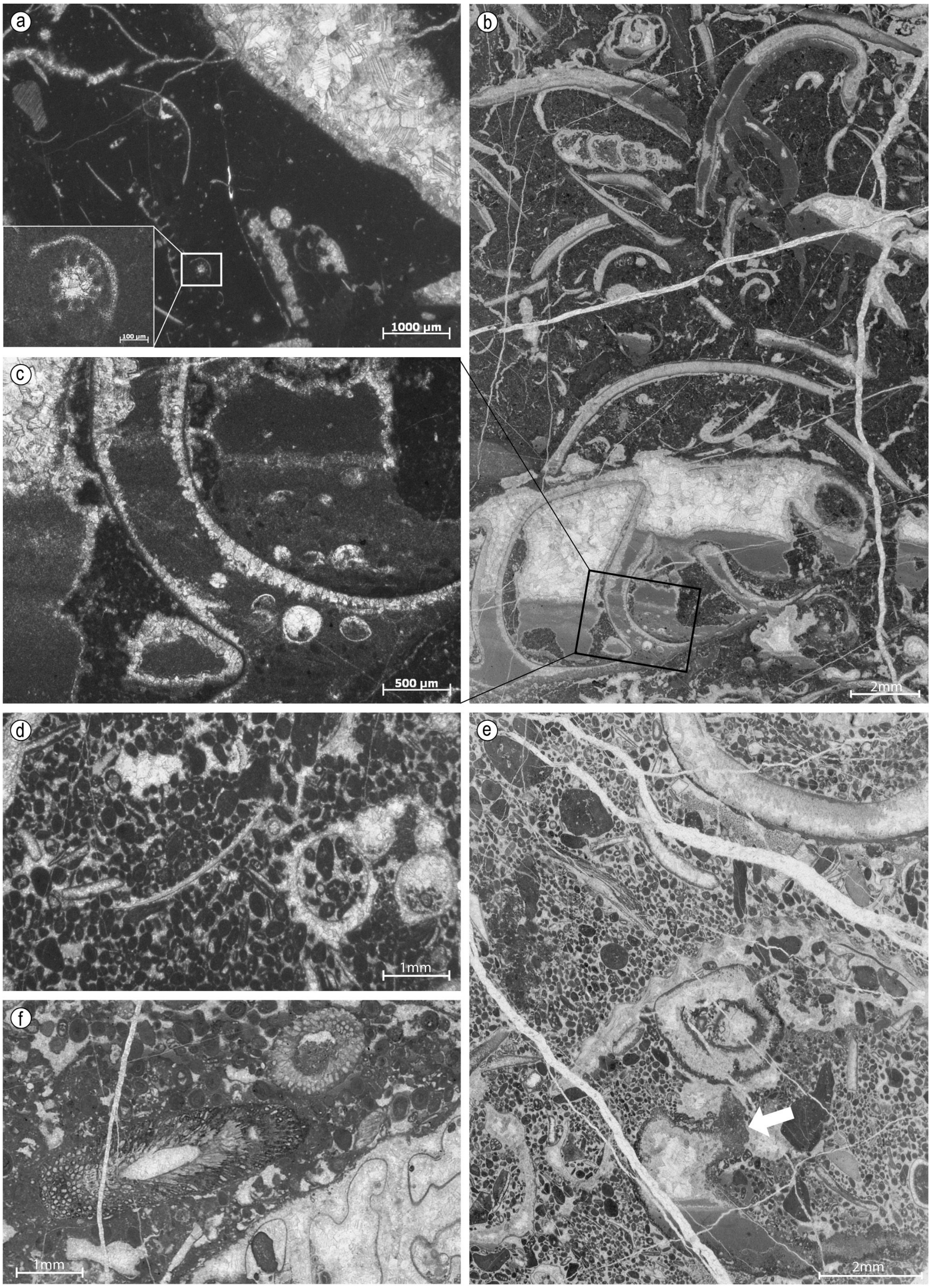


Fig. 7. Microfacies of bioclastic limestone.

a) Bioclastic wackestone with large recrystallized bivalve. Small circular grain (enlarged in boxed area) could be gyrogonites (mf-type F2A, sample 27.4).

b) Gastropods and bivalves as main cm-sized grains in floatstone (boxed area enlarged in Fig. 7c) (mf-type F2B, sample 35.1).

c) Complex pattern of poly-generation dissolution and subsequent infilling of bioclastic floatstone as a result of repeatable subaerial exposure (enlargement of boxed area from Fig. 7b) (mf-type F2B, sample 35.1).

d) Gastropod and bivalve within generally finer partly-washed packstone (mf-type F2C, sample 18.2).

e) Large fossils (bivalves, brachiopod, dasycladacean algae) and intraclasts inside intra/bioclastic and ooidal grainstone. Arrow indicates microbial crusts on completely dissolved and geopetally infilled grain, probably bivalve in origin (mf-type F2D, sample 26.35).

f) Dasycladacean algae and large gastropod inside ooidal and intraclastic partly-washed packstone (mf-type F2E, sample 19.8).

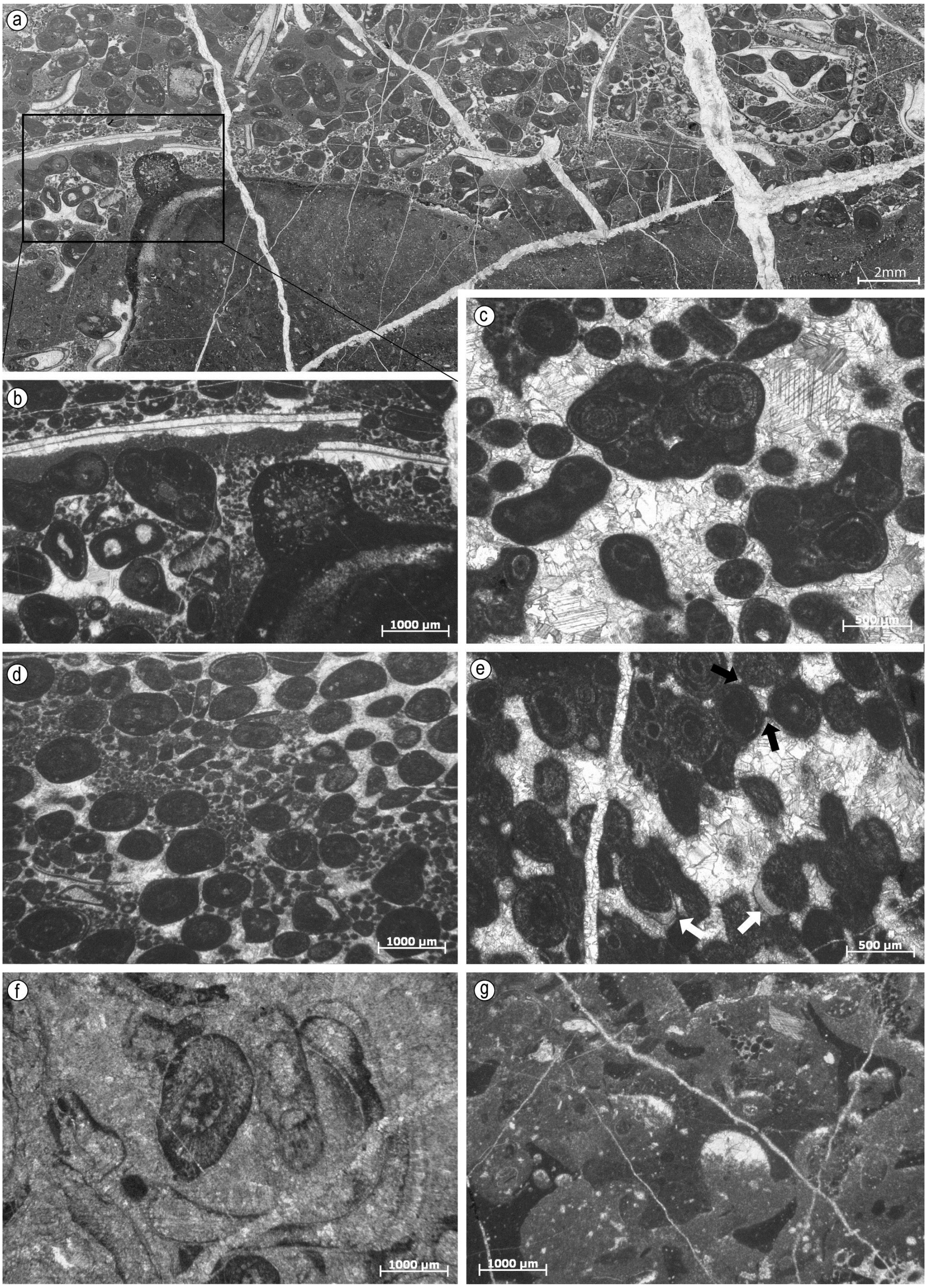


Fig. 8. Microfacies of calcarenite, lumachella and litoclastic microbreccia.

a) Hardground with irregular surface ending with encrusting organisms (boxed are enlarged in Fig. 8b) and overlain by partly-washed packstone with aggregate grains and large bioclasts, mainly bivalves and dasycladacean algae (mf-type F3A, sample 28.95).

b) Encrusting organism at the surface of the hardground and structure below bivalve shells (enlarged from boxed area in fig. 8a) (mf-type F3A, sample 28.95).

c) Grainstone composed of aggregate grains and ooids (mf-type F3B, sample 15.4).

d) Laminae of pelletal packstone within ooidal grainstone (mf-type F3C, sample 2.3).

e) Ooidal packstone with dissolution voids often selective to matrix. Cements are fibrous-rim, drusy-mosaic and possibly stalactitic (white arrows) and micritic meniscus (black arrows) cements. The latter could also represent the remains of an undissolved matrix that remained close to contacts of dissolution-resistant ooids (mf-type F3D, sample 34.8).

e) Recrystallized dasycladacean algae and mollusks inside rudstone (mf-type F4A, sample 20.5).

f) Diverse lithoclasts that form a floatstone matrix. Note that the margins of lithoclasts are highly irregular, which points to very short transport. Some also show burrows at margins (mf-type F5A, sample 6.3).

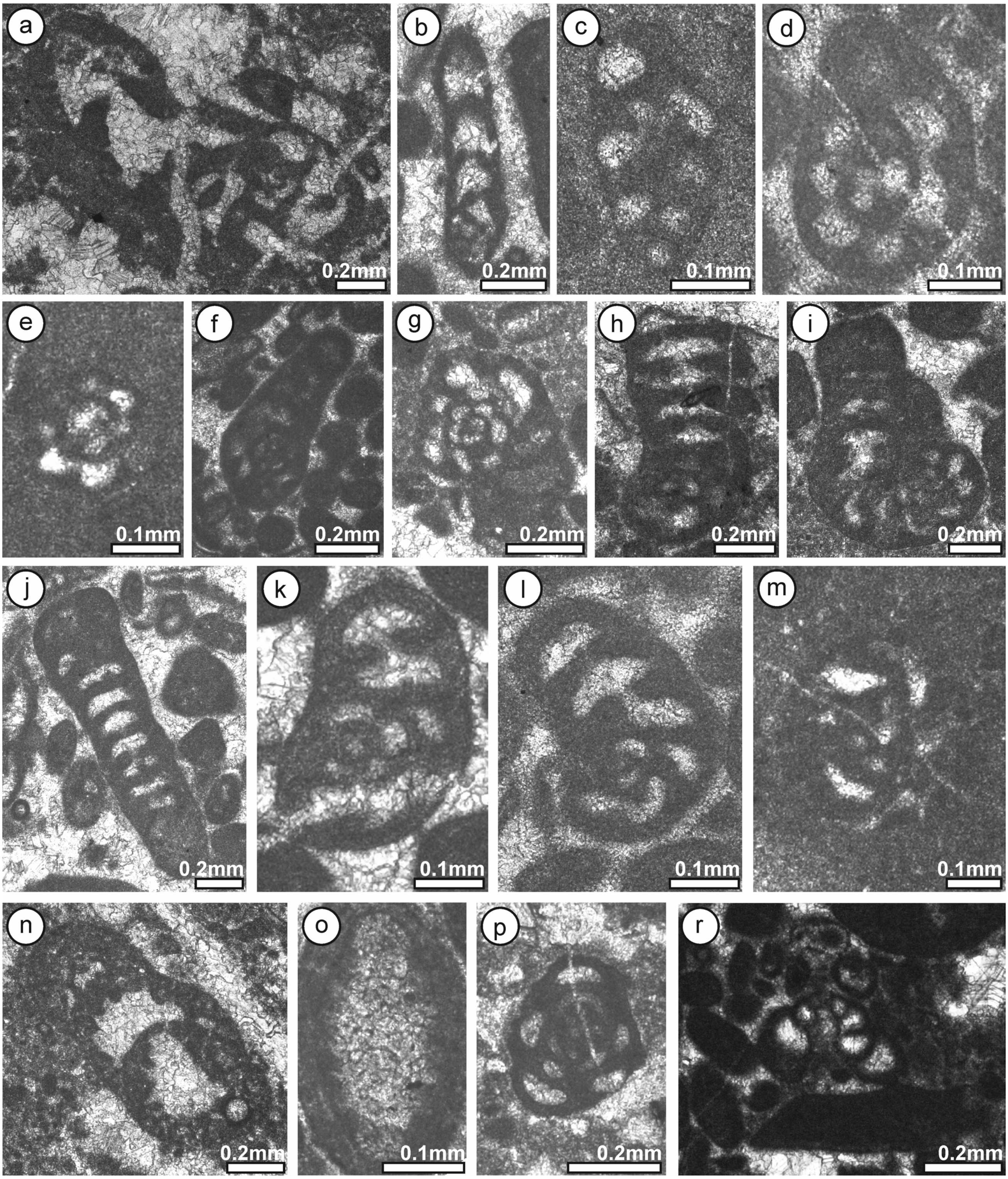


Fig. 9. Foraminifers from the logged Staje succession.

a-b: *Everticyclammina praevirguliana* Fugagnoli. Thin sections 4.1 and 18.2, respectively.

c: *Pseudopfenderina butterlini* (Brun). Thin section 3.3.

d-g: *Mesoendothyra* sp. 4: Thin section 18.2. 5: Thin section 5.3. 6: Thin section 4.5. 7: Thin section 34.55.

h-m: ?*Lituolipora termieri* (Hottinger). 8-10: Thin section 37.55. 11: Thin section 28.25. 12: Thin section 18.2. 13: Thin section 5.3.

n: Undetermined Lituolida. Note canaliculate wall structure. Thin section 7.1.

o: *Involutina farinacciae* Brönnimann & Koehn-Zaninetti. Thin section 15.9.

p: ?*Quinqueloculina* sp. Thin section 5.4. Infill of neptunian dyke.

r: *Siphovalvulina ex gr. gibraltarensis* BouDagher-Fadel, Rose, Bosence & Lord. Thin section 25.9.

Table 1. Microfacies types of the Staje section. Standard Microfacies types (SMF) are summarized after Flügel (2004). Please note that fenestrae are considered as generally synsedimentary and are described within the composition (including infill sediment and cements) of the particular microfacies type.

Facies	Microfacies	Description
F1 – Micritic limestone	F1A – Mudstone Sample 22.8	**Composition:** Micrite strongly predominates. Very rare are small, oval sparitic grains (bioclasts). **Diagenesis:** Contains dense network of thin calcite veins. **SMF / environment:** SMF23 / Supra-intertidal, restricted lagoon.
	F1B - Fenestral mud/wackestone Samples 0.5, 1.0, 1.5, 4.8, 5.4, 7.6, 10.5, 13.9, 14.1, 15.8, 21.6, 25.7, 26.85, 36.3,	**Composition:** Micrite contains rare pellets and small bioclasts (fig. 5a): predominantly ostracods, very rare small bivalves and gastropods. Fenestrae are small (mm-sized) and irregular, rarely of stromatactis type or oval shaped (fig. 5c). Infillings show geopetal structures: micrite/calcisiltite (laminated, can contain ostracods) is at the bottom, while the top is filled with mosaic calcite. Some fenestrae (of stromatactis type) contain isopachous fibrous rim cements that can post- or pre-date calcisiltite fill. Some small-scale fenestrae in sample 0.5 are grouped in larger fields and divided by very thin, undulated micrite films, thus forming an irregular, geopetally filled mesh (fig. 5b). Large (cm-sized) dissolution voids locally post-date fenestrae. They are irregular, mostly filled by isopachous fibrous or drusy-mosaic cements. Some are filled with mudstone with ostracods. Large void in sample 14.1 shows complex multi-generation filling with peloidal/intraclastic/ooidal packstone that either grades or sharply passes to mudstone. Older fillings exhibit partial dissolution (fig. 5a). **Diagenesis:** Locally, micrite is recrystallized to microsparite. Present are stylolites and dense network of thin, occasionally thicker calcite veins. Some fractures in samples 4.8 and 5.4 are filled by younger sediment (neptunian dykes). Sample 4.8 shows dispersed dolomite crystals close to and inside of neptunian dyke. **SMF / environment:** SMF21 / Supra-intertidal, restricted lagoon; repeatable periods of post-depositional subaerial exposure.
	F1C - Fenestral laminated mudstone Samples 6.4, 24.7	**Composition:** Irregular laminae of dense, aphanitic micrite with rare ostracods alternate with microsparite with birds-eyes fenestrae of various sizes. Aphanitic micrite may laterally pass into pelletal micrite. Fenestrae are filled by mosaic calcite cement. **Diagenesis:** Thin calcite veins run in various directions. Sample 24.7 has thicker calcite veins oriented sub parallel to laminae. Laminated mudstone in sample 6.4 shows almost complete dolomitization: dolomite is slightly reddish; dense micritic laminae remain partly preserved in irregular fields. **SMF / environment:** ?SMF 19 / Supra-intertidal, restricted lagoon.
	F1D - Fenestral mudstone with clusters of small circular grains Sample 25.5	**Composition:** Micrite contains highly irregular – cauliflower-like bodies of microsparite with abundant small circular grains (sometimes sparite, sometimes with sparitic rim and micritic core) (figs. 5d, e). These bodies could originate during early diagenetic (?bacterial-induced) cementation. Micrite shows compaction along the margins with microsparite. It can contain very rare ostracods. Fenestrae can be birds-eyes or very irregular and tend to appear selectively in micrite between the microsparite bodies. Larger have complete or geopetal filling with calcisiltite. Upper parts of partly filled fenestrae often show two generations of cementation. First-formed is the isopachous rim cement (can be followed by second generation of calcisiltite fill). The second cement is drusy-mosaic calcite. Large (cm-sized) dissolution voids (younger than fenestrae) are irregular, filled by mud/wackestone with very small pellets. Infill sediment can contain last generation of small birds-eyes filled with drusy-mosaic calcite. **Diagenesis:** Pyrite occurs along the stylolites or in form of rare framboidal pyrite within the sediment **SMF / environment:** SMF21 / Supra-intertidal, restricted lagoon; repeating periods of subaerial exposure.
	F1E - Disintegrated laminated mudstone Sample 26.55	**Composition:** Large (cm-sized) intraclasts of dense laminated mudstone that show partly fitted fabrics are sunk into underlying micrite (fig. 5f). Downwards, intraclasts are progressively smaller and more rounded. Small, geopetally filled birds-eyes fenestrae occur inside and between intraclasts. The micrite in the lower part of the thin-section contains rare coated grains (?pisoids) and a foraminifer. Few coated grains occur also in matrix between the intraclasts. **Diagenesis:** Thin calcite veins run in various directions. Pyrite occurs along stylolites and small dissolution seams within micrite. **SMF / environment:** ?SMF24 / Restricted lagoon.
	F1F - Fenestral mudstone with large gastropods Sample 1.9	**Composition:** Very rare small bioclasts (recognizable are bivalve fragments), and up to a few mm large gastropods, which can have geopetal infilling (fig. 6a). Two kinds of dissolution voids are present: -smaller fenestrae: these usually contain geopetal infill with micrite/calcisiltite and drusy-mosaic calcite. Some have thin calcite rim that formed prior to sediment infill. Dissolution occasionally includes the walls of gastropod shells and also the primary micrite infill of shell-cavities. -large (cm-sized) irregular dissolution voids infilled with large micrite intraclasts (originating from collapse of the void roof) and calcisiltite, occasionally with pellets. **Diagenesis:** Network of thin calcite veins that run in various directions. Other features are stylolites and rare framboidal pyrite. **SMF / environment:** Between SMF21 and SMF12 / Lagoon (restricted); repeating periods of subaerial exposure.
	F1G - Fenestral pelletal packstone Sample 1.0	**Composition:** Pellets are small and densely packed. Small bioclastic fragments are present but rare. Three types of dissolution voids can be recognized (fig. 6b): -small fenestrae filled with drusy-mosaic calcite, -large cm-sized irregular dissolution voids filled with micrite containing rare ostracods and small bioclastic fragments, -small fenestrae occurring solely inside or at upper margins of micrite infills of large voids; these fenestrae show geopetal infill with calcisiltite and drusy-mosaic calcite. **Diagenesis:** Network of thin calcite veins that run in various directions. Stylolites occur. **SMF / environment:** Between SMF16-NONLAMINATED and SMF21 / Restricted lagoon; repeating periods of subaerial exposure.

	F1H - Parallel and low-angle cross laminated pelletal pack/grainstone Samples 11.8, 12.7, 30.45, 32.2	**Composition:** Pellets predominate. Subordinate are small bioclastic fragments (mostly unrecognizable, some fragmented shells, echinoderms and foraminifers). Some laminae have grainstone texture. They contain larger grains, including superficial ooids and cortoids. Sample 32.2 contains elongated fenestrae (birds-eyes) that replace certain bedding-parallel laminae or are (more rarely) curved. Infill is drusy-mosaic calcite (figs. 6c, d). **Diagenesis:** Network of thin calcite veins that run in various directions. Stylolites are rare. Samples 11.8 and 12.7 have large coarse-crystalline calcite veins. Sample 32.2 has large fractures, partly filled by coarse-crystalline calcite and subsequent sediment, which is alternating with levels of calcisiltite and bio/intraclastic fine-grained packstone. **SMF / environment:** SMF16-LAMINATED; sample 32.2 has characteristics also of SMF 21 / Restricted lagoon.
	F1I - Bioturbated intraclastic/ pelletal wackestone Sample 16.3	**Composition:** The amount of grains is variable, mostly due to bioturbation (Fig. 6e) and also bedding-parallel lamination. Grains are represented by intraclasts, peloids and pellets, rare micritized ooids, and very rare bioclasts (echinoderm plates, bivalve shells and small gastropods). Rare fenestrae occur in form of small irregular voids or larger stromatactis; both are filled with drusy-mosaic cement. **Diagenesis:** Network of thin calcite veins that run in various directions. Sample contains large fractures that are partly filled by coarse-crystalline calcite and partly by calcisiltite (?neptunian dyke) **SMF / environment:** ?SMF24 / Structural inversion: low energy (lagoonal) mud with grains from environment of higher energy (intraclasts, ooids).
	F1J - Fenestral wackestone with coated grains (oncoids) Samples 3.1, 7.1, 17.5, 17.6	**Composition:** Main constituents are foraminifer, intraclasts and aggregate grains (simple lumps composed of few, up to 0.5 mm large ooids and intraclasts). Quantity of individual constituents varies significantly between the thin-sections (lumps are dominated in sample 17.5, foraminifers in samples 3.1 and 7.1). Other grains are ooids (sample 17.5) and diverse bioclasts: bivalves, ostracods, dasycladacean algae (sample 3.1), oval *Tubiphytes*-like grains (sample 3.1, 7.1), *Thaumatoporella* sp. (sample 3.1, 7.1, 17.6), echinoderm plates and spines. Sample 17.6 has cm-sized bivalve, that was dissolved, geopetally filled with calcisiltite with peloids and large-crystalline drusy-mosaic calcite. Matrix occasionally reveals a composition of small, densely packed pellets. Coated grains have bioclastic core (Fig. 6f; bivalves, dasycladaceas). Some are well developed (rounded) oncoids, others have thin coatings and mimic the original shape of a core. Coatings are mostly by filamentous mats (sometimes with clearly visible filaments), but encrusting foraminifers also occur. Fenestrae are present and are geopetally filled with calcisiltite/micrite and drusy-mosaic calcite. Samples 7.1 and 17.5 show bioturbation. **Diagenesis:** Network of thin calcite veins that run in various directions. Stylolites occur. **SMF / environment:** SMF 8-9 and SMF 22 / Open-marine lagoon close to more restricted environment; subaerial exposure.
F2 – Bioclastic limestone	F2A – Bioclastic wackestone with or without large mollusks Samples 3.3, 5.3, 27.4	**Composition:** Bioclasts are bivalves, gastropods, foraminifers, ostracods and small unrecognizable detritus. In sample 27.4 echinoderm spines are present. There are similar, but poly-crystalline oval grains with radially distributed rim of small circular cavities. They resemble gyrogonites or small dasycladacean algae (Fig. 7a), but show no central cavity. Other grains are pellets and in sample 3.3 also intraclasts. Samples 3.3 and 27.4 contain rare large bivalves and sample 27.4 also a large gastropod. Sample 3.3 has burrows filled by pelletal packstone and sparite. Fenestrae are present and are geopetally filled with calcisiltite and drusy-mosaic calcite. In sample 3.3 they occur in burrows. Large bivalves were dissolved and replaced by drusy-mosaic calcite, in case of sample 37.4 molds were first lined by thin rim-cement. **Diagenesis:** Network of thin calcite veins that run in various directions. Thick fractures are filled mostly by drusy-mosaic calcite, but in sample 27.4 the fracture (neptunian dyke) has geopetal fill with calcisiltite, showing different orientation than in fenestrae (fig. 10c). Stylolites are present and sample 27.4 has rare framboidal pyrite **SMF / environment:** SMF8 and SMF9 / Open-marine lagoon with subaerial exposure.
	F2B – Molluskan floatstone Samples 1.4, 35.1, 37.4	**Composition:** Large (cm-sized) mollusks float in bioclastic wackestone matrix (fig. 7b). Sample 1.4 contains thick-shelled bivalves. In samples 35.1 and 37.4, gastropods and medium-thick shells of bivalves predominate, but sample 37.4 contains fragmented thick-shelled bivalve with multi-layered prismatic texture. Bioclasts in matrix are small (mm-sized), frequently fragmented bivalves, gastropods, ostracods and foraminifers. Sample 35.1 contains dasycladacean algae and 37.4 crinoids. Intraclasts and subordinate micritized ooids were locally observed. All samples show intense dissolution: -most intense dissolution attacked large bioclasts, and places with largest concentration of fossils, dissolution often deviates from shells to surrounding matrix, -isolated fenestrae within the matrix are rare. Multiple generations of infill can be seen in voids: -the first generation is thin rim-cements (not observed in sample 37.4), -the second is a geopetal infill by calcisiltite (in sample 35.1 with ostracods and 37.4 with small intraclasts/pellets), -in sample 35.1, it is followed by the second generation of thin rim-cement (some parts show even more complex alternation of rim cements and sediment infills; figs. 7b, c). -large-crystalline, isopachous rim (often bladed) or drusy-mosaic cement, -matrix in sample 35.1 shows dense network of irregular thin fractures filled with calcite, which we attribute to the desiccation. **Diagenesis:** Network of thin calcite veins that run in various directions. Stylolites occur. Sample 1.4 has wide fracture partly filled with large calcite (occasionally bladed) and subsequent sediment: very-fine packstone with pellets or calcisiltite (it could either be neptunian dyke or coarser synsedimentry infill of larger dissolution void). In sample 35.1 is mm-size field of pyrite. Sample 37.4 has system of brown-coloured (?pyrite) carbonate veins. **SMF / environment:** SMF8 / Open-marine lagoon with at least one longer period of subaerial exposure.

	F2C – Intraclastic, ooidal, pelletal partly-washed packstone with large bivalves and intraclasts Samples 4.5, 6.9, 14.9, 18.2, 25.9, 34,55, 38.7	**Composition:** The commonest grains are intraclasts, ooids (mostly micritisized), and pellets. Other subordinate grains are cortoids and bioclasts: foraminifers, small and mostly fragmented bivalves, echinoderms (sample 6.9), *Tubiphytes*–like fossils, calcimicrobes (sample 4.5). Large (few-mm sized) grains float within the packstone matrix and are mostly bivalves and intraclasts. Subordinate are gastropods (Fig. 7d; samples 14.9, 18.2, 25.9) and brachiopods (samples 25.9, 34.55). Large bioclasts tend to be completely recrystallized. Intraclasts reveal primary structure of mudstone or wackestone with ostracods, fragmented bivalves, and other small biodetritus. Sample 4.5 has large intraclast of pelletal and ooidal packstone with micritic rim. Sample 6.9 is partly washed-out packstone, composed mostly of intraclasts and pellets, and contains fenestrae. **Diagenesis:** Network of thin calcite veins that run in various directions. Thick fractures are filled mostly by drusy-mosaic calcite; in sample 4.5 also calcisiltite (neptunian dyke). Some thick, calcitic veins in sample 4.5 are unusually curved. In sample 34.55, one thick vein is brown colored and contains pyrite. Stylolites were noticed and small dispersed pyrite occurs in samples 25.9 and 34.55. **SMF / environment:** ?SMF8-18, close to SMF11 / Open-marine, low- energy lagoon; subaerial exposure.
	F2D – Intraclastic, ooidal, pelletal grainstone with large mollusks and intraclasts Samples 4.1, 26.35, 28.25, 37.55	**Composition:** Bimodal grain-size (fig. 7e). Small grains are intraclasts and pellets, subordinate are ooids (often superficial and/or micritized), cortoids (mostly from bivalve fragments) and foraminifers. Rare are echinoderms and *Tubiphytes*–like fossils. In sample 4.1 aggregate grains (lumps) were also observed. Large grains are predominantly bivalves (thick to medium shelled) and gastropods, but brachiopods and dasycladacean algae are also present. Most samples (4.1, 26.35, 37.55) have also large, well rounded mudstone intraclasts, which in sample 4.1 tend to be dolomitized. Large grains tend to have endolithic margins or overgrowths of calcimicrobes (filaments are still visible) or encrusting foraminifers. Shells are recrystallized or were dissolved and filled with cement. In sample 26.35, one such fossil has geopetal infill with calcisiltite, a thin rim-cement and subsequent drusy-mosaic cement. Same grains have thin calcimicrobial overgrowth. Bellow large shells shelter pores are common. Thin micritized surface (?hardground level) was observed in sample 28.25. Sample 26.35 has few fenestrae in local very-fine grain/packstone that occurs bellow shelter structure. Fenestrae are lined with thin rim-cement and filled with drusy-mosaic cement. **Diagenesis: N**etwork of thin calcite veins that run in various directions, but thicker calcite veins also occur. Sample 26.35 has pyrite concentrated in some micritic grains (particularly in larger intraclasts). Sample 4.1 has selective dolomitisation of micritic grains, particularly the large intraclasts. Sample 37.55 has stylolites with adjacent minor dolomitisation. **SMF / environment:** ?SMF8-10 / High-energy environment (or event) within open-marine lagoon. Sample 26.35 shows subaerial exposure.
	F2E – Dasycladacean & molluskan pack/floatstone Sample 19.8 (several thin sections)	**Composition:** Large grains are dasycladacean algae, bivalves and gastropods (fig. 7f). Rare are cm-sized mud/wackestone intraclasts with pellets and small biodetritus. Matrix between large fossils is partly-washed packstone composed of ooids (mostly micritized) and pellets, subordinate are foraminifera, cortoids, intraclasts and unrecognizable biodetritus. Rare are smaller bivalves, fragmented dasycladaceas, *Tubiphytes*- like grains, echinoderm plates. Fenestrae are mm-sized and highly irregular. They are filled with thin isopachous rim cement followed by drusy-mosaic cement. The same cements are observed in mollusks, particularly the walls of gastropod shells. **Diagenesis:** Network of thin calcite veins that run in various directions, but one direction prevails (one of these veins is thicker). One thin-section exhibits highly irregular “vein” that could be larger, elongated dissolution void. Pyrite rarely occurs in dispersed framboids or small clusters. **SMF / environment:** SMF18 / Open-marine, close to ooidal shoals; subaerial exposure.
F3 - Calcarenite	F3A – Partly washed packstone with aggregate grains Samples 28.95, 29.1, 29.2	**Composition:** The main components are aggregate grains (fig. 8a). In sample 28.95, their average size is from 1.46 to 1.69 mm, with largest being a few millimetres long. They are lumps composed of several medium-sized grains, mostly ooids, but pellets, intraclasts and bioclasts also occur. Other rare, sand-size grains are ooids (mostly micritized), intraclasts and bioclasts (often with microbial crusts): bivalves, dasycladacean algae (fragments of large specimens and small whole specimens), rare crinoids, gastropods and small foraminifers. Tiny pellets occur in matrix. Large fossils occur in samples 28.95 and 29.2; these are bivalves, dasycladacean algae and rarer gastropods. Bivalves often form shelter texture. They have endolithic margins and sometimes also thin microbial overgrowths. In sample 28.95, below the herein described microfacies there is a laterally discontinuous hardground (Fig. 8a). The hardground formed on microfacies corresponding to sample 16.3 (bioturbated intra/pel wackestone). Towards the margins (vertical and lateral) it becomes micritic, with visible irregular laminae (?microbial mats). At the hardground edge there is an encrusting fossil (fig. 8b). Sample 29.2 has fenestrae with shapes adjusting to the margins of larger grains (dissolved is matrix with pellets). These voids together with shelter textures and fossil cavities are infilled geopetally by calcisiltite, radiaxial fibrous and subsequent drusy-mosaic cement. **Diagenesis:** Network of thin calcite veins that run in various directions, but thicker calcite veins also occur. Stylolites and dispersed framboidal pyrite (mostly in micritic grains and matrix) occur. Cements in grainstone parts are thin fibrous rim-cements (differ from those filling the larger voids) and drusy-mosaic calcite. **SMF / environment:** SMF 17 / Open marine lagoon established after the cessation of sedimentation and formation of agitated sea-floor (hardgrond). Sample 29.2 shows subaerial exposure.
	F3B – Grainstone with aggregate grains Sample 15.4	**Composition:** The main components are aggregate grains, ooids and pellets (fig. 8c). Average size of aggregate grains is 1.55 mm; these are lumps composed of numerous fine-to medium-grained ooids (radial and tangential) and pellets. Average size of ooids is 0.37 mm; they have five laminae; the nucleus:cortex ratio is 42:58. Other grains are bioclasts (sometimes with microbial crusts): bivalves, dasycladacean algae, cortoids and rare echinoderms and foraminifers. **Diagenesis: C**ements are thin fibrous rim-cement and subsequent drusy-mosaic calcite cement. Network of thin calcite veins that run in various directions, but thicker calcite veins also occur. **SMF / environment:** SMF 17 / High-energy environment within open marine lagoon (close to sandy shoals).

	F3C – Ooidal grainstone, subordinate packstone Samples 2.3, 19,8sp1, 27.85, 34.7	**Composition:** The main components are ooids and pellets. Pellets are small, showing bimodal size distribution and concentrated in generally thinner laminae (fig. 8d). Type and size of ooids varies from 0.37 to 0.79 mm. They have between four and six laminae, and the nucleus:cortex ratio around 44:56. They are predominantly tangential and micritized, in sample 34.7 radial ooids also occur. Other grains are bioclasts, mainly foraminifers, but fragmented bivalves, echinoderms and dasycladacean algae also occur. Sporadic are *Tubyphites*- like grains, small gastropods and cortoids, aggregate grains, intraclasts and gastropods. **Diagenesis:** Cements are thin fibrous rim-cement and subsequent drusy-mosaic cement. Sample 2.3 contains very sporadic dolomite rhomboeders in micritized ooids. Network of thin calcite veins that run in various directions. Sample 34.7 has also network of thick calcite veins. Stylolites and dispersed framboidal pyrite are rare. **SMF / environment:** SMF15 / Sandy shoals, close to the open marine lagoon.
	F3D – Ooidal packstone with fenestae Sample 34.8	**Composition:** The main components are mostly radial ooids, but tangential and small superficial ooids also occur (fig. 8e). They have average size of 0.48 mm and have six laminae. The ratio nucleus:cortex is 41:59. Other grains are pellets, rare small foraminifers. It contains also rare large bioclasts: bivalves, gastropod, mm-sized dasycladacean algae and partly recrystallized calcimicrobes. Fenestrae are of millimeter size. Ooids show some dissolution at their margins. Fenestrae and intergranular spaces are filled with thin rim cement and drusy-mosaic calcite cement. Meniscus cement occurs as pendant micrite (it could also be matrix which escaped dissolution). Microstalactitic spar cement also occurs (because orientations are in various directions, some of these cements could also be meniscus bridging cement). **Diagenesis:** Network of thin calcite veins that run in various directions. Some veins are a bit thicker, one of these shows partial infill with calcisiltite (neptunian dyke). Pyrite occurs in up to 1 mm large fields or as dispersed framboids. **SMF / environment:** ?SMF15 / Structural inversion: grains from high-energy environment (ooidal shoals) resedimented into quiet environment (lagoon); subaerial exposure.
F4 - Lumachella	F4A – Dasycladacean & molluskan rudstone Sample 20.5	**Composition:** Grains are almost exclusively cm-sized bivalves and gastopods, and mm-sized dasycladacean algae (fig. 8f). Cm-sized wackestone intraclast with fragmented bivalves and echinoderms was detected (these grains resemble those from 19.8). Bioclasts are strongly recrystallized, some have thin microbial crusts. Mollusks were probably dissolved and filled with cements. Some central cavities (medulla) of dasycladan algae contain pellets and small ooids or intraclasts. Rare small grains are ooids and intraclasts. **Diagenesis:** Intergranular pores are filled with radiaxial rim-cements followed by drusy-mosaic cements. Large dissolution void is irregular and filled with drusy-mosaic cement. Calcite veins are rare and thin. **SMF / environment:** SMF14 / Lag-deposit within or close to open marine lagoon; subaerial exposure
F5 - Limestone microbreccia	F5A – Litoclastic floatstone Sample 6.3	**Composition:** Mm- to cm-sized litoclasts within wackestone matrix with pellets and bioclasts (fig. 8g): small ostracods, echinoderms, small bivalves, oval sparitic grains (probably bioclasts). Lithoclasts are angular (some even show borings) and diverse: A) mud/wackestone, sometimes with visible pellets, small unrecognisable biodetritus, and undetermined oval sparitic grains; some are small, angular and elongated (could be mud chips), B) pelletal grain/packstone, and C) ooidal grainstone with medium-grained tangential and less frequent radial ooids, rare pellets, intraclasts, and aggregate grains. **Diagenesis:** Some mudstone lithoclasts show dispersed dolomitic rhomboeders. Network of thin calcite veins that run in various directions. **SMF / environment:** SMF 24 / Storm deposit within tidal flat or redeposited into restricted lagoon.

In the sample at 5.3 m of the section, the angle between the primary geopetal orientation and those of the neptunian dykes can reach up to 69° (fig. 10c), and in the sample from 1.4 m of the section a difference of 33° was measured (fig. 10b). From the laminations in the sample at 32.2 m of the section, the maximum difference in angle is 57°.

The neptunian dykes from the sample at 4.8 m of the section show complex evolution (fig. 10a). The first generation of dykes is irregular and filled with early generations of cement and subsequent very fine calcisiltite. The second generation cuts through the first filling of the dykes. It is represented by a thin cement layer, followed by very fine calcisiltite. Infill of the first two generations shows mostly dispersed dolomite crystals similar to those observed in the host-rock. It could point to an older (maybe even Lower Jurassic) opening of the dykes, but dolomitization could also be selective to the lithology (dolomite is more abundant in micrite and very fine calcisiltite). In the third phase, new fractures formed or the old fractures re-activated. This generation of dykes is filled primarily by coarse-crystalline calcite and sporadic fine calcisiltite, followed by a deposition of generally coarser sediment within the cracks. This sediment can be further divided into first-settled sediment, consisting of calcisiltite that contains fine-grained packstone laminae and shows some plastic deformation, whereas the youngest sediment is fine-grained packstone, and is in composition very similar to the sediment infill of the neptunian dyke from the sample at 6.4 m of the section.

Foraminifera ?*Quinqueloculina* sp. and dasycladacean algae *Clypeina jurassica* Favre (det. by R. Radoičić; fig. 10d) were found in the intra-bioclastic packstone filling of the neptunian dykes. The latter indicates infiltrated sediment of Upper Jurassic age (Chiocchini et al., 1994; Senowbari-Daryan et al., 1994).

Other structures are fractures and veins, but we emphasize that the fractures observed in the weathered rock largely follow the orientation of a particular vein-cluster. Most fractures and veins are oriented in an approximate N-S stike (fig. 3). Other veins run in the NW-SE direction. The most common veins are also the thickest, and could be extensional fractures originating from the latest Jurassic tectonic movements, but they lack the sediment infill. The azimuth and dip of the main wall of the potential Roman quarry is 60/75, and the rock behind the wall is fractured in the same direction. Other calcite veins are generally thinner and strike in various directions (commonly W-E and NE-SW) and cross cut the neptunian dykes. The azimuth and dip of the beds is constant, with small variations around 220/40.

Discussion

Sedimentary environment: The lower Lower Jurassic (Sinemurian) succession of the Staje section shows characteristics of the platform interior. The first of the dominating facies, micritic limestone, is characterized by fenestrae (birds-eyes). This facies deposited in a shallow subtidal environment such as a restricted lagoon with frequent subaerial exposure. A stromatolite bed, probably also laminated mudstone and limestone microbreccia, deposited in intertidal environment (tidal flats). The second dominating facies, bioclastic limestone, is of variable texture and shows a rich fossil assemblage. It was sedimented in an open-marine lagoon. The transition to a restricted lagoon is marked by fenestral wackestone that contains oncoids and pelletal pack/grainstone (laminated and fenestral subtypes). The lagoon was occasionally subjected to more agitated conditions (storms) as evidenced by grainstone with large bioclasts and particularly by a lumachella bed. A more agitated yet still lagoon environment can also be implied for the grain/packstone composed predominantly of aggregate grains, and ooidal grain/packstone as well. The latter was deposited at the transition to the ooid shoals.

Correlation: In recent years, several sections were studied within the Lower Jurassic beds that outcrop along the southern margin of the Ljubljana Moor (Gale, 2014, 2015; Gale & Kelemen 2017). The Staje section correlates well with the Sinemurian Preserje, Tomišelj, Jezero and Zalopate sections, in which the authors describe a gradual opening up of lagoonal sedimentary environments as documented by the increasing presence of bioclastic and later also ooidal limestones (Gale & Kelemen, 2017). The same sedimentary trend continues upwards into Pliensbachian “Podpeč limestone” (microfacies described in detail by Gale, 2015) in which grain-supported facies (pack/grain/rudstone) become even more frequent or even dominate the succession (Buser & Debeljak, 1995; Debeljak & Buser, 1997; Gale, 2014, 2015; Kramar et al., 2015). Sedimentation of the “Podpeč limestone” took place in the lagoon close to ooid shoals that characterized the margin of the Dinaric Carbonate Platform during the

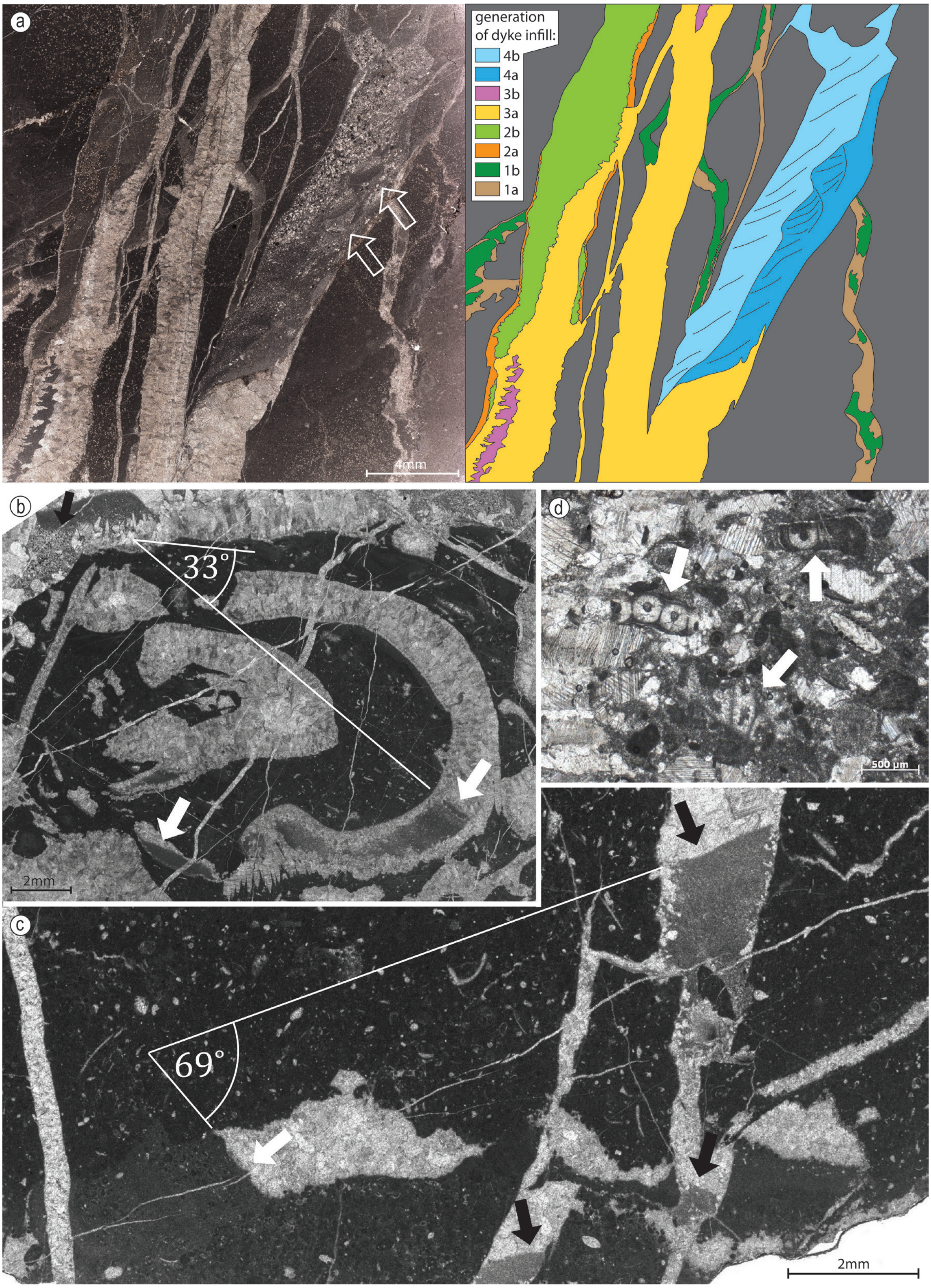


Fig. 10. Microfacies of neptunian dykes.

a) A complex pattern of neptunian dykes. Older dykes are irregular and filled first with cement (1a) and later by fine sediment (1b). The younger phase forms straight, wide-opened fractures filled with thin cement (2a), followed by calcisiltite (2b). The third generation re-opens fractures of previous generations and opens new. It was first filled with coarse-crystalline cement (3a) and small amount of calcisiltite (3b). The last generation re-opens old fractures that fill with sediment, presumably in two generations: the older (4a) shows sliding (indicated by arrows) that occurred during the final opening and refilling (4b) of the fracture (sample 4.8).

b) Difference of 33° in geopetal infilling of dissolved bivalve shell and fenestrae (white arrows) and those of neptunian dykes (black arrow) (sample 1.4).

c) Difference of 69° in geopetal infilling of fenestrae (white arrows) and those of neptunian dykes (black arrows) (sample 5.3).

d) Composition of neptunian dyke: intraclasts, small superficial ooids, pellets, echinoderm plates and other bioclasts with latest Jurassic *Clypeina jurassica* Favre (arrows) (sample 5.4).

Lower Jurassic (Buser & Debeljak, 1995). A similar Lower Jurassic succession is also described from the Kovk section in western Slovenia (Črne & Goričan, 2008) and can be recognized in the lithostratigraphic subdivision that was proposed by Dozet and Strohmenger (2000) and Dozet (2009).

Neptunian dykes: The neptunian dykes from the Staje section show a rather complex relationship between cement and sediment infills, which points to a pulsating opening of the fractures. The nature of infill during each pulse is related to the connection of the fractures to the surface. Cements were closing the fractures during periods of poor connection with the surface or during emersion. Sediment infilled the fractures during the well-established connection of the fractures with the sea bottom. Although these opening pulses could originate during several chronologically distant extensional phases, we propose that these fractures formed inside a relatively short time during the Late Jurassic. This is suggested by (A) *Clypeina jurassica* Favre determined in the sediment of the neptunian dykes, (B) the similar sediment infill of different pulses and (C) a soft deformation inside the older sediment covered by younger sediment.

The neptunian dykes of the Staje section are connected to the middle Late Jurassic tectonic phase that is well expressed on the Dinaric Carbonate Platform. It is seen as a widespread emersion that terminated the growth of the vast barrier reef and is documented in the form of bauxites and horizons of polymict breccias (Buser, 1989; Strohmenger & Dozet, 1990; Dozet, 1994; Dozet et al.,1996; Turnšek, 1997; Vlahović et al., 2005; Buser & Dozet, 2009). The breccia is polygenetic, and is interpreted as karst breccia or talus breccia originating along scarps and is followed by shallow water limestones characterised by *Clypeina jurassica* Favre (Strohmenger & Dozet, 1990; Buser & Dozet, 2009). Reports of neptunian dykes within the Jurassic strata of the Dinaric Carbonate Platform are rare (Otoničar, 2015; Žibret, 2015). On the contrary, they are well known from the northerly Julian Carbonate Platform located today in the Southern Alps (Babić, 1981; Buser, 1996). One of these extensional phases was dated as upper Late Jurassic (Šmuc, 2005; Črne et al., 2007).

The Lower Jurassic beds are covered in the Krim-Mokrec Mountain Range by a succession of Middle Jurassic ooidal limestone strata some several hundred meters thick, followed in the wider region by Upper Jurassic reefal limestone and subsequent lagoonal limestones with C*lypeina jurassica* (Turnšek 1997; Miler & Pavšič, 2008; Buser & Dozet, 2009). The connection of the fractures within Lower Jurassic strata to the upper Upper Jurassic surface/sea bottom is therefore somewhat problematic, especially as no large-scale neptunian dykes have yet been detected within the younger strata. A possible solution arises out of the fact that in the wider surroundings of the Staje area only Lower Jurassic beds outcrop (fig. 1). It is possible that the investigated succession originated already in marginal parts of the platform that are otherwise known to contain a large-scale (Middle) Jurassic gap (Buser & Dozet, 2009; Otoničar, 2015). A specific succession, where the latest Jurassic strata lies directly on Lower Jurassic lagoonal limestones, was recently described in the Avče area in western Slovenia, which represents one of the northernmost (marginal) Jurassic outcrops of the Dinaric Carbonate Platform (Kovač, 2016).

Natural stone: In the case the Roman quarry existed in the selected location near the village of Staje, the stonecutting products that would have come from the quarry would have been composed predominantly of micritic limestone in microfacies, mostly as fossil-poor mudstone or wackestone with two (or more) distinct generations of dissolution voids (F1B microfacies type). Some voids are filled with reddish sediment. This facies could contain parts (laminae, lenses, pockets…) of other facies, such as bioclastic limestone, calcarenite or microbreccia (lithoclastic rudstone). Another possible facies would be bioclastic limestone in the form of various microfacies, but partly-washed packstone with large mollusks is most common (F2C microfacies type). Calcarenites composed either of ooids or aggregate grains are subordinate and occur in generally thinner beds. Their use is less probable, but could be considered more probable in view of their characteristics that make them suitable for stone-cutting. Our field observations show that similar natural stones would have been obtained also from other potential quarries of the wider Staje (Ig) area, as the composition of the succession is monotonous. A thin-section made from the massive outcrop with the “Stari dedec” stela at the entrance of the valley confirms our proposition. It shows that the outcrop is a fenestral (birds-eyes) mudstone (F1B microfacies type). On the margin of the thin section it passes with a sharp, curved contact into intraclastic/pelletal dense wackestone/partly-washed packstone, which generally corresponds to our F1I microfacies type, but additionally contains some anomuran pellets. The later grains were not detected from the Staje section, but are reported from other, Lower Jurassic sections (Gale, 2015) located close by. This helps explain the fact that, despite dense sampling, it is not possible to describe all the microfacies that can be extracted from the studied section, and other varieties can be expected within the frame of the studied sedimentary environment.

Similar natural stones could have been acquired also from quarries of the Podutik area, located just north of Ljubljana. This natural stone is known as "gliničan" and was likely quarried already in Roman times (Ramovš, 1990; in Šašel-Kos, 1997). The Lower Jurassic limestone of the Podutik area represents a time and facies equivalent of the succession studied in the Staje section (Novak, 2003; Vodnik, 2016; Vodnik et al., 2017). Those characteristics that might distinguish the sites may consist in the Late Jurassic neptunian dykes that were detected in the "main wall" of the potential Roman quarry near Staje. Such features were not described from the Podutik area, but reddish and greenish colored veins, i.e. potential neptunian dykes, are reported (Ramovš, 1990; Novak, 2003; Vodnik, 2016, Vodnik et al., 2017), and study of their microfacies would be welcomed in the future.

Conclusions

Geomorphological study and field observations indicate that the Roman quarry in the Staje area could potentially be located in the valley running SE of the village. The section logged across the wall at the SW bank of the valley shows that the studied succession is composed of micritic limestone, subordinate bioclastic limestone and rare calcarenite and limestone microbreccia. Most common microfacies are mud/wackestone with several generations of dissolutions voids (often with geopetal fill) and partly-washed packstone with large mollusks. Calcarenite is pack/grainstone, dominated either by aggregate grains or ooids.

The sedimentary environment was restricted to an open marine lagoon with repeating subaerial exposure. High-energy events, which are indicated by sandy facies (ooidal pack/grainstone, aggregate grains pack/grainstone, bioclastic grainstone) and lumachella (bioclastic rudstone), occasionally interrupted the "quiet" lagoonal conditions. The studied section is Sinemurian in age and fits well within the Hettangian to Pliensbachian opening of the sedimentary environment from intertidal flats to a differentiated lagoon from the previously described northern part of the Dinaric Carbonate Platform.

The section is characterized by neptunian dykes that reveal a pulsating opening of the fractures but which were presumably formed within a relatively short time in the Late Jurassic, as evidenced by *Clypeina jurassica* Favre determined in the sediment fill. The neptunian dykes could be distinguishing characteristics of the Staje succession, allowing for a distinction from the potential Roman quarry site in Podutik, just north of Ljubljana, that represents a time and facies equivalent succession. However, an additional study of the reddish and green-coloured "veins" that are reported from the Podutik site are needed to confirm our proposal.

Acknowledgment

This research was financially supported by the Slovenian Research Agency (research core funding No. P1-0195(B) and No. P1-0011). We sincerely thank Rajka Radojčić for determination of *Clypeina jurassica* Favre. Anonymous reviewers are acknowledged for their thorough review of the manuscript, and Ema Hrovatin for preparation of thin sections.

References

Babić, L. 1981: The origin of "Krn breccia" and the role of the Krn area in the Upper Triassic and Jurassic history of the Julian Alps. Vesnik Zavoda geol. Geofiz. istraživanja NR Srbije, 38/39: 59–87.

BouDagher-Fadel, M. & Bosence, D. W. J. 2007: Early Jurassic benthic foraminiferal diversification and biozones in shallow-marine carbonates of Western Tethys. Senck. Lethaea, 87: 1-39.

Buser, S. 1968: Osnovna geološka karta SFRJ, list Ribnica. Zvezni geološki zavod Jugoslavije, Beograd.

Buser, S. 1989: Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian Basin NW Yugoslavia. Memor. Soc. Geol. Ital., 40: 313–320.

Buser, S. 1996: Geology of Western Slovenia and its paleogeographic evolution. In: Drobne, K., Goričan, Š. & Kotnik, J. (eds.): The role of impact processes in the geological and biological evolution of planet earth. Abstracts from Int. Symp., Postojna, Slovenia, September 1996, 111–123.

Buser, S., Grad, K. & Pleničar, M. 1967: Osnovna geološka karta SFRJ, list Postojna. Zvezni geološki zavod Jugoslavije, Beograd.

Buser, S. & Debeljak, I. 1995: Lower Jurassic beds with bivalves in South Slovenia. Geologija, 37/38: 23–62, doi: https://doi.org/10.5474/geologija.1995.001.

Buser, S. & Dozet, S. 2009: Jura - Jurassic. In: Pleničar, M., Ogorelec, B. & Novak, M. (eds.): Geologija Slovenije = The geology of Slovenia. Geološki zavod Slovenije, Ljubljana: 215-254.

Celarc, B. 2004: Problems of the Cordevolian limestone and dolomite in the Slovenian part of the Southern Alps. Geologija, 47: 139-149, doi: https://doi.org/10.5474/geologija.2004.011

Celarc, B. 2008: Carnian bauxite horizon on the Kopitov grič near Borovnica (Slovenia) - is there a „forgotten" stratigraphic gap in its footwall? Geologija, 51/2: 147-152, doi: https://doi.org/10.5474/geologija.2008.015

Chiocchini, M., Farinacci, A., Mancinella, A., Molinari, V. & Potetti, M. 1994: Foraminiferal, dasycladacean and calpionellid biostratigraphy of the Mesozoic carbonates of the Central Apennines Italy. In: Biostratigraphy of the Central Italy. Studi Geol. Camerti, Roma, 9-130.

Črne, A. E., Šmuc, A. & Skaberne, D. 2007: Jurassic neptunian dikes at Mt Mangart (Julian Alps, NW Slovenia). Facies, 53: 249-265, doi: https://doi.org/10.1007/s10347-007-0102-8 .

Črne, A. E. & Goričan, Š. 2008: The Dinaric Carbonate Platform margin in the Early Jurassic: a comparison between successions in Slovenia and Montenegro. Boll. Soc. Geol. It. - Ital. J. Geosci., 127: 389–405.

Debeljak, I. & Buser, S. 1997: Lithiotid bivalves in Slovenia and their mode of life. Geologija, 40: 11–64, doi: https://doi.org/10.5474/geologija.1997.001.

Dozet, S. 1994: Malmian bauxites at Kočevska Reka and Kočevje. RMZ-Materials and Geoenvironment, 41: 215-219.

Dozet, S. 2009: Lower Jurassic carbonate succession between Predole and Mlačevo, Central Slovenia. RMZ – Materials and Geoenvironment, 56: 164–193.

Dozet, S. 2014: Apneničarstvo na južnem robu Ljubljanskega barja – Apnenice na Ižanskem. Mostiščar. 20/5: 18-19.

Dozet, S. & Strohmenger, C. 2000: Podbukovje Formation, Central Slovenia. Geologija, 43/2: 197–212, doi: https://doi.org/10.5474/geologija.2000.014.

Dozet, S., Mišič M. & Žuža, T. 1996: Malm Bauxite Occurences in Logatec, Nanos and Kočevje area. RMZ-materials and geoenvironment, 43: 23-35.

Djurić, B. & Rižnar, I. 2017: Kamen Emone = The rocks for Emona. In: Vičič, B. & Županek, B. (eds.): Emona MM: urbanizacija prostora - nastanek mesta = urbanisation of space - beginning of a town. Zavod za varstvo kulturne dediščine Slovenije: Mestni muzej, Muzej in galerije mesta Ljubljane: 121-144.

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

Gale, L. 2014: Lower Jurassic foraminiferal biostratigraphy of Podpeč limestone External Dinarides, Slovenia. Geologija, 57/2: 119–146, doi: https://doi.org/10.5474/geologija.2014.011.

Gale, L. 2015: Microfacies characteristics of the Lower Jurassic lithiotid limestone from Northern Adriatic Carbonate Platform Central Slovenia. Geologija, 58/2: 121–138, doi: https://doi.org/10.5474/geologija.2015.010.

Gale, L. & Kelemen, M. 2017: Early Jurassic foraminiferal assemblages in platform carbonates of Mt. Krim, central Slovenia. Geologija, 60: 99-115, doi: https://doi.org/10.5474/geologija.2017.008.

Kovač, A. 2016: Biostratigrafija in sedimentologija srednjejurskih in spodnjekrednih plasti v dolini Soče pri HE Doblar. Diplomsko delo, Univerza v Ljubljani, Ljubljana: 61 p.

Kramar, S., Bedjanič, M., Mirtič, B., Mladenovič, A., Rožič, B., Skaberne, D., Gutman, M., Zupančič, N. & Cooper, B. J. 2015: Podpeč limestone: a heritage stone from Slovenia. In: Pereira, D. et al. (eds.): Global heritage stone: towards international recognition of building and ornamental stones, London, 219–231, doi: http://dx.doi.org/10.1144/SP407.2.

Miler, M. & Pavšič, J. 2008: Triassic and Jurassic beds in Krim Mountain area Slovenija = Triasne in jurske plasti na območju Krima. Geologija, 51/1: 87–99, doi: https://doi.org/10.5474/geologija.2008.010.

Mušič, B. 1990: Razvoj zgornjepermijskih in spodnjetriasnih plasti pri Višnji gori in Skopačniku pri Želimljah. – Neobjavljena diplomska naloga / Unpublished BA thesis. Oddelek za geologijo, Naravoslovnotehniška fakulteta Univerze v Ljubljani.

Novak, M. 2003: Zgornjetriasne in spodnjejurske plasti na območju Podutika pri Ljubljani - Upper Triassic and Lower Jurassic beds in the Podutik area near Ljubljana (Slovenia). Geologija, 46/1: 65-74, doi: https://doi.org/10.5474/geologija.2003.004.

Otoničar, B. 2015: Evolucija severovzhodnega obrobja Jadranske karbonatne platforme med zgornjim triasom in zgornjo juro Dolenjska, JV Slovenija:. In: Rožič, B. (ed.): Razprave, poročila = Treatises, reports, 22. posvetovanje slovenskih geologov = 22nd Meeting of Slovenian Geologists, Ljubljana, november 2015, Geološki zbornik, 23: Ljubljana: Univerza v Ljubljani, NTF, Oddelek za geologijo, 23: 147-150.

Placer, L. 1999: Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. Geologija, 41: 223-255, doi: https://doi.org/10.5474/geologija.1998.013.

Placer, L. 2008: Principles of the tectonic subdivision of Slovenia. Geologija, 51: 205-217, doi: https://doi.org/10.5474/geologija.2008.02.1

Ragolič, A. 2016: The funerary stele of Petto from Ig. Arheološki vestnik, 67: 277-296.

Ramovš, A. 1990: Gliničan od Emone do danes. Odsek za geologijo, VTOZD Montanistika, Fakulteta za naravoslovje in tehnologijo, Ljubljana.

Ramovš, A. 2000: Podpeški in črni ter pisani lesnobrdski apnenec skozi čas. Mineral, Ljubljana.

Senowbari-Daryan, B., Bucur, I. & Abate, B. 1994: Upper Jurassic calcareous algae from the Madonie Mountains, Sicily. Beitr. Paläont., 19: 227-259.

Strohmenger, C. & Dozet, S. 1990: Stratigraphy and geochemistry of Jurassic carbonate rocks from Suha krajina and Mala gora mountain (Southern Slovenia). Geologija, 33: 315-351, doi: https://doi.org/10.5474/geologija.1990.008.

Šašel, J. 1959: Prispevki za zgodovino rimskega Iga. Kronika, Časopis za slovensko krajevno zgodovino, 7: 117–123.

Šašel Kos, M. 1997: The Roman Inscriptions in the National Museum of Slovenia / Lapidarij Narodnega muzeja Slovenije. Situla: razprave Narodnega muzeja Slovenije = dissertationes Musei nationalis Sloveniae, 35: 541 p.

Šašel Kos, M. 2009: Ig – a rural settlement on the southern edge of the Ljubljansko barje. In: Turk, P., Istenič, J., Knific, T. & Nabergoj, T. (eds.): The Ljubljanica – a River and its Past. Ljubljana: 108–111.

Šmuc, A. 2005: Jurassic and Cretaceous Stratigraphy and Sedimentary Evolution of the Julian Alps, NW Slovenia. Založba ZRC, Ljubljana: 98 p.

Turnšek, D. 1997: Mezosoic Corals of Slovenia. Založba ZRC, Ljubljana: 512 p.

Velić, I. 2007: Stratigraphy and palaeobiogeography of Mesozoic benthic Foraminifera of the Karst Dinarides SE Europe. Geologia Croatica, 60: 1-113.

Velušček, A. 2004: Past and present lake-dwelling studies in Slovenia. Ljubljansko barje the Ljubljana Marsh: In: Menotti, F. (ed.): Living on the Lake in Prehistoric Europe. 150 years of Lake-dwelling Research, London, New York: 69–82.

Velušček, A. 2010: Koliščarji: o koliščarjih in koliščarski kulturi Ljubljanskega barja. Založba ZRC, Ljubljana: 109 p.

Veranič, D. & Repanšek, L. 2016: Rimski kamniti spomeniki iz cerkve sv. Janeza Krstnika v Podkraju pri Tomišlju = Roman stone monuments in the Church of St. John the Baptist in Podkraj near Tomišelj. Arheološki vestnik, 67: 297–320.

Vlahović, I., Tišljar, J., Velić, I. & Matičec, D. 2005: Evolution of the Adriatic Carbonate Platform: Paleogeography, main events and depositional dynamics. Paleogeography, Paleoclimatology, Paleoecology, 220: 333-360, doi: https://doi.org/10.1016/j.palaeo.2005.01.011.

Vodnik, P. 2016: Litološke značilnosti spodnjejurskega apnenca pri Podutiku in Kamni Gorici ter primerjava z artefakti iz časa Emone: diplomsko delo = Lithological characteristics of Lower Jurrasic limestone at Podutik and Kamna Gorica Central Slovenia: and its comparison with artefacts from Roman Emona: diploma work. Ljubljana: 49 p.

Vodnik, P., Djurić, B. & Gale, L. 2017: Vrednotenje možnosti lokacije rimskega kamnoloma v Podutiku na podlagi sedimentološke analize. In: Rožič, B. (ed.): Razprave, poročila = Treatises, reports, 23. posvetovanje slovenskih geologov = 23rd Meeting of Slovenian Geologists, Geološki zbornik, 24: 183-185.

Vuga, D. 2000a: Stari Dedec pri Stajah: lapis sepulcralis gentis Laepiae. Kras, 42: 10-11.

Vuga, D. 2000b: Ižanski lapidarij. Rodna gruda. Revija za Slovence po svetu. 47/7: 48.

Žibret, L. 2015: Kinematski in paleonapetostni razvoj NW-SE usmerjenih dinarskih prelomov v severozahodnih zunanjih Dinaridih: doktorska disertacija = Kinematic and paleostress evolution of the NW-SE trending Dinaric faults in the northwestern External Dinarides. PhD Thesis, University of Ljubljana, Ljubljana: 84 p.

Žvab Rožič, P., Gale, L. & Rožič, B. 2016: Rock analysis of Roman tombstones from Podkraj and Ig near Ljubljana. Arheološki vestnik, 67: 359-369.

GEOLOGIJA 61/1, 73-84, Ljubljana 2018
https://doi.org/10.5474/geologija.2018.005

Calcite deformation twins in Pohorje marbles

Deformacijski dvojčki v kalcitu pohorskega marmorja

Mirijam VRABEC, Nastja ROGAN ŠMUC & Marko VRABEC

University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Geology, Aškerčeva 12, SI-1000 Ljubljana, Slovenia; e-mails: mirijam.vrabec@ntf.uni-lj.si, nastja.rogan@guest.arnes.si,

Prejeto / Received 3. 5. 2018; Sprejeto / Accepted 20. 6. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Key words: calcite, marble, deformation twins, paleotemperature, Pohorje, Eastern Alps
Ključne besede: kalcit, marmor, deformacijski dvojčki, paleotemperatura, Pohorje, Vzhodne Alpe

Abstract

Marbles in Pohorje occur in lenses and smaller bodies in the southern and southeastern part of the massif. Marbles are very pure, predominantly calcitic and rarely calcitic-dolomitic, containing a maximum of 5 % of non-carbonate mineral phases. The latter comprise pyroxenes (diopside), amphiboles (tremolite), olivines (forsterite) in places replaced by serpentine, quartz, feldspars (potassium feldspars and plagioclases), epidote, zoisite, vesuvianite, scapolite, muscovite, biotite partly replaced by chlorite, phlogopite, rare grains of titanite, rutile, zircone, apatite, and small grains of ferric oxides and sulfides. Calcite exhibits intensive deformational e-twinning whereas dolomite is undeformed and untwined. All four known types of mechanical twins in calcite were recognized: thin Type I twins, straight thick Type II twins, curved, lensoid and tapered thick Type III twins, and thick patchy Type IV twins. Type III twins are the dominant mechanical twins in the Pohorje marbles indicating the temperature of deformation somewhat above 200 °C. Since they lack signs of grain boundary recrystallization, we assume that the twinning was followed by a decrease temperature during exhumation. With increasing temperature the process of recrystallization along calcite grain becomes pronounced. Small individual untwined calcite crystals are progressively replacing bigger calcite grains. In few examples second generation of Type I deformational twins develop in recrystallized calcite grains, which also implies lowering of temperature due to exhumation.

Izvleček

Pohorski marmor se pojavlja v lečah in manjših telesih v južnem in jugovzhodnem delu pogorja. Marmorji so po sestavi zelo čisti, skoraj izključno kalcitni, izjemoma kalcitno-dolomitni in vključujejo največ do 5 % nekarbonatnih mineralnih faz. Te vključujejo piroksene (diopsid), amfibole (tremolit), olivine (forsterit) mestoma nadomeščen s serpentinom, kremen, glinence (kalijeve glinence in plagioklaze), epidot, zoisit, vezuvianit, skapolit, muskovit, biotit deloma nadomeščen s kloritom, flogopit, redka zrna titanita, rutila, cirkona in apatita ter majhna zrna železovih oksidov in sulfidov. Kalcitni kristali so močno deformirani z mehanskim dvojčenjem, dolomitni kristali pa so nedeformirani in brez dvojčkov. Našli smo vse štiri znane tipe mehanskih dvojčkov v kalcitu: tanke dvojčke tipa I, ravne in debele dvojčke tipa II, zakrivljene, lečaste in zašiljene dvojčke tipa III, ter debele krpaste dvojčke tipa IV. Prevlada dvojčkov tipa III v pohorskem marmorju nakazuje temperaturo deformacije nekoliko nad 200 °C. Ker ti dvojčki ne kažejo znakov rekristalizacije na robovih zrn, sklepamo, da je dvojčenju sledilo znižanje temperature zaradi ekshumacije kamnin. Z višanjem temperature postane bolj izrazit proces rekristalizacije vzdolž robov kalcitnih zrn. Velika kalcitna zrna so pri tem vedno bolj nadomeščena z majhnimi kristali brez mehanskih dvojčkov. V nekaj primerih so v rekristaliziranih kalcitnih zrnih nastali mehanski dvojčki tipa I druge generacije, kar tudi nakazuje zniževanje temperature zaradi ekshumacije.

Introduction

Deformation (or mechanical) twinning is an important mode of plastic deformation in carbonate minerals. Mechanical twinning is well known and characteristic in calcite, rare in dolomite, and almost absent in other carbonate minerals. Mechanical twins are often observed in coarse-grained carbonate rocks and/or veins that were deformed at temperatures below 400 °C (Turner, 1953; Carter & Raleigh, 1969; Groshong, 1988). Twin width and morphology are a function of temperature of deformation (e.g. Ferrill, 1991; Ferrill et al., 2004; and references therein). Twins in calcite deformed at low temperature are thin, less than 5 μm wide (Groshong, 1974; Groshong et al., 1984; Ferrill, 1991; Ferrill et al., 2004). With increasing temperature thick twins develop since higher temperature deformation allows twin widening to accommodate increasing strain (Heard, 1963; Ferrill, 1991; Ferrill et al., 2004). Thick twins are straight initially but bend with increasing temperature. Eventually, the recrystallization starts to occur at grain boundaries (Ferrill, 1991; Ferrill et al., 2004).

Twins in carbonate minerals were observed in different kinds of carbonate lithologies: marbles (e.g. Turner, 1953), unmetamorphosed and undeformed (e.g. Groshong, 1972; Groshong et al., 1984; Tourneret & Laurent, 1990; Ferrill, 1991; Lacombe & Laurent, 1992; and many references therein) or weakly deformed carbonate rocks (e.g. Tullis, 1980; Craddock & van der Pluijm, 1988). Twinning in carbonates is never a predominant deformation mechanism since even extensive twinning cannot accommodate large amount of strain (Barber & Wenk, 1979).

Here, we present a comprehensive study of deformational twin patterns in marbles from Pohorje. We use the frequency distribution of twin types to infer the temperature of deformation and the thermal history of the rocks, i.e. exhumation vs. burial.

Theoretical background

Deformation twins in carbonate minerals

Carbonates considered here are rhombohedral. The cleavage rhomb indexes in structural cell are $\{10\bar{1}4\}$, using four-digit Miller-Bravais hexagonal indices (e.g. Nicholas, 1966).

Calcite (CaCO3, space group $R\bar{3}c$) has dimensions of the hexagonal structural unit cell a=4.99 Å and c=17.06 Å. Twinning in calcite has been known for more than 150 years. Four different kinds of twins occur in naturally grown calcite (fig. 1), which include all possible twins that may form either during crystal growth or by deformation (Wenk et al., 1983; Bruno et al., 2010). These twin laws are expressed by the twin planes c = $\{00\bar{1}1\}$, r = $\{10\bar{1}4\}$, e = $\{01\bar{1}8\}$, and f = $\{01\bar{1}2\}$ which coincide with the original composition planes. The main deformation twin law of calcite is on e-planes (Weiss & Turner, 1972; Barber & Wenk, 1979; Bueble & Schmahl, 1999), for which the shear displacement is in positive sense, in the direction $< 0\bar{2}21 >$ (fig. 2a). The twinned (lower) layers of a crystal, which has positive e-axis upwards, are displaced in a sense opposed to the positive e-axis of the untwined layers. During deformation twinning the e-axis moves through an angle of 52.5 ° while the plane of the carbonate groups, which is perpendicular to the e-axis, must be rotated through the same angle (Barber & Wenk, 1979). Minor deformation twining in calcite may be observed also on r-planes and f-planes (Paterson & Turner, 1970), where the sense of r-twinning is positive (Weiss & Turner, 1972) and r-plane is the usual slip plane (Barber & Wenk, 1979).

Dolomite ($Ca_{0.5}Mg_{0.5}CO_3$, space group $R\bar{3}$) has lower symmetry than calcite due to the alternating layers of Ca and Mg atoms arranged parallel to the basal plane. Ca can exist in excess up to 0.25 apfu (atoms per formula unit) in non-stoichiometric dolomite, which are maximum substitutions the formula support (dos Santos et al., 2017). Additionally, Mg ions in dolomite may be partly substituted by Fe ions, producing isostructural mineral ankerite, or rarely Mn ions giving exotic mineral kutnahorite. For stoichiometric dolomite the lattice parameters of the hexagonal structural unit cell are a=4.81 Å and c=16.01 Å. Twin laws, also applying to deformation twinning, are dependent on symmetry characteristics (e.g. Dana

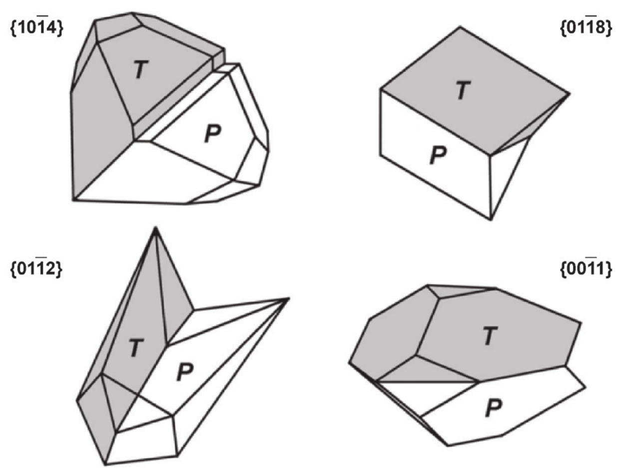


Fig. 1. The four twin laws of calcite (from Bruno et al., 2010). P–parent, T–twin.

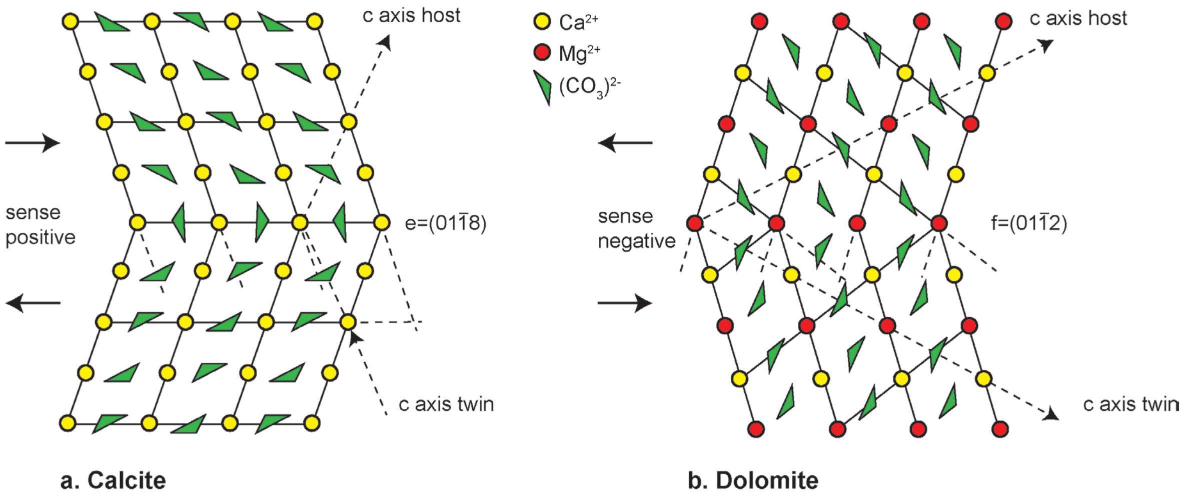


Fig. 2. Twining on (a) e-planes in calcite, sense positive, viewed along < 2$\bar{1}\bar{1}$0 > direction, and (b) f-planes in dolomite, sense negative, viewed along < 2$\bar{1}\bar{1}$0 > direction. The carbonate groups are denoted as triangles and lie in the {0001} planes parallel to the viewing direction. The triangles are drawn to indicate their alternate orientations in adjacent planes. See text for detailed explanation (redrawn from Barber & Wenk, 1979).

et al., 1951). As expected from its lower symmetry, dolomite possesses fewer twin forms than calcite, and only one type of deformation twinning is known (Barber & Wenk, 1979; Chang et al., 1998). It is expressed by f = {01$\bar{1}$2} twin plane which occurs within an f compositional plane. The shear displacement is in the < 0$\bar{1}$11 > direction (Barber & Wenk, 1979) and is negative in sense (Turner et al., 1954; fig. 2b). The f-plane is a usual slip plane for dolomite (Barber, 1977), and the resulting slip has positive sense (Barber & Wenk, 1979). Complete absence of e-twinning in dolomite which is the pervasive mechanism of mechanical twinning in calcite, is explained by dolomite composition, since the {01$\bar{1}$8} planes contain both Ca and Mg atoms, while the f planes do not. A shear on the e-planes would bring like species of cations into "closer-than-allowed" proximity (Bradley et al., 1953).

Among structural analogues of calcite, magnesite ($MgCO_3$), rhodochrosite ($MnCO_3$), and siderite ($FeCO_3$), only in rhodochrosite deformation twinning on e-planes is observed (Barber & Wenk, 1979). Due to structural similarities to dolomite, mechanical twinning on f-planes in ankerite and kutnahorite is reported (e.g. Barber & Wenk, 1979; and references therein).

Deformation twins in calcite as deformation temperature indicators

Calcite twin morphology, i.e. their width and intensity, may be used as low-temperature deformation geothermometer, especially in coarse-grained limestones or marbles that typically lack other indicators for deformation or maximum (peak) temperature (e.g. Burkhard, 1993; Ferrill et al., 2004; and references therein).

In calcitic rocks deformed at temperatures below 400 °C mechanical e-twinning is the main intracrystalline deformation mechanism (Turner, 1953; Carter & Raleigh, 1969; Groshong, 1988). With increasing temperature of deformation, four step changes in twin morphology may be observed (fig. 3). First are the thin Type I twins which form at very low temperatures (below 170 °C), followed by Type II straight thick twins forming at higher temperatures (above 200 °C). Type I twins are less than 5 μm thick and are visible only as thin black lines under the optical microscope. Type II twins are to > 10 μm thick with thickness measured as perpendicular distance between adjacent boundaries. The next step is characterized by bent and lensoid thick twins (Type III) that are frequently tapering towards the grain boundaries. Finally thick and patchy twins (Type IV) result from intensive recrystallization at grain boundaries (Schmid et al., 1980; Rowe & Rutter, 1990; Ferrill, 1991; Burkhard, 1993; Ferrill et al., 2004; Fig. 3). Dynamic recrystallization becomes an important deformation mechanism in calcite above 250 °C (Ferrill et al., 2004).

Mean calcite twin width correlates positively with temperature of deformation while mean twin density (twin planes/mm) correlates negatively (Ferrill et al., 2004). Twin densities in rocks deformed above 200 °C rarely exceed 400 twin planes/mm and cross plots of twin density with twin width can provide useful information about both strain and temperature of deformation (Ferrill et al., 2004).

The pattern of deformation microstructures may be used as a fingerprint for interpreting the thermal history. In case when twinning occurs at 200 °C during temperature increase (up to 300 °C),

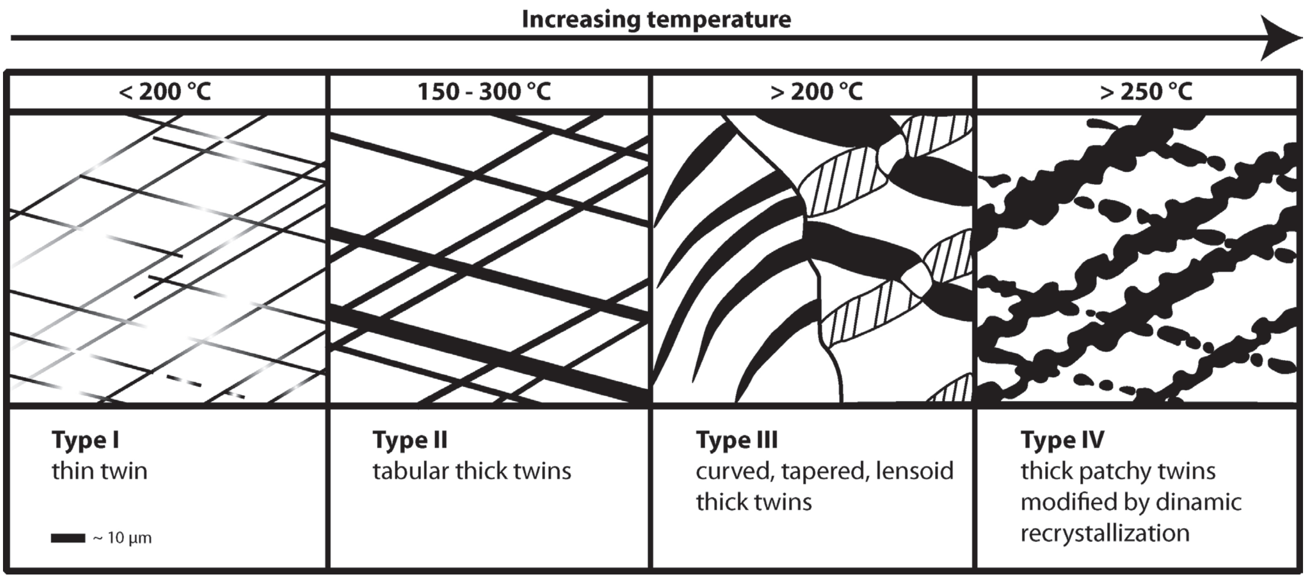


Fig. 3. Four different types of mechanical twins interpreted in terms of deformation temperature and mechanisms (after Ferrill, 1991; Burkhard, 1993; Ferrill et al., 2004).

calcite crystals will exhibit thick twins, grain boundary recrystallization, and recrystallization that has advanced inward from the grain boundaries. In contrast, when twinning occurring at 200 °C is followed by a temperature decrease, thick twins will lack signs of grain boundary recrystallization, and a greater abundance of thin twins will be present, some of those in the same set as the thick twins and others possibly even cutting through the thick twins (Ferrill et al., 2004).

Geological setting and sample location

Pohorje Massif forms the southeasternmost part of the Alpine chain and belongs to the Austroalpine units of the Eastern Alps. Its major structural unit, the Pohorje nappe (Janák et al., 2006) is composed of high-grade metamorphic rocs, mainly gneisses and micaschists which contain smaller bodies and lenses of amphibolites, eclogites, quartzites, and marbles (Mioč & Žnidarčič, 1977; Fodor et al., 2008; Kirst et al., 2010). A small body of ultramafic rocks occurs at the southeastern margin of the massif (Slovenska Bistrica Ultramafic Complex – SBUC; Janák et al., 2006) comprising strongly serpentinized harzburgites and several smaller bodies of better preserved garnet peridotites (Hinterlechner-Ravnik, 1987; Janák et al., 2006; De Hoog et al., 2009). Pohorje massif was subjected to metamorphism in the Late Cretaceous (ca. 95–92 Ma; Thöni, 2002; Miller et al., 2005; Janák et al., 2009) when these units reached conditions within stability field of diamond (Janák et al., 2004, 2006, 2015; Vrabec et al., 2012). The major exhumation of the Pohorje nappe, from ultrahigh pressure depth to mid crustal levels most probably occurred already during the Upper Cretaceous, similarly to the Koralpe area, the north-westward extension of the Pohorje nappe, where Upper Cretaceous (75-70 Ma) cooling ages were determined (Schuster et al., 2004). The final stage of exhumation to the surface was achieved in the Early to Mid Miocene by east- to north-east-directed low-angle extensional shearing, associated with the main opening phase of the Pannonian basin and leading to the core-complex structure of the Pohorje Mountains (Fodor et al., 2008). The Miocene shearing event reactivated and overprinted the nappe boundaries in the Pohorje area (Janák et al., 2006; Fodor et al., 2008).

The central part of Pohorje is intruded by the igneous body of granodioritic to tonalitic composition (Zupančič, 1994). The main intrusion was followed by the formation of aplite and pegmatite veins and in the western part of Pohorje also by shallow dacite bodies and dykes. In the southern part of the pluton a small body of dioritic composition is preserved (Faninger, 1965; Jarc et al., 2017). Granodiorites and pegmatites intruded in the host rocks in Miocene time (Altherr et al., 1995; Fodor et al., 2008; Trajanova et al., 2008; Uher et al., 2014).

Marbles occur in forms of lenses and smaller bodies mainly in eastern and southern part of Pohorje (fig. 4), where also some small isolated marble quarries are located (fig. 5). Their country rocks are mainly gneisses and micaschists. In some places, marbles are intercalated with lenses and boudins of darker amphibolitic material and

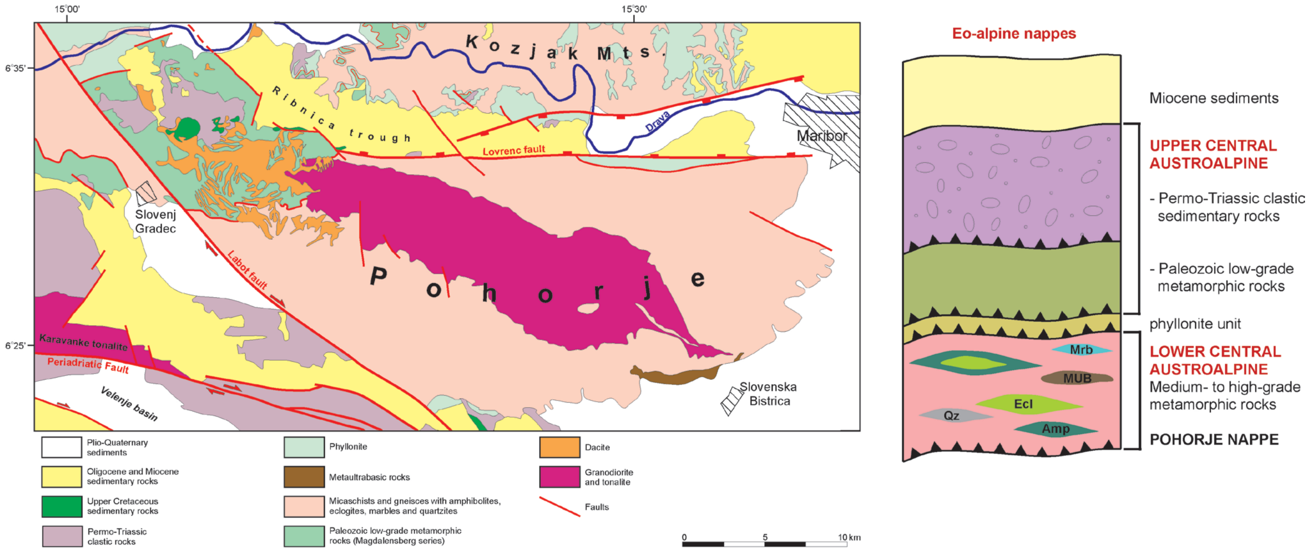


Fig. 4. Simplified tectonic map of Pohorje and succession of tectonic nappes in Pohorje in cross section (modified after Mioč & Žnidarčič, 1977).

sheets of silicate leucocratic material. Marble outcrops in the close vicinity of the main magmatic intrusion are commonly cut by aplite veins in different orientations. Aplite veins in horizontal orientations are sometimes extensionally torn into boudins while those in vertical direction show typical ptygmatic folding due to simultaneous vertical shortening (fig. 5). The composition and structure of Pohorje marbles was previously described by Jarc & Zupančič (2009) and Jarc et al. (2010).

Samples were taken from 25 localities outcropping in the eastern and southern part of Pohorje as shown on Fig. 6. Where possible, the samples were taken in the oriented position.

Methods

To perform reliable measurements of deformation twin lamellas in calcite grains, oriented thin sections are obligatory. It is difficult to observe twin lamellae that are subparallel to a thin section. The stochastic modelling of this effect showed that 20-25 % of twin lamellae can be overlooked due to this effect, depending on the skills of the operator (Yamaji, 2015). In order to diminish this effect as much as possible, we prepared polished thin sections from several sample in three perpendicular orientations.

From 25 localities (fig. 6) 104 polished thin sections were prepared and analyzed under the optical microscope in plain polarized light. In all thin sections, the presence of different types

Fig. 5. (a) Part of the Roman Quarry north from Slovenska Bistrica was used as the source of marble already in Roman times. Relict bedding and numerous aplite veins in different orientations may be observed. The vertically oriented aplitic vein on the left side of the picture displays prominent ptygmatic folds. (b) Boudins of aplite in marble.

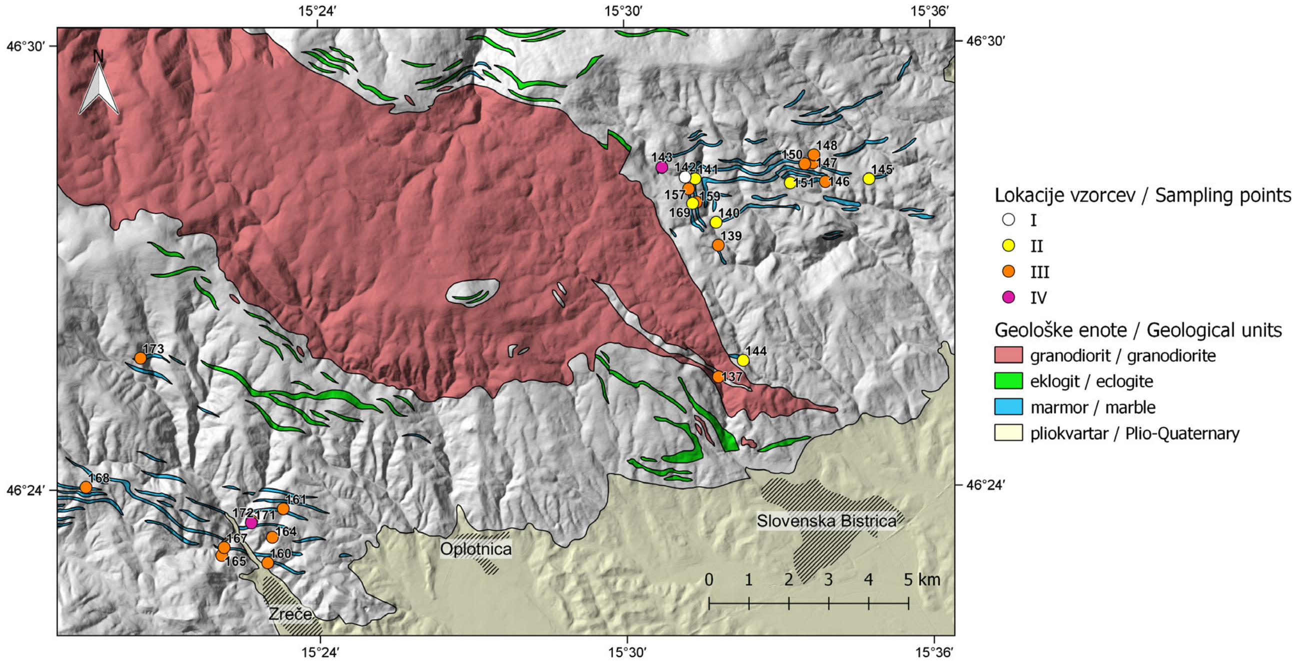


Fig. 6. Simplified geological map of southeastern Pohorje, based on Mioč & Žnidarčič (1977) and Žnidarčič & Mioč (1989), showing the locations of marble sampling locations. The main granodioritic intrusion as well as larger marble lenses and eclogite/amphibolite lenses are outlined. Different colors of the sampling localities correspond to the dominating type of twins found at respective locality: Type I, Type II, Type III, and Type IV.

of twins was quantitatively estimated. The proportion of non-carbonate mineral phases was neglected because in most cases they are present only in small amounts. The degree of recrystallization and the percentage of non-twinned calcite grains were estimated.

Results and discussion

Petrography and mineralogy

In macroscopic observation, marbles from Pohorje are white, only in rare occasions they show areas of pinkish, greyish or brownish coloring. In some samples laminas, layers or lenses of darker colored material of amphibolitc composition are present. All marble samples are crystalline medium- to coarse-grained; in some cases, granoblastic texture is pronounced.

In microscopic view, Pohorje marbles are mostly calcitic marbles. Very rarely calcitic-dolomitic species were detected; and even then, the dolomite was subordinate. All samples are very pure marbles since they contain less than 5 % of non-carbonate mineral phases. These non-carbonate minerals sometimes occur as individual grains evenly/randomly distributed in the samples but more often, they are found in form of lenses or laminas heterogeneously penetrating the samples. Among main non-carbonate minerals we detected pyroxenes (diopside), amphiboles (tremolite), olivines (forsterite), quartz, feldspars (potassium feldspars and plagioclases), epidote, zoisite, vesuvianite, scapolite, muscovite, biotite, phlogopite, rare grains of titanite, rutile, zircone, apatite, and small ferric oxides and sulfides. Chlorite and serpentine minerals are found as secondary phases, first replacing biotite and second replacing olivines.

The discovery of scapolite, vesuvianite and olivines that the maximum temperature conditions of metamorphism of 500 °C reported by Jarc et al. (2010) may be underestimated. Moreover, according to work of Janák et al. (2015), the Pohorje metamorphic terrane represented a coherent unit during peak ultrahigh-pressure metamorphism in the Late Cretaceous (c.95– 92 Ma) and during the subsequent exhumation. Therefore the marble lenses must have been exposed to the same peak pressure and temperature conditions of ≥3.5 GPa and 800–850 °C as the rest of the unit (Janák et al., 2015), but the marbles apparently did not preserve indicators of this peak pressure and temperature conditions.

The non-carbonate minerals often occur in lenses and seams heterogeneously penetrating marble samples. This random distribution may be interpreted in two ways. First, it can represent the pathways of fluids percolating through the carbonate material during metamorphism, or it may represent the remnants of non-carbonate precursor lithologies in parent carbonate rocks.

Deformation twins

In all investigated marble samples from Pohorje the mechanical twins were detected only in calcite grains. In calcitic-dolomitic marbles, all dolomite grains were clear and undeformed. Twinning in calcite occurs predominantly at low temperatures, and is characterized by the generation of large numbers of glide dislocations, while in dolomite it is more common at high temperatures (Barber & Wenk, 1979). Therefore, one of the reasons why twinning in naturally deformed dolomite rocks is less common and less abundant than e-twinning in calcite marbles is because dolomite does not twin at low temperatures. Moreover, at the range of temperatures we inferred for deformation of the Pohorje marbles, dolomite grains in calcite-dolomite composites remain completely rigid whereas calcite is considerably weaker and will display various crystaloplastic deformation mechanisms (Davis et al., 2008; Kushnir et al., 2015.

In marble samples from Pohorje all four types of mechanical e-twins in calcite are present. Thin twins of Type I (fig. 7a) are prevailing type of e-twining only in samples from Kresnik area (Site No. 142 in and in fig. 6). Twins are not exceeding 5 µm in width and are seen as tiny lines crosscutting bigger calcite grains. In subordinate amount, Type I twins are present also in samples from six other localities (Table 1. Tabular thick

Table 1. Twin frequency distribution in Pohorje marbles. Percentage of each type of twins was calculated using all available samples per locality. The untwined area includes also the recrystallized grains when they do not show secondary deformational twinning. The dominant twin type at each locality is marked with shaded cell.

Location	Samples	Type I	Type II	Type III	Type IV	Untwined	Recrystallization
Rimski kamnolom	137-1a, b, c; 137-4, 137-9	10 %	20 %	30 %	-	40 %	M
Motaln	139-1a, b, c; 139-2	10 %	30 %	50 %	-	10 %	M
Pregl	140-2, 140-4	20 %	70 %		-	10 %	W
Velika Polskava	141-1a, b, c; 141-3	-	60 %	20 %	-	20%	M
Kresnik	142-1	60 %	40 %		-	0 %	N
Surč	143-1, 143-2, 143-3, 143-5	-	-	10 %	20 %	70 %	EXT
Zgornja Nova Vas	144-1, 144-2, 144-3a, b, c; 144-4, 144-4, 144-5, 144-6, 144-6a, 144-7, 144-8, 144-8a	15 %	40 %	15 %	-	30 %	W-M
Planica	145-1a, b, c, d, e; 145-2a, b, c; 145-3	-	45 %	25 %	-	30 %	W-M
Sveti Križ	146-1a, b, c; 146-2	-	25 %	45 %	-	30 %	W
Nacek	147-1, 147-2	-	10 %	30 %	20 %	40 %	S
Vešnarjeva jama	148-1a, b, c; 148-2	-	20 %	50 %	10 %	20 %	VS
Vešner	150-1	-	35 %	50 %	-	15 %	M
Bavhnik	151-1	10 %	40 %	20 %	-	30 %	M
Kresnikova lipa	157-1/1, 157-1/2, 157-2, 157-3a, b, c; 157-4, 157-5	-	25 %	55 %	-	20 %	W-M
Bojtina	159-1/1, 159-1/2, 159-1/3, 159-2/1, 159-2/2, 159-3, 159-4, 159-6,159-7, 159-8, 159-9a, b, c; 159-10	-	20 %	40 %	20 %	20 %	VW-W
Orlovo gnezdo	160-1, 160-2, 160-3	-	10 %	50 %	30 %	10 %	W
Črešnova 1	161-1, 161-2, 161-3	-	-	40 %	30 %	30 %	M
Klančnik	164-1, 164-2	-	-	50 %	-	50 %	S-VS
Jozl 1	165-1, 165-1a, b; 165-2	-	-	50 %	10 %	40 %	VS
Jozl 2	167-1	-	-	50 %	20 %	30 %	S
Gorjak	168-1, 168-2, 168-3	-	-	70 %	10 %	20 %	S
Trmot	169-1, 169-2	10 %	40 %	30 %	-	20 %	N
Gorenje 2	171-1, 171-2	-	10 %	40 %	20 %	30 %	M-S
Gorenje 3	172-1, 172-2, 172-3, 172-4	-	-	20 %	40 %	40 %	M-S
Ločnikar	173-1, 173-2/1, 173-2/2	-	-	40 %	20 %	40 %	VS

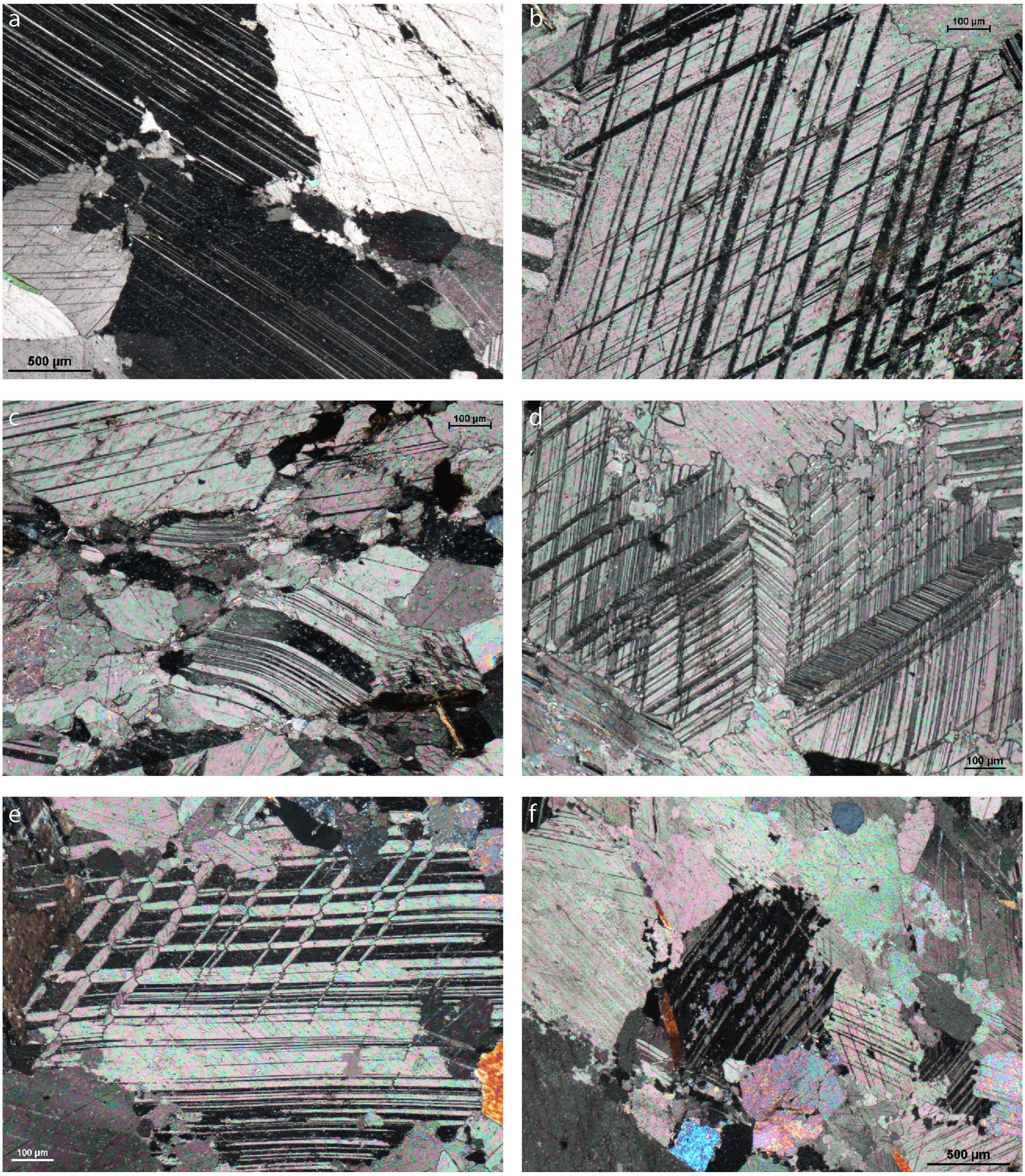


Fig. 7. Representative examples of twin patterns from Pohorje samples: (a) thin straight twins of Type I; three sets of twins may be recognized in the grain on the lower left and upper right; (b) two sets of thick straight twins of Type II; (c) curved and tapered thick twins of Type III; (d) twinned twins of Type III; thin straight twins developed within thick twin lamellae; (e) thick lensoid twins of Type III; thin straight twins within thick lamellae are visible; (f) thick patchy twins in of Type IV "NE–SW" direction with irregular – sutured boundaries that formed most probably due to grain boundary migration processes postdating twinning (Burkhard, 1993).

twins (> 5 µm) of Type II are the main deformation twin type in six localities (Table 1). They are accompanied by minor amount of twins of Type I and/or Type III. They are perfectly straight, parallel and frequently developed in several sets with different orientation (fig. 7b). Type III twins are the dominant type of deformation pattern in the majority of the investigated marble samples. Sixteen out of twenty-five localities are characterized by different shapes of curved, tapered and lensoid thick twins of Type III (fig. 7c-e, Table 1). The nods in lensoid twins are indicating the start of the recrystallization process. One of the characteristics of the Type III twins is the

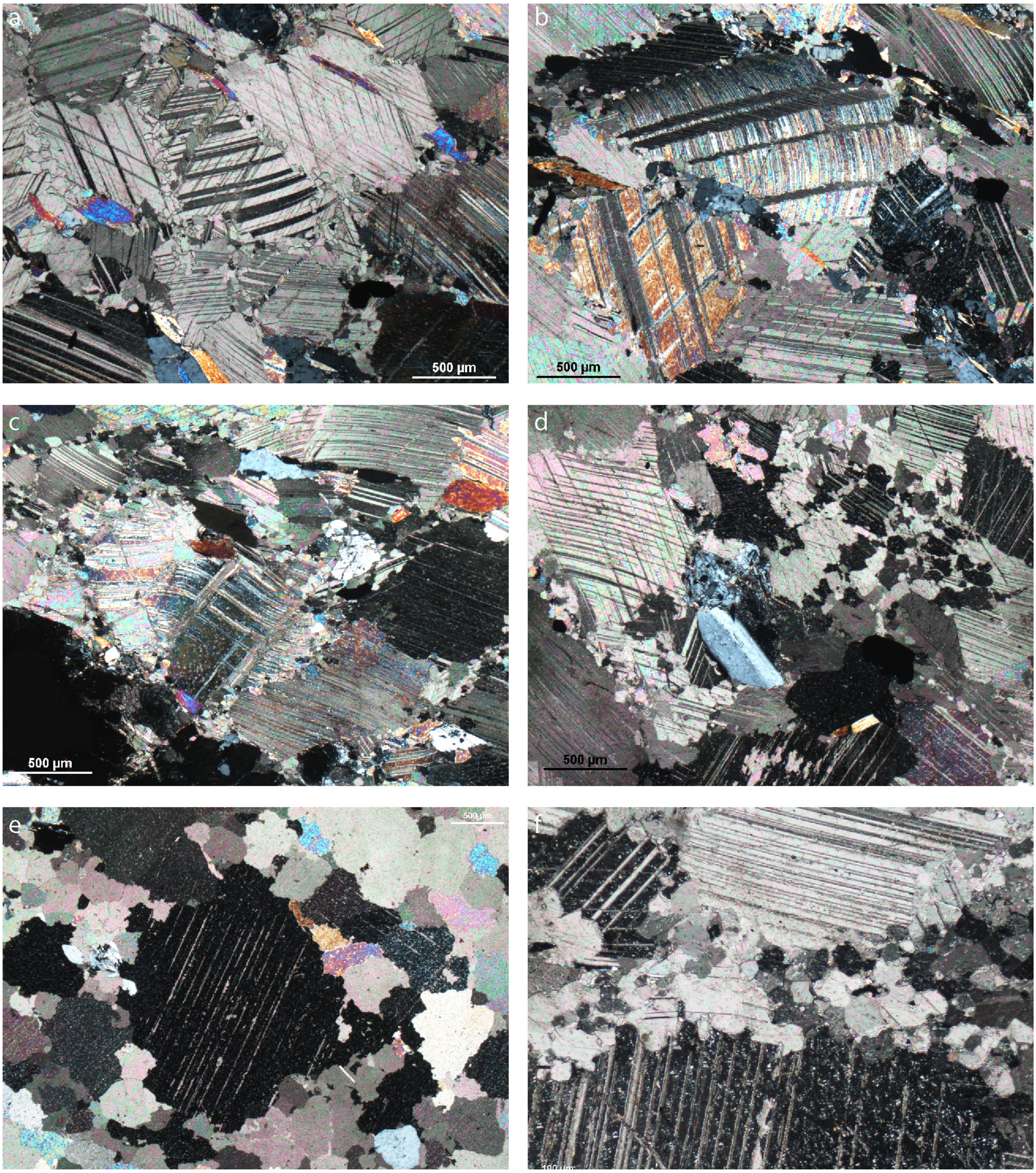


Fig. 8. Type III thick twins of various shapes (curved, tapered, twinned, lensoid) and Type IV twins are accompanied with the increasing degree of recrystallization along grain boundaries following from figure (a) to (e). Deformation twins in recrystallized calcite grains (f).

development of twinned twins expressed as thin straight twins within thick twin lamellae (fig. 7d, e). Type IV twins prevail at only two localities (Surč - Site No. 143 and Gorenje 3 - Site No. 172 in Table 1 and in fig. 6). These thick patchy twins show irregular, sutured boundaries modified by dynamic recrystallization due to grain-boundary migration (fig. 7f). They are often found as complementary type of twins at localities where Type III twins are the dominant deformation pattern. They are absent in samples where twins of Type I and II are prevailing (Table 1).

With increasing dominance of Type III (and Type IV) twins the recrystallization along grain boundaries becomes very pronounced. Initially, a single line of small individual untwined calcite crystals forms along big twinned calcite grains (fig. 8a, b) producing extremely irregular grain boundaries. With increasing deformation and recrystallization, increasingly larger parts of the grains become recrystallized, and former deformed large grains are replaced by smaller undeformed calcite grains (fig. 8c–e). In few locations, the second generation of deformational twining was observed in the form of mechanical twins of Type I starting to develop in recrystallized calcite grains (fig. 8f).

From the study of the twin pattern abundance in Pohorje marbles we deduce that the prevailing type of e-twinning are twins of Type III, which correspond to the temperature of deformation exceeding 200 °C. Thick twins do not show signs of grain boundary recrystallization, therefore we interpret that twinning developed during temperature decrease due to exhumation.

Conclusions

Marbles from Pohorje are mostly pure calcitic marbles and only rare examples with calcitic-dolomitic compositions were encountered. Calcite (and dolomite) represent 95 % of the rock, the rest is composed of pyroxenes (diopside), amphiboles (tremolite), olivines (forsterite), quartz, feldspars (potassium feldspars and plagioclases), epidote, zoisite, vesuvianite, scapolite, muscovite, biotite, phlogopite, rare grains of titanite, rutile, zircone, apatite, small ferric oxides and sulfides, chlorite after biotite and serpentine minerals replacing olivines.

All four known types of mechanical e-twins are present in calcite whereas dolomite crystals are undeformed and show no signs of twinning. Type III twins are the dominant type of deformation pattern, followed by Type II twins. Type I and Type IV twins are very rare. Type IV twins are never found in localities where twins of Type I and II are dominating. Twinning in Pohorje marbles occurred above 200 °C and was followed by a decrease of temperature during exhumation.

In samples with Type III and IV twins recrystallization becomes an important process. Small individual untwined calcite crystals along grain boundaries are progressively replacing bigger calcite grains. Second generation of e-twining was observed in form of Type I twins develop in recrystallized calcite grains.

Acknowledgements

The field work and sample preparation costs were financially supported by the Slovenian Research Agency (Research Programme Number P1-0195).

References

Altherr, R., Lugović, B., Meyer, H. P. & Majer, V. 1995: Early miocene post-collisional calc-alkaline magmatism along the easternmost segment of the periadriatic fault system (Slovenia and Croatia). Mineral. Petrol., 54/3–4: 225–247, doi: https://doi.org/10.1007/BF01162863.

Barber, D. J. 1977: Defect microstructures in deformed and recovered dolomites. Tectonophysics, 39/1-3: 193–213, doi: https://doi.org/10.1016/0040-1951(77)90096-8.

Barber, D. J. & Wenk, H.-R. 1979: Deformation twinning in Calcite, Dolomite, and other rhombohedral carbonates. Phys. Chem. Miner., 5: 141–165.

Bradley, W. F., Burst, J. F. & Graf, D. L. 1953: Crystal chemistry and differential thermal effects of dolomite. Am. Mineral., 38: 207–217.

Bruno, M., Massaro, F. R., Rubbo, M., Prencipe, M. & Aquilano, D. 2010: (10.4), (01.8), (01.2), and (00.1) Twin Laws of Calcite (CaCO3): Equilibrium Geometry of the Twin Boundary Interfaces and Twinning Energy. Cryst. Growth Des., 10/7: 3102–3109, doi: 10.1021/cg100233p.

Bueble, S. & Schmahl, W. W. 1999: Mechanical twinning in calcite considered with the concept of ferroelasticity. Phys. Chem. Miner., 26/8: 668–672, doi: https://doi.org/10.1007/s002690050232.

Burkhard, M. 1993: Calcite twins, their geometry, appearance and significance as stress-strain markers and indicators of tectonic regime: a review. J. Struct. Geol., 15/3-5: 351–368, doi: https://doi.org/10.1016/0191-8141(93)90132-T.

Carter, N. L. & Raleigh, C. B. 1969: Principal Stress Directions from Plastic Flow in Crystals. GSA Bull., 80/7: 1231–1264, doi: https://doi.org/10.1130/0016-7606(1969)80[1231:PSDFPF]2.0.CO;2

Chang, L. L. Y., Howie, R. A. & Zussman, J. 1998: Carbonates. In: Chang, L. L. Y., Howie, R. A. & Zussman, J. (eds.): Rock-forming Minerals. Volume 5B - Non-silicates: Sulphates, Carbonates, Phosphates, Halides. 2nd ed. The Geological Society of London: 95–294.

Craddock, J. P. & van der Pluijm, B. A. 1988: Kinematic analysis of an en échelon–continuous vein complex. J. Struct. Geol., 10/5: 445–452, doi: https://doi.org/10.1016/0191-8141(88)90032-6.

Dana, J. D., Palache, C., Berman, H. & Frondel, C. 1951: The System of Mineralogy of Dana, vol. 2. 7th ed. Wiley, New York: 834 p.

Davis, N. E., Kronenberg, A. K.& Newman, J. 2008: Plasticity and diffusion creep of dolomite. Tectonophysics, 456/3–4: 127–46, doi: https://doi.org/10.1016/j.tecto.2008.02.002.

Faninger, E. 1965: Čizlakit v novejši petrografski klasifikaciji. Geologija, 8: 263–278.

Ferrill, D. A. 1991: Calcite twin widths and intensities as metamorphic indicators in natural low-temperature deformation of limestone. J. Struct. Geol., 13/6: 667–675, doi: https://doi.org/10.1016/0191-8141(91)90029-I.

Ferrill, D. A., Morris, A. P., Evans, M. A., Burkhard, M., Groshong, R. H. & Onasch, C. M. 2004: Calcite twin morphology: a low-temperature deformation geothermometer. J. Struct. Geol., 26/8: 1521–1529, doi: https://doi.org/10.1016/j.jsg.2003.11.028.

Fodor, L. I., Gerdes, A., Dunkl, I., Koroknai, B., Pécskay, Z., Trajanova, M., Horváth, P., Vrabec, M., Jelen, B., Balogh, K. & Frisch, W. 2008: Miocene emplacement and rapid cooling of the Pohorje pluton at the Alpine-Pannonian-Dinaridic junction, Slovenia. Swiss J. Geosci., 101(SUPPL. 1), doi: https://doi.org/10.1007/s00015-008-1286-9.

Groshong, R. H. J. 1972: Strain Calculated from Twinning in Calcite. GSA Bull., 83/7: 2025–2038, doi: https://doi.org/10.1130/0016-7606(1972)83[2025:SCFTIC]2.0.CO;2.

Groshong, R. H. J. 1974: Experimental Test of Least-Squares Strain Gage Calculation Using Twinned Calcite. GSA Bull., 85/12: 1855–1864, doi: https://doi.org/10.1130/0016-7606(1974)85%3C1855:ETOLSG%3E2.0.CO.

Groshong, R. H. J. 1988: Low-temperature deformation mechanisms and their interpretation. GSA Bull., 100/9: 1329–1360, doi: https://doi.org/10.1130/0016-7606(1988)100%3C1329:LTDMAT%3E2.3.CO.

Groshong, R. H. J., Teufel, L. W. & Gasteiger, C. 1984: Precision and accuracy of the calcite strain-gage technique. GSA Bull., 95/3: 357–363, doi: https://doi.org/10.1130/0016-7606(1984)95<357:PAAOTC>2.0.CO;2

Heard, H. C. 1963: Effect of Large Changes in Strain Rate in the Experimental Deformation of Yule Marble. J. Geol., 71/2: 162–195, doi: https://doi.org/10.1086/626892.

Hinterlechner-Ravnik, A. 1987: Garnet peridotite from the Pohorje Mountains. Geologija, 30: 149–181.

De Hoog, J. C. M., Janák, M., Vrabec, M. & Froitzheim, N. 2009: Serpentinised peridotites from an ultrahigh-pressure terrane in the Pohorje Mts. (Eastern Alps, Slovenia): Geochemical constraints on petrogenesis and tectonic setting. Lithos, 109: 209–222, doi: https://doi.org/ 10.1016/j.lithos.2008.05.006.

Janák, M., Cornell, D., Froitzheim, N., De Hoog, J. C. M., Broska, I., Vrabec, M. & Hurai, V. 2009: Eclogite-hosting metapelites from the Pohorje Mountains (Eastern Alps): P-T evolution, zircon geochronology and tectonic implications. Eur. J. Mineral., 21: 1191–1212, doi: https://doi.org/10.1127/0935-1221/2009/0021-1966.

Janák, M., Froitzheim, N., Lupták, B., Vrabec, M. & Ravna, E. J. K. 2004: First evidence for ultrahigh-pressure metamorphism of eclogites in Pohorje, Slovenia: Tracing deep continental subduction in the Eastern Alps. Tectonics, 23, doi: https://doi.org/10.1029/2004TC001641.

Janák, M., Froitzheim, N., Vrabec, M., Krogh Ravna, E. J. & De Hoog, J. C. M. 2006: Ultrahigh-pressure metamorphism and exhumation of garnet peridotite in Pohorje, Eastern Alps. J. Metamorph. Geol., 24: 19–31, doi: https://doi.org/10.1111/j.1525-1314.2005.00619.x.

Janák, M., Froitzheim, N., Yoshida, K., Sasinková, V., Nosko, M., Kobayashi, T., Hirajima, T. & Vrabec, M. 2015: Diamond in metasedimentary crustal rocks from Pohorje, Eastern Alps: A window to deep continental subduction. J. Metamorph. Geol., 33: 495–512, doi: https://doi.org/10.1111/jmg.12130.

Jarc, S., Maniatis, Y., Dotsika, E., Tambakopoulos, D. & Zupancic, N. 2010: Scientific characterization of the pohorje marbles, Slovenia. Archaeometry, 52/2: 177–190, doi: https://doi.org/10.1111/j.1475-4754.2009.00476.x.

Jarc, S. & Zupančič, N. 2009: A cathodoluminescence and petrographical study of marbles from the Pohorje area in Slovenia. Chemie der Erde, 69/1: 75–80, doi: https://doi.org/10.1016/j.chemer.2008.01.001.

Jarc, S., Zupančič, N., Rogan Šmuc, N. & Vrabec, M. 2017: Ghost structures in »Čizlakite« from Pohorje revealed under CL imaging. 2nd Slovene Microscopy Symposium: book of abstracts. Slovensko društvo za mikroskopijo: 50.

Kirst, F., Sandmann, S., Nagel, T. J., Froitzheim, N. & Janák, M. 2010: Tectonic evolution of the southeastern part of the Pohorje Mountains (Eastern Alps, Slovenia). Geol. Carpathica, 61/6: 451–461, doi: https://doi.org/10.2478/v10096-010-0027-y.

Kushnir, A. R. L., Kennedy, L. A., Misra, S., Benson, P. & White, J. C., 2015: The mechanical and microstructural behaviour of calcite-dolomite composites: An experimental

investigation. J. Struct. Geol., 70: 200–216, doi: https://doi.org/10.1016/j.jsg.2014.12.006.
Lacombe, O. & Laurent, P. 1992: Determination of principal stress magnitudes using calcite twins and rock mechanics data. Tectonophysics, 202/1: 83–93, doi: https://doi.org/10.1016/0040-1951(92)90456-G.
Miller, C., Mundil, R. & Thöni, M. 2005: Refining the timing of eclogite metamorphism: a geochemical, petrological, Sm-Nd and U-Pb case study from the Pohorje Mountains, Slovenia (Eastern Alps). Contrib. to Mineral. Petrol., 150: 70–84, doi: https://doi.org/10.1007/s00410-005-0004-0.
Mioč, P. & Žnidarčič, M. 1977: Geological map of SFRJ 1:100.000. Sheet Slovenj Gradec. Federal Geological Survey, Beograd.
Nicholas, J. F. 1966: The simplicity of Miller-Bravais indexing. Acta Crystallogr., 21/6: 880–881, doi: https://doi.org/10.1107/S0365110X66004122.
Paterson, M. S. & Turner, F. J. 1970: Experimental Deformation of Constrained Crystals of Calcite in Extension. In: Paulitsch, P. (ed.) Experimental and Natural Rock Deformation. Springer Verlag: 109–141.
Rowe, K. J. & Rutter, E. H. 1990: Palaeostress estimation using calcite twinning: experimental calibration and application to nature. J. Struct. Geol., 12/1: 1–17, doi: https://doi.org/10.1016/0191-8141(90)90044-Y.
dos Santos, N. H., Neumann, R. & Ávila, C. A. 2017: Mineral Quantification with Simultaneous Refinement of Ca-Mg Carbonates Non-Stoichiometry by X-ray Diffraction, Rietveld Method. Minerals ,7/9: 164–178, doi: https://doi.org/10.3390/min7090164.
Schmid, S. M., Paterson, M. S. & Boland, J. N. 1980: High temperature flow and dynamic recrystallization in carrara marble. Tectonophysics, 65/3: 245–280, doi: https://doi.org/10.1016/0040-1951(80)90077-3.
Schuster, R., Koller, F., Hoeck, V., Hoinkes, G. & Bousquet, R. 2004: Explanatory notes to the Map: Metamorphic Structures of the Alps - Metamorphic evolution of the Eastern Alps. Mitt. Österr. Geol. Ges., 149: 175–199.
Thöni, M. 2002: Sm–Nd isotope systematics in garnet from different lithologies (Eastern Alps): age results , and an evaluation of potential problems for garnet Sm–Nd chronometry. Chem. Geol., 185: 255–281.
Tourneret, C. & Laurent, P. (1990: Paleo-stress orientations from calcite twins in the North Pyrenean foreland, determined by the Etchecopar inverse method. Tectonophysics, 180/2: 287–302, doi: https://doi.org/10.1016/0040-1951(90)90314-X.
Trajanova, M., Pecskay, Z. & Itaya, T. 2008: K-Ar geochronology and petrography of the Miocene Pohorje Mountains batholith (Slovenia). Geol. Carpathica, 59/3: 247–260.
Tullis, T. E. 1980: The use of mechanical twinning in minerals as a measure of shear stress magnitudes. J. Geophys. Res.: Solid Earth, 85/B11: 6263–6268, doi: https://doi.org/10.1029/JB085iB11p06263.
Turner, F. J. 1953: Nature and dynamic interpretation of deformation lamellae in calcite of three marbles. Am. J. Sci., 251/4: 276–298, doi: https://doi.org/10.2475/ajs.251.4.276.
Turner, F. J., Griggs, D. T. & Heard, H. 1954: Experimental deformation of calcite crystals. GSA Bull., 65/9: 883–934, doi: https://doi.org/10.1130/0016-7606(1954)65[883:EDOCC]2.0.CO;2.
Uher, P., Janak, M., Konecny, P. & Vrabec, M. 2014: Rare-element granitic pegmatite of Miocene age emplaced in UHP rocks from Visole, Pohorje Mountains (Eastern Alps, Slovenia): accessory minerals, monazite and uraninite chemical dating. Geol. Carpathica, 65/2: 131–146, doi: https://doi.org/10.2478/geoca-2014-0009.
Vrabec, M., Janák, M., Froitzheim, N. & De Hoog, J. C. M. 2012: Phase relations during peak metamorphism and decompression of the UHP kyanite eclogites, Pohorje Mountains (Eastern Alps, Slovenia). Lithos, 144/145: 40–55, doi: https://doi.org/10.1016/j.lithos.2012.04.004.
Weiss, L. E. & Turner, F. J. 1972: Some Observations on Translation Gliding and Kinking in Experimentally Deformed Calcite and Dolomite. In: Heard, H. C., Borg, I. Y., Carter, N. L. & Raleigh, C. B. (eds.): Flow and Fracture of Rocks. American Geophysical Union: 95–107, doi: https://doi.org/10.1029/GM016p0095.
Wenk, H.-R., Barber, D. J. & Reeder, R. J. 1983: Microstructures in carbonates. Rev. Mineral. Geochemistry, 11/1, p. 301 LP-367.
Yamaji, A. 2015: How tightly does calcite e-twin constrain stress?. J. Struct. Geol., 72(Supplement C): 83–95, doi: https://doi.org/10.1016/j.jsg.2015.01.008.
Žnidarčič, M. & Mioč, P. 1989: Geological map of SFRJ 1:100.000. Sheet Maribor. Federal Geological Survey, Beograd.
Zupančič, N. 1994: Petrografske značilnosti in klasifikacija pohorskih magmatskih kamnin. RMZ, 41: 101–112.

GEOLOGIJA 61/1, 85-99, Ljubljana 2018
https://doi.org/10.5474/geologija.2018.006

Fosilni mnogoščetinci spodnjekarnijskega apnenca pri Lesnem Brdu

Fossil polychaetes of the Lower Carnian limestone at Lesno Brdo, central Slovenia

Tim SOTELŠEK[1], Nik GRAČANIN[2], Matic RIFL[3] & Luka GALE[4,5]

[1]Kocjanova ul. 4, SI-4000 Kranj, Slovenija; e-mail: tim.sotelsek@gmail.com
[2]Cesta Jaka Platiše 21, SI-4000 Kranj, Slovenija; e-mail: nickster.gracanin@gmail.com
[3]Pionirska ul. 13a, SI-1235 Radomlje, Slovenija; e-mail: rifl.matic@gmail.com
[4]Univerza v Ljubljani, Naravoslovnotehniška fakulteta, Oddelek za geologijo; Privoz 11, SI-1000 Ljubljana, Slovenija; e-mail: luka.gale@ntf.uni-lj.si
[5]Geološki zavod Slovenije, Dimičeva ul. 14, SI-1000 Ljubljana, Slovenija; e-mail: luka.gale@geo-zs.si;

Prejeto / Received 29. 3. 2018; Sprejeto / Accepted 15. 6. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Ključne besede: Polychaeta, Terebellida, trias, Zunanji Dinaridi, karbonatna platforma, greben
Key words: Polychaeta, Terebellida, Triassic, External Dinarides, carbonate platform, reef

Izvleček

V spodnjekarnijskem masivnem apnencu v kamnolomu pri Lesnem Brdu nastopajo nepravilna lečasta telesa z veliko gostoto cevk fosilnih mnogoščetincev reda Terebellida. Razlike v gostoti in velikosti cevk znotraj leč smo preučili na primeru dveh leč. Cevke so orientirane poševno ali vzporedno z nekdanjim morskim dnom in obdane z drobnozrnatim apnencem, ali pa so fragmentirane in obrasle z zgodnjediagenetskim kalcitnim cementom. V notranjosti cevk in v medzrnskem prostoru so pogoste geopetalne teksture. Domnevamo, da leče predstavljajo in situ nakopičenja/populacije terebelid, ki so tvorile goste sestoje na zunanjem robu ali zgornjem pobočju nekdanje karbonatne platforme. Pri večji od obeh leč je gostota cevk največja v spodnjem delu leče, proti vrhu in robovom pa se zmanjšuje. Pri drugi leči je razporeditev gostote bolj naključna. Statistične povezave med gostoto cevk in njihovo velikostjo nismo potrdili. Zrna, ki so vključena v stene cevk, ustrezajo sestavi okolnega sedimenta, kar kaže, da mnogoščetinci niso selektivno pobirali zgolj ene vrste zrn. Tako manjši kot večji osebki so steno zgradili iz zrn enega velikostnega razreda.

Abstract

Lower Carnian massive limestone, quarried at Lesno Brdo in central Slovenia, contains irregular lenses of limestone riddled with fossil agglutinated tubes of Terebellida (Polychaeta). The aims of this study were to investigate changes in density and tube sizes within two of the lenses. Most of the tubes are oriented oblique or sub-parallel to former sea floor. They are embedded in fine-grained matrix or fragmented and overgrown by early diagenetic cement. Interiors of the tubes and larger voids within the matrix often display geopetal structures. We presume that lenses represent in situ populations of terebellid worms at the outer margin or upper slope of the former carbonate platform. For the larger of the two lenses, it seems that the tube density is largest at the bottom of the lens, whereas the density gets lower towards the top and the sides of the lens. The density distribution is more irregular in the second, smaller lens. We found no statistical correlation between the density and the size of the tubes. Grains, incorporated into the tube wall, match the composition of the surrounding sediment, meaning that the animals were not particularly selective for the grain type. The walls are also predominantly built of one grain size, irrespective of the size of the tube.

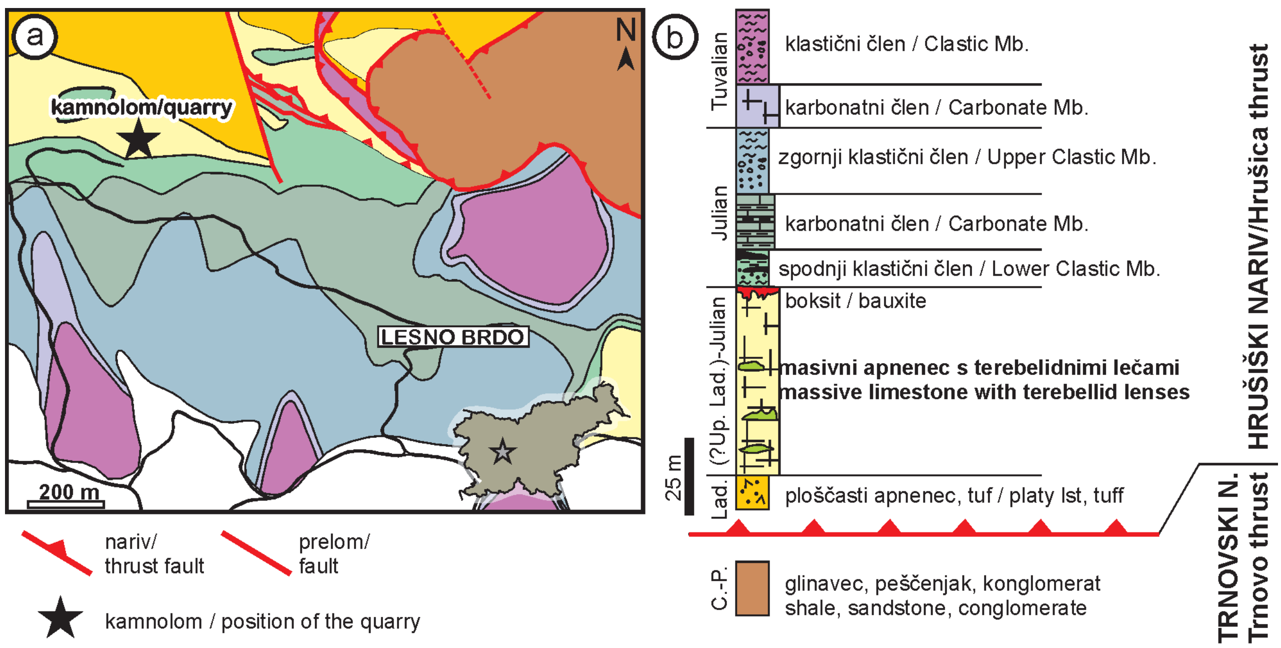
Uvod

Mnogoščetinci (razred Polychaeta, red Chaetopoda) so skupina kolobarnikov (deblo Annelida) s hitinastimi ščetinami na parapodijih (Fauchald, 1977). So pogosti prebivalci peščenega ali muljastega dna priobalnih delov morij, poznamo pa tudi globljemorske, nekaj sladkovodnih, planktonskih in celo kopenskih vrst (Fauchald, 1977; Bailey-Brock, 1976; Zatoń et al., 2012; Guido et al., 2014). Glede na način življenja in razvoj sprednjega dela telesa jih tradicionalno delimo na prosto živeče Errantia in pritrjene Sedentaria (Fauchald, 1977). Znotraj obeh skupin lahko najdemo vrste, ki telo obdajo z organsko, karbonatno ali aglutinirano cevko. V slednjem primeru so zrna, ki jih žival pobere iz sedimenta, vezana z biocementom, ki ga izloča posebna žleza (Reish & Mason, 2003; Fournier et al., 2010; Vinn & Luque, 2013). Zaradi krhkosti se aglutinirane cevke razmeroma redko fosilizirajo. Čeprav danes tovrstne cevke tvorijo predstavniki več družin mnogoščetincev (Vinn & Luque, 2013), večino fosilnih primerkov pripisujejo redu Terebellida, katerega fosilni zapis sega vsaj do ordovicija (po Zatoń & Bond, 2016). Terebelidne cevke se v paleozojskih in mezozojskih kamninah večinoma pojavljajo v manjšem številu in kot posamični primerki (npr. Samankassou, 2001; Kuss, 1988; Brandner et al., 1991; Bernecker, 1996; Schmid et al., 2001; Samankassou et al., 2013; Peybernes et al., 2015; Chesnel et al., 2016, 2017). Večje koncentracije mnogoščetincev so znane le z robov norijsko-retijskih slabo prezračenih intraplatformnih bazenov v Apeninih in Južnih Alpah, kjer skupaj z mikrobialiti tvorijo bioherme (Iannace & Zamparelli, 1996; Cozzi & Podda, 1998; Cirilli et al., 1999; Iannace & Zamparelli, 2002; Iannace et al., 2005).

Spodnjekarnijski masivni apnenec pri Lesnem Brdu vsebuje številne leče z veliko gostoto terebelidnih cevk. Po trenutni interpretaciji (Gale et al., 2018) gre morda za in situ ohranjene terebelidne tvorbe z zunanjega roba ali zgornjega pobočja platforme. V članku opisujemo cevke in zgradbo terebelidnih leč. Zanimale so nas lateralne spremembe v gostoti in velikosti terebelidnih cevk ter povezava med velikostjo (premerom), sestavo zrn, ki so bila vgrajena v steno cevk in sestavo obdajajočega sedimenta. Primerke iz Lesnega Brda prav tako primerjamo z drugimi primeri fosilnih terebelid iz literature.

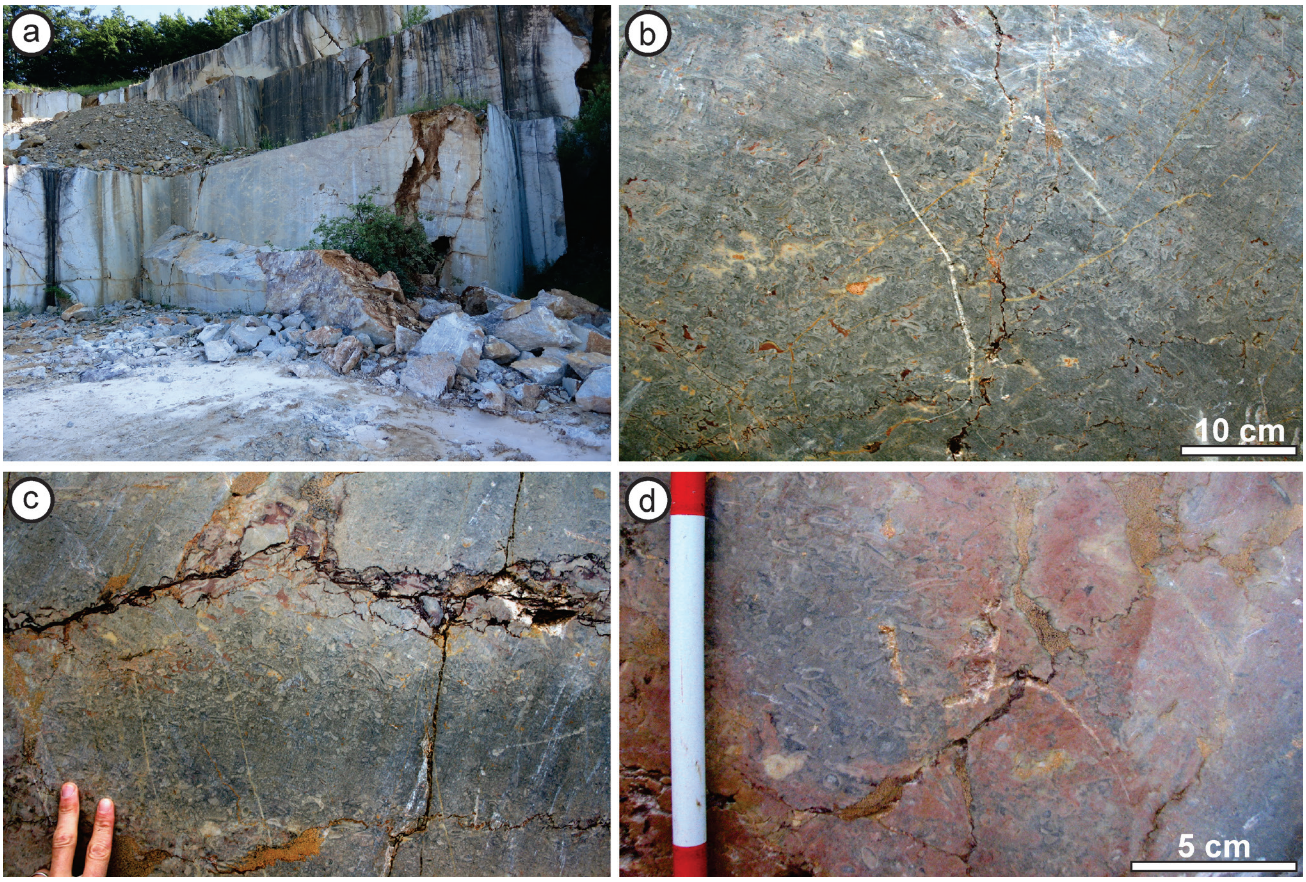
Geološka zgradba

Terebelidne cevke so del masivnega »pisanega lesnobrdskega apnenca«, ki je razgaljen v kamnolomu podjetja Mineral (Mirtič et al., 1999). Masivni apnenec, ki dosega debelino 66 m (Jelen, 1990), je del nagubanega zaporedja klastičnih, piroklastičnih in karbonatnih kamnin Hrušiškega nariva Zunanjih Dinaridov (sl. 1; Placer, 1998). Pod masivnim apnencem se nahajajo ladinijski tufski in litični peščenjaki, zgornjo površino apnenca pa predstavlja kraško-erozijska diskordanca z žepi boksita. Nad diskordanco leži zaporedje laporov-

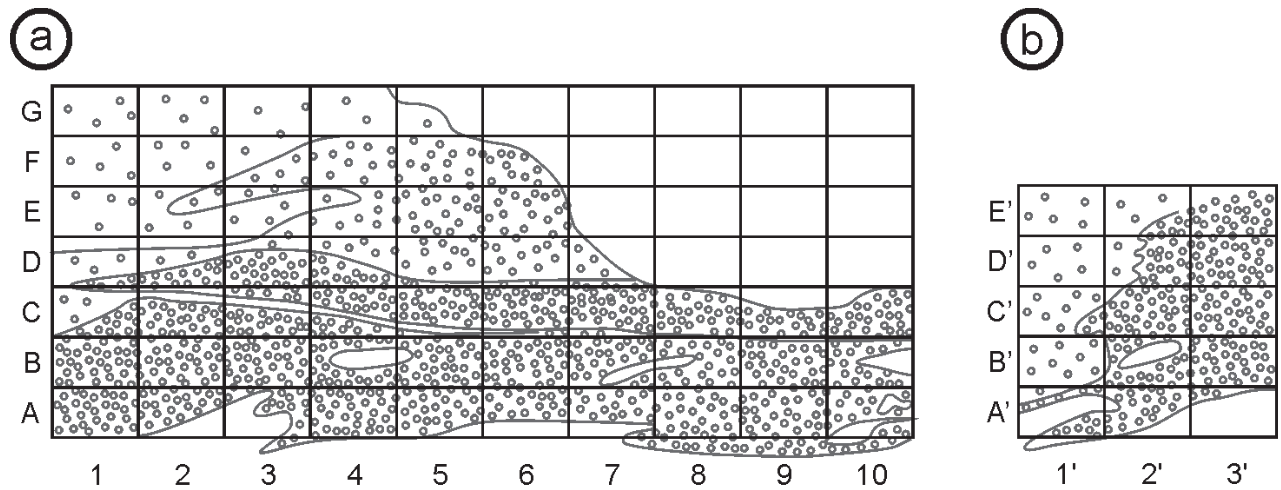


Sl. 1. Geološka zgradba okolice Lesnega Brda. a: Geološka karta (po Jelenu, 1990). b: Stratigrafski stolpec (po Jelenu, 1990).
Fig. 1. Geological structure of the area around Lesno Brdo. a: Geological map (after Jelen, 1990). b: Stratigraphic column (after Jelen, 1990).

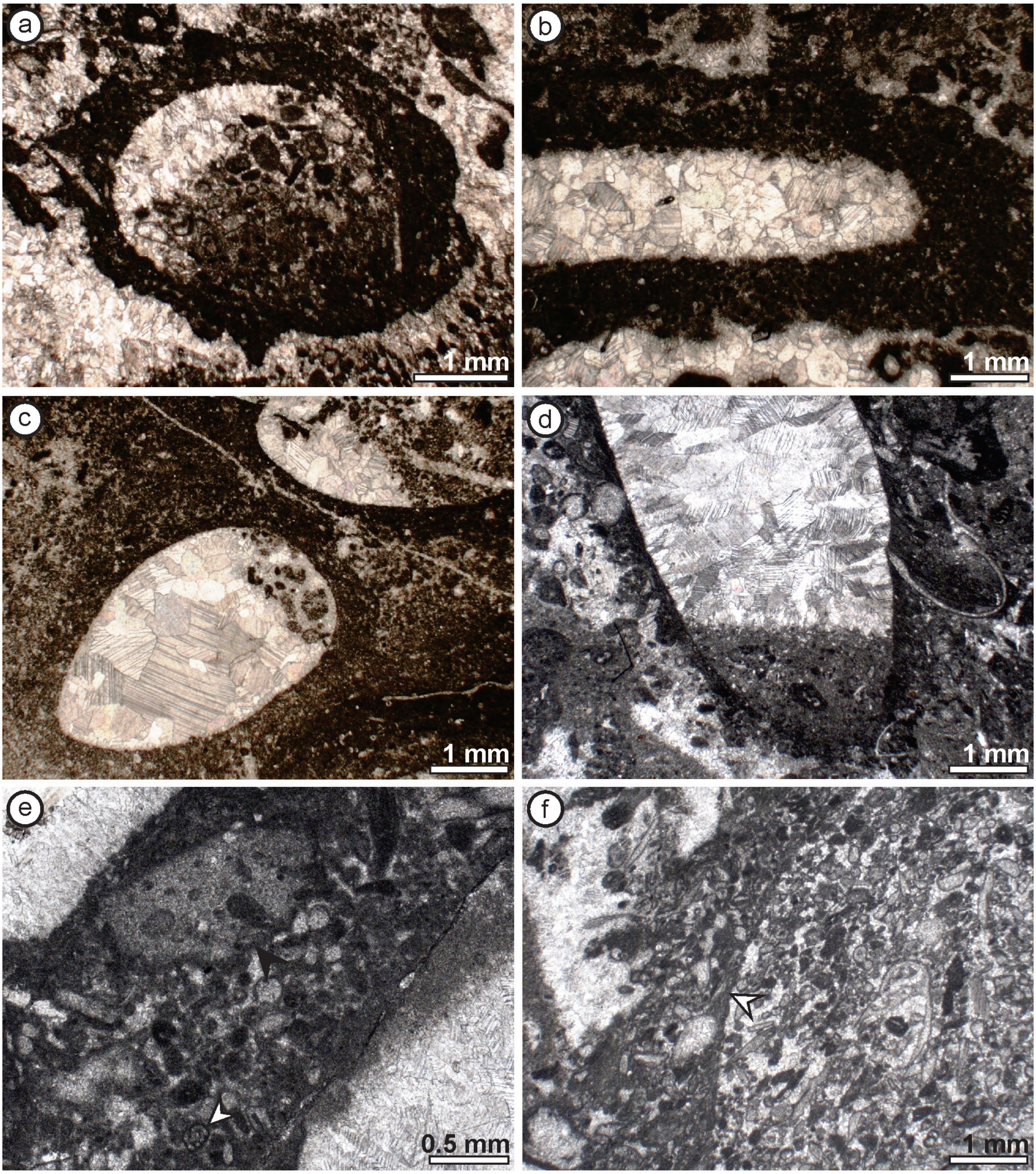
ca, muljevca ter sivega in rdečkastega meljevca z vložki antracita v skupni debelini 13 m (»julski spodnji klastični člen« po Jelen, 1990). Sledi 20 m črnih plastnatih mikritnih apnencev z vmesnimi plastmi črnega glinavca (»julski srednji apnenčevo-laporni člen« po Jelen, 1990), nato okoli 23 m črnih in zelenih muljevcev, tankoplastnatih kalkarenitov in konglomeratov ter tufski peščenjak (»julski zgornji klastični člen« po Jelen, 1990). Začetek tuvala domnevno predstavlja 15 m debel horizont sivega laminiranega apnenca s peleti rakov (Jelen, 1990). Vijolično-rdeči meljevci, podrejeno kalkareniti in konglomerati, ki zaključujejo zaporedje klastičnih sedimentov, so verjetno ekvivalent tuvalske Travenanzes formacije v severni Italiji (Gerčar et al., 2017).



Sl. 2. Terebelidne leče v spodnjekarnijskem apnencu kamnoloma Lesno Brdo. a: Vzhodni del kamnoloma. b: Del terebelidne leče. c: Del terebelidne leče. Vijoličast glinavec na stilolitiziranih površinah je verjetno rezultat zakrasevanja apnenca v zgodnjem karniju. d: Redkejše terebelidne cevke v rožnatem mikritnem apnencu.



Sl. 3. Skici analiziranih terebelidnih leč. Gostota cevk je ponazorjena z gostoto krogov. Velikost posameznega kvadranta je 0,3 m × 0,25 m. a: Prva leča. b: druga leča.
Fig. 3. Sketches of analized terebellid lenses. The density of tubes is shown as the density of small circles. Size of individual quandrant is 0.3 m × 0.25 m. a: First lens. b: second lens.



Sl. 4. Terebelidne cevke. a: Prečni presek. Vidna je geopetalna zapolnitev. Zbrusek 1075. b: Poševen presek. Steno sestavljajo predvsem peloidna zrna. Zbrusek 1093. c: Prečna preseka dveh terebelidnih cevk, obdanih s peloidnim karbonatom, verjetno mikrobnega izvora. Cevki imata geopetalno zapolnitev. Zbrusek 1093. d: Poševen presek. Vidna je geopetalna zapolnitev. Zbrusek 1234. e: Detajl stene terebelidne cevke. Bela puščica kaže na drobno foraminifero, ki je bila vključena v steno, črna puščica pa večji klast. Zbrusek 1237. f: Gladka notranja stran cevke (puščica) in nepravilna zunanja stran. Sestava stene je skoraj identična sestavi zrnom, ki zapolnjujejo notranjost cevke. Zbrusek 1242.

Fig. 4. Terebellid tubes. a: Transverse section. Note the geopetal infill of the tube. Thin section 1075. b: Oblique section. The tube wall is composed mostly of peloids. Thin section 1093. c: Transverse sections of two terebellid tubes, embedded in peloid carbonate, probably microbial in origin. Thin section 1093. d: Oblique section. Note the geopetal infill of the tube. Thin section 1234. e: The detail of the tube wall. Note the small foraminifera (white arrowhead) and the larger clast (black arrowhead) that were incorporated into wall structure. Thin section 1237. f: Smooth inner side of the tube (white arrowhead) is in contrast with the rough outer tube surface. The composition of the wall is almost identical to the composition of the sediment infilling the tube. Thin section 1242.

Metode in materiali

Za opis zgradbe dveh leč s terebelidnimi cevkami smo natančneje popisali 5,25 m^2 in 1,35 m^2 stene v zahodnem delu kamnoloma Lesno Brdo (sl. 2). Na navpični ploskvi kamnine smo narisali mrežo kvadrantov velikosti 0,3 m × 0,25 m (sl. 3). Vsak kvadrant smo naknadno razdelili na štiri manjša polja velikosti 0.15 m × 0.125 m. Kvadrante smo fotografirali z razdalje 0,3 m. Na podlagi posnetih fotografij smo v programu JMicroVision v. 1.2.7 (Nicolas Roduit 2002-2008) s štetjem 100 točk v naključni mreži določili delež terebelidnih cevk (*bulk grain* metoda v Flügel, 2004, str. 254). Za določitev povprečne velikosti cevk smo merili zunanji premer cevk. Pri poševnih presekih smo upoštevali krajšo os preseka. V prvi leči smo v 205 poljih prešteli 12.850 terebelidnih cevk, v drugi leči v 60 poljih 5.305 premerov. Na podlagi meritev smo v programu Microsoft Excell 2010 za vsak kvadrant izračunali povprečni premer cevke. Sestavo in velikost zrn v stenah terebelidnih cevk smo opazovali v osmih zbruskih, narejenih iz osmih vzorcev kamnine. Osnovne statistične izračune (aritmetična sredina, standardni odklon) smo opravili v programu Microsoft Excell 2010. Normalnost porazdelitve podatkov smo preverili s Shapiro-Wilkovim testom. Ker je ta pokazal, da podatki o gostoti cevk nimajo normalne porazdelitve, smo korelacijo med gostoto in povprečno velikostjo cevk izračunali z neparametričnim Spearmanovim razvrstitvenim korelacijskim koeficientom r_s (Hammer & Harper, 2006). Izračune smo opravili v programu PAST v. 2.17 (Hammer et al., 2001).

Rezultati

Opis terebelidnih leč

»Pisani lesnobrdski apnenec« ni homogen, temveč v njem nastopa več litoloških različkov apnenca (Gale et al., 2018). Največji del in okolico terebelidnih leč predstavlja gost, drobnozrnat apnenec, ki ga lahko po Dunhamu (1962) opišemo kot wackestone, packstone, drobnozrnat grainstone in floatstone. Med zrni prevladujejo peloidi, drobni koščki mikrobialitov in drugi intraklasti, fragmentirani bioklasti (predvsem zelene alge in neprepoznavni sparitni drobci, redkejše so foraminifere, mikroproblematika in drugi fosili), redko onkoidi. Drugi najpogostejši različek apnenca je mikrobialitni boundstone, ki nastopa kot večji bloki ali kroglaste tvorbe (in situ bioherme?). V manjši meri so poleg stromatolitov v boundstone-u prisotne spužve, mikroproblematika, rdeče alge in korale. Po površini tretji največji del apnenca predstavljajo terebelidne leče. Pisan videz dajejo kamnini polja debelokristalnega, verjetno poznodiagenetskega dolomita ter vložki zelenega in vijoličnega glinavca, ki so domnevno rezultat glavne (končne) okopnitve platforme pred odložitvijo »spodnjega klastičnega člena« (Gale et al., 2018).

Leče s terebelidnimi cevkami so dolge od 2 m do 8 m in debele do 1,75 m. Oblike leč so nepravilne; pogosto imajo strme stranice in izbočeno zgornjo površino. Cevke so obdane z gostim, drobnozrnatim apnencem (bioklastični-peloidni wackestone, packstone ali grainstone), ali deloma z rožnatim mikritom in deloma s karbonat-

G	22	18	10	22	38	24														
	20	20	18	24	28	24														
F	38	28	28	22	26	18	10	10	15	11										
	16	20	22	20	28	22	11	12	17	17	22									
E	26	34	26	22	24	18	18	20	15	18	25	21								
	32	26	28	34	24	44	24	27	19	18	27	24	24							
D	26	18	34	36	22	32	22	18	18	20	30	23	24							
	20	34	34	36	36	26	22	24	18	23	19	23	25	20						
C	30	12	28	36	36	18	15	17	22	22	18	18	23	23	24	25	26	23	26	32
	12	42	38	32	30	30	20	17	25	22	23	27	30	25	21	20	28	25	31	23
B	18	28	44	24	38	32	32	32	28	24	21	28	29	37	23	21	29	25	27	28
	34	26	42	34	40	34	38	36	29	25	30	35	34	31	35	34	32	29	30	31
A	36	42	22	40	40	22	42	36	30	38	31	41	38	28	34	32	36	31	32	31
	48	48	20	32	22	40	46	36	30	18	25	53	40	34	38	33	35	31	32	31
	1		2		3		4		5		6		7		8		9		10	

Sl. 5. Gostota terebelidnih cevk (v %) v prvi leči. Temno siva polja: 10-24 % cevk; svetlo siva polja: 25-39 % cevk; siva polja: 40-54 % cevk. Za položaj kvadrantov glej sliko 3.

Fig.5. Density of terebellid tubes (in %) in lens 1. Dark grey: 10-24 %; light grey: 25-39 %; grey: 40-54 %. See figure 3 for quadrant positions.

G	3,2 (n: 16; s: 0,6)	2,9 (n: 14; s: 0,9)	4,4 (n: 11; s: 1,9)	4,4 (n: 17; s: 1,4)	5,1 (n: 36 s: 1,6)	4,9 (n: 32; s: 1,4)														
	2,8 (n: 19; s: 1)	2,8 (n: 15; s: 1)	4,2 (n: 113; s: 1,4)	5,5 (n: 21; s: 1,7)	5,5 (n: 34; s: 2)	5,1 (n: 21; s: 1,4)														
F	5,7 (n: 20; s: 2)	4,3 (n: 27; s: 1,1)	4,5 (n: 27; s: 1,5)	4,9 (n: 22; s: 1,7)	6,7 (n: 20; s: 2,7)	5,7 (n: 20; s: 1,7)	4,9 (n: 17; s: 2,5)	3,2 (n: 29; s: 1,3)	3,3 (n: 46; s: 1,1)	2,6 (n: 35; s: 1)										
	4,6 (n: 18; s: 0,9)	5,2 (n: 17; s: 1,5)	5,3 (n: 25; s: 1,4)	4,8 (n: 24; s: 1,4)	5,4 (n: 22; s: 2)	6,3 (n: 21; s: 2)	4,6 (n: 37; s: 1,6)	3,5 (n: 52; s: 1,4)	3,4 (n: 58; s: 1,2)	2,8 (n: 80; s: 1,1)	3,4 (n: 114; s: 1,2)									
E	4,3 (n: 28; s: 1,3)	5,2 (n: 29; s: 1,6)	5,3 (n: 22; s: 1)	4,4 (n: 23; s: 1,4)	6 (n: 21; s: 1,2)	5,1 (n: 21; s: 1,2)	6,1 (n: 26; s: 1,8)	4,7 (n: 31; s: 1,5)	4,8 (n: 28; s: 2,1)	4 (n: 48; s: 1,5)	4,5 (n: 91; s: 1,8)	2,9 (n: 96; s: 0,9)								
	5,2 (n: 31; s: 1,8)	5 (n: 28; s: 1,9)	4 (n: 26; s: 1,4)	4,5 (n: 35; s: 0,9)	5 (n: 20; s: 1,5)	5,7 (n: 41; s: 2,2)	4,4 (n: 54; s: 1,4)	4,7 (n: 56; s: 1,2)	4,3 (n: 49; s: 1,8)	4,4 (n: 43; s: 1,3)	3,6 (n: 109; s: 1,3)	3,5 (n: 119; s: 1,1)	2,4 (n: 128; s: 1)							
D	5 (n: 19; s: 1,6)	4,5 (n: 17; s: 1,7)	5,1 (n: 25; s: 1,6)	4,2 (n: 28; s: 1,7)	3,8 (n: 12; s: 1,3)	4,8 (n: 29; s: 1,9)	4,5 (n: 70; s: 1,3)	5,2 (n: 26; s: 1,1)	4,6 (n: 32; s: 1,5)	4,9 (n: 38; s: 1,6)	4,7 (n: 107; s: 2,1)	3,8 (n: 83; s: 1,7)	4,1 (n: 94; s: 1,6)							
	3,7 (n: 21; s: 1,2)	4,5 (n: 27 s: 1,5)	4,3 (n: 28; s: 1,2)	4,4 (n: 47; s: 1,6)	4,4 (n: 37; s: 1,2)	4,7 (n: 29; s: 1,3)	4,9 (n: 45; s: 1,5)	5,1 (n: 46; s: 1,5)	4,2 (n: 38; s: 1,5)	4,1 (n: 54; s: 1,4)	3,2 (n: 88; s: 0,9)	3,5 (n: 108; s: 1,2)	3,4 (n: 167; s: 1,3)	3,7 (n: 122; s: 1,3)						
C	4,2 (n: 22; s: 2,6)	4,1 (n: 20; s: 2,1)	3,6 (n: 32; s: 1,9)	4,1 (n: 37; s: 1,3)	5,9 (n: 33; s: 2,5)	3,6 (n: 18; s: 1,2)	5,7 (n: 17; s: 2,7)	5 (n: 28; s: 1,5)	4,8 (n: 40; s: 1,5)	3,8 (n: 56; s: 1)	4,1 (n: 61; s: 1,2)	3,1 (n: 106; s: 1)	4 (n: 142; s: 1,3)	3,6 (n: 120; s: 1,2)	2,8 (n: 188; s: 1,4)	3,1 (n: 149; s: 1,1)	3,2 (n: 143; s: 1,3)	4,1 (n: 78; s: 1,8)	5,1 (n: 81; s: 1,9)	3,9 (n: 117; s: 1,8)
	4 (n: 13; s: 0,9)	4,3 (n: 63; s: 1,1)	4,8 (n: 36; s: 1,8)	4 (n: 35; s: 1,4)	3,2 (n: 26; s: 1,3)	5,3 (n: 28; s: 2)	5 (n: 35; s: 2,3)	4,6 (n: 42; s: 1,6)	3,7 (n: 41; s: 1)	3,8 (n: 49; s: 1,1)	3,4 (n: 80; s: 1,2)	4 (n: 87; s: 1,3)	3,6 (n: 162; s: 1,2)	3,9 (n: 98; s: 1,2)	2,9 (n: 100; s: 1,1)	3 (n: 92; s: 1,2)	2,7 (n: 174; s: 1,1)	2,7 (n: 154; s: 0,9)	3,8 (n: 149; s: 1,5)	3,2 (n: 114; s: 1,5)
B	6,3 (n: 25; s: 1,4)	5,9 (n: 40 ; s: 1,7)	6 (n: 33; s: 1,4)	4,9 (n: 47; s: 1,3)	4,8 (n: 41; s: 1,6)	4,9 (n: 49; s: 1,6)	6,2 (n: 35; s: 1,4)	5,8 (n: 28; s: 1,2)	4,4 (n: 61; s: 1,9)	4,2 (n: 44; s: 1,9)	4,3 (n: 81; s: 1,2)	4,4 (n: 81; s: 1,4)	4,4 (n: 132; s: 1,8)	3,9 (n: 158; s: 1,8)	5 (n: 85; s: 1,6)	4 (n: 113; s: 1,4)	4,3 (n: 118; s: 1,6)	4 (n: 118; s: 1,6)	4 (n: 106; s: 1,4)	3,7 (n: 93; s: 1,3)
	4,9 (n: 16; s: 1,4)	5,3 (n: 17; s: 1,3)	4,8 (n: 21; s: 1)	4,3 (n: 32; s: 0,9)	4,7 (n: 45; s: 1,5)	4,4 (n: 27; s: 1,1)	5,4 (n: 39; s: 2,3)	4,9 (n: 28; s: 1,6)	4,3 (n: 70; s: 1,9)	4,4 (n: 76; s: 1,8)	4,1 (n: 88; s: 1,3)	3,5 (n: 119; s: 1)	4,3 (n: 97; s: 1,5)	2,9 (n: 185; s: 1,3)	4,5 (n: 103; s: 2,4)	4,3 (n: 122; s: 1,5)	4,2 (n: 113; s: 1,3)	3,3 (n: 156; s: 1,4)	3,6 (n: 122; s: 1,7)	2,8 (n: 197; s: 1,1)
A	6 (n: 28; s: 1,4)	5,5 (n: 24; s: 1,4)	4,7 (n: 15; s: 1,5)	6,4 (n: 19; s: 1,9)	6,2 (n: 28; s: 1)	5,1 (n: 39; s: 1,5)	7,1 (n: 24; s: 1,7)	6,3 (n: 45; s: 1,8)	5,6 (n: 75; s: 1,9)	5,4 (n: 84; s: 2,1)	6 (n: 71; s: 2,1)	4,6 (n: 105; s: 1,7)	4,9 (n: 85; s: 1,6)	4,2 (n: 80; s: 1,6)	4,1 (n: 168; s: 1,7)	3,2 (n: 190; s: 1,5)	5,7 (n: 79; s: 1,9)	4,5 (n: 88; s: 1,6)	4,1 (n: 121; s: 1,6)	4,4 (n: 101; s: 1,5)
	6,5 (n: 44; s: 1,5)	6,6 (n: 28; s: 2,8)	6,1 (n: 18; s: 1,8)	5,4 (n: 18; s: 1,8)	4,9 (n: 30; s: 1,6)	4,6 (n: 30; s: 1,2)	6,7 (n: 66; s: 2,1)	6,6 (n: 42; s: 2,1)	5,8 (n: 63; s: 2,2)	4,8 (n: 59; s: 1,2)	5,1 (n: 79; s: 2)	4,2 (n: 121; s: 1,1)	0,37 (n: 105; s: 1,1)	4 (n: 123; s: 1,6)	4,4 (n: 123; s: 1,6)	3,9 (n: 137; s: 1,6)	5,2 (n: 112; s: 1,9)	5,5 (n: 82; s: 1,8)	4,2 (n: 114; s: 1,4)	3,7 (n: 118; s: 1,5)
	1		2		3		4		5		6		7		8		9		10	

Sl. 6. Povprečna velikost terebelidnih cevk (v mm) v prvi leči. Temno siva polja: 2,4-3,9 mm; svetlo siva polja: 4-5,5 mm; siva polja: 5,6-7,1 mm. V oklepaju sta navedena število meritev (n) in standardni odklon (s). Za položaj kvadrantov glej sliko 3.

Fig. 6. Average size (in mm) of terebellid tubes in lens 1. Dark grey: 2.4-3.9 mm; light grey: 4.0-5.5 mm; grey: 5.6-7.1 mm. Number of measurements (n) and standard deviation (s) are given in brackets. See figure 3 for quadrant positions.

G	4,3	4,2	9,2	8,4	8,6	8,8														
	5,2	4,7	7,7	8,6	12,8	7,5														
F	9,4	6,7	9,2	8,7	14,6	9,3	13,1	6,6	6,9	5										
	6,3	7,6	7,9	8	10,6	10,8	8,2	7,8	7,8	8,2	6,7									
E	6,9	10,1	9,5	7,7	10,4	10,3	10,1	8,9	10,6	9,7	11,7	5,8								
	9,7	9,5	7,4	6,5	8,9	10	7,9	8,4	9	7,8	8,9	8,6	8,3							
D	8,9	9	8,8	8,3	6,9	11,3	7,5	7,4	10,1	10,2	12	9	9,7							
	6,3	9,5	7,8	8,2	7,1	8,2	9,1	8,1	8,9	8,4	5,7	7,3	8,9	8						
C	15	10,5	10,6	7	12,6	6,6	10,9	8,7	9,3	6,1	8	7,1	8,8	6,7	8,7	8,2	9,8	9,5	10	13,8
	5,4	8,5	10,7	7,7	7,7	9,5	12,4	10,6	6,6	6,8	8,4	8,7	8,2	8,1	9,4	7,9	10	6,1	9	10,7
B	9,1	12,1	9,8	9,4	9	9,4	9,9	8,3	12	10,9	7,5	10,5	10,5	10,9	10,2	7,9	10,3	10,8	7,8	7,6
	8,2	7,9	6,3	6,4	9,3	7,1	16,2	9,7	10,1	10,9	9	6,3	9,4	10,7	15,9	11,3	7,5	8,8	12,7	8,5
A	9	8,9	7,5	14	11,6	8,9	12,4	10,3	11,1	11,7	12,1	10,1	10,4	12,1	11,6	8,4	11,6	9,7	10,6	8,2
	10,4	17,5	9,6	11,3	8,9	8,2	13,1	11,6	12,7	6,8	11,8	7,4	8,5	11,7	10,6	9,2	10,2	12,4	9,6	10,8
	1		2		3		4		5		6		7		8		9		10	

Sl. 7. Največja velikost cevk (v mm) v prvi leči. Temno siva polja: 4,2-7,7 mm; svetlo siva polja: 7,8-11,3 mm; siva polja: 11,4-17,5 mm. Za položaj kvadrantov glej sliko 3.

Fig. 7. Maximum size (in mm) of terebellid tubes in lens 1. Dark grey: 4.2-7.7 mm; light grey: 7.8-11.3 mm; grey: 11.4-21.8 mm. See figure 3 for quadrant positions.

nim cementom (obrobni vlaknati ali igličasti in druzi-mozaični kalcit). V slednjem primeru so razlomljene na centimeter velike koščke. Lokalno so prisotne geopetalne teksture. Posamične cevke so rahlo ukrivljene. V dolžino merijo tudi več kot 10 cm in dosežejo premer 1,75 cm. Njihova notranja površina je ostro ločena od notranjega polnila in razmeroma gladka, medtem ko je zunanja površina lahko bolj nepravilna (sl. 4). Stene cevk so zgrajene iz aglutiniranih peloidov in drobnih bioklastov (večinoma gre za nedoločljive sparitne drobce, prepoznavni so le koščki zelenih alg, redke bentoške foraminifere, iglokožci in ostrakodi). Vmesni prostor zapolnjuje mikrosparit. Povpre-čna velikost aglutiniranih zrn v preiskanih zbruskih je 0,05-0,08 mm in ni odvisna od premera cevk. Pri nekaterih primerkih lahko opazimo, da so večja podolgovata zrna usmerjena vzporedno s površino cevk.

Gostota terebelidnih cevk v prvi leči variira med 10 % in 53 % površine, v drugi leči pa cevke predstavljajo med 6 % in 64 % površine. Večina cevk leži skoraj vodoravno ali poševno na podlago. Slike 5-10 prikazujejo razporeditev gostote (sl. 5, 8) povprečne velikosti (sl. 6, 9) in največje velikosti cevk (sl. 7, 10) v posameznih poljih. Dobljene vrednosti so bile za lažji prikaz razporejene v tri razrede, ki so obarvani z temno sivo (spodnja tretjina vrednosti v leči), svetlo sivo (srednja tretjina vrednosti) in sivo (za najvišje vrednosti v leči). V prvi leči je največja gostota cevk v spodnjem delu leče, na zgornjih robovih pa je na splošno najmanjša. Povprečna velikost cevk v posamičnih poljih v prvi leči se giblje med 2,4 in 7,1 mm, pri čemer je standardni odklon 0,9-2,8 mm (sl. 6). Največje cevke merijo v premer od 4,2 do 17,5 mm (sl. 7). Pri drugi leči (sl. 8) je gostota največja v srednjem delu, ki prikazuje zgolj pol leče, razporeditev velikosti pa ne kaže vzorca. Povprečna velikost cevk znaša 2,4-5,7 mm (sl. 9), pri čemer je standardni odklon 0,6-1,5 mm. Največji premeri cevk v kvadrantih merijo od 4,4 do 13,5 mm (sl. 10).

E'	12	16	22	34	36	36
	20	14	22	24	52	54
D'	16	12	34	38	38	36
	6	12	42	52	42	44
C'	12	18	12	38	60	64
	16	28	28	38	50	59
B'	17	26	39	47	60	55
	20	22	41	53	55	58
A'	15	33	37	40	39	35
	30	38	35	41	30	25
	1'		2'		3'	

Sl. 8. Gostota terebelidnih cevk (v %) v drugi leči. Temno siva polja: 6-25 % cevk; svetlo siva polja: 26-45 % cevk; siva polja: 46-65 % cevk. Za položaj kvadrantov glej sliko 3.

Fig. 8. Density of terebellid tubes (in %) in lens 2. Dark grey: 6-25 %; light grey: 26-45 %; grey: 46-65 %. See figure 3 for quadrant positions.

E'	4,4 (n: 14; s: 1,1)	4,8 (n: 11; s: 1,1)	4,5 (n: 17; s: 1,2)	4,3 (n: 22; s: 1,0)	3,1 (n: 39; s: 0,9)	3,6 (n: 32; s: 1,3)
	5,7 (n: 16; s: 1,6)	4,8 (n: 17; s: 1,7)	3,9 (n: 22; s: 1,3)	4,3 (n: 11; s: 1,4)	3,7 (n: 74; s: 1,2)	4,2 (n: 82; s: 1,5)
D'	3,4 (n: 17; s: 1,1)	4,0 (n: 14; s: 1,1)	4,7 (n: 25; s: 2,5)	5,0 (n: 23; s: 1,6)	4,6 (n: 22; s: 1,2)	4,3 (n: 24; s: 1,1)
	5,3 (n: 6; s: 1,1)	3,5 (n: 16; s: 1,1)	5,0 (n: 35; s: 1,4)	4,8 (n: 40; s: 1,7)	4,5 (n: 18; s: 1,4)	4,8 (n: 33; s: 1,4)
C'	5,0 (n: 11; s: 1,2)	5,1 (n: 16; s: 1,4)	5,0 (n: 10; s: 1,2)	5,4 (n: 24; s: 1,6)	3,3 (n: 116; s: 1,5)	3,0 (n: 184; s: 1,4)
	5,5 (n: 13; s: 1,5)	4,8 (n: 24; s: 1,5)	5,1 (n: 23; s: 1,3)	5,6 (n: 40; s: 1,6)	2,8 (n: 173; s: 1,0)	2,9 (n: 184; s: 1,2)
B'	2,7 (n: 76; s: 1,1)	3,1 (n: 116; s: 1,1)	3,2 (n: 157; s: 1,1)	2,4 (n: 256; s: 1,0)	3,0 (n: 243; s: 1,4)	3,1 (n: 251; s: 1,2)
	2,7 (n: 92; s: 1,0)	3,0 (n: 112; s: 0,6)	2,8 (n: 211; s: 1,0)	2,8 (n: 226; s: 0,9)	3,1 (n: 229; s: 1,0)	3,1 (n: 247; s: 0,9)
A'	2,8 (n: 66; s: 1,1)	2,7 (n: 158; s: 1,1)	2,9 (n: 98; s: 1,0)	2,4 (n: 13; s: 0,9)	3,8 (n: 137; s: 1,1)	3,1 (n: 147; s: 1,0)
	3,0 (n: 108; s: 1,1)	2,6 (n: 186; s: 0,8)	2,7 (n: 160; s: 0,8)	2,7 (n: 140; s: 0,7)	2,9 (n: 156; s: 0,9)	3,3 (n: 104; s: 1,0)
	1'		2'		3'	

Sl. 9. Povprečna velikost terebelidnih cevk (v mm) v drugi leči. Temno siva polja: 2,4-3,5 mm; svetlo siva polja: 3,6-4,7 mm; siva polja: 4,8-5,9 mm. V oklepaju sta navedena število meritev (n) in standardni odklon (s). Za položaj kvadrantov glej sliko 3.

Fig. 9. Average size (in mm) of terebellid tubes in lens 2. Dark grey: 2.4-3.5 mm; light grey: 3.6-4.7 mm; grey: 4.8-5.9 mm. Number of measurements (n) and standard deviation (s) are given in brackets. See figure 3 for quadrant positions.

E'	6,9	7,5	6,3	6,2	6	7,8
	8,8	6,4	8,9	7,1	7,4	13,1
D'	6	6,8	13,4	8,2	8,2	8,1
	7,6	6	7,6	11,4	6,9	7,3
C'	7,4	8	6,7	9,2	10,7	11,6
	9,7	7,9	7,8	9,9	6,7	8
B'	6,6	6,9	8,5	7,6	13,5	7,5
	6,9	4,4	7,2	7,3	6,8	7,2
A'	6,1	8,5	7	6,4	7,2	6,5
	7,8	6,5	5,7	4,7	5,8	7,5
	1'		**2'**		**3'**	

Sl. 10. Največja velikost cevk (v mm) v drugi leči. Temno siva polja: 4,4-7,4 mm; svetlo siva polja: 7,5-10,5 mm; siva polja: 10,6-13,6 mm. Za položaj kvadrantov glej sliko 3.

Fig. 10. Maximum size (in mm) of terebellid tubes in lens 2. Dark grey: 4.4-7.4 mm; light grey: 7.5-10.5 mm; grey: 10.6-13.6 mm. See figure 3 for quadrant positions.

Shapiro-Wilkov test normalnosti porazdelitve podatkov je pokazal, da so povprečne velikosti cevk porazdeljene normalno (W = 0,988, verjetnost p = 0,0896), vrednosti gostote pa ne (W = 0,986, p = 0,0374), zato smo v nadaljevanju uporabili neparametrične statistične teste. Spermanova korelacijska koeficieta za povezavo med gostoto in povprečno velikostjo cevk sta za obe leči sicer statistično značilna, a majhna (okrog 0,3). Razpršenost podatkov potrjujeta tudi razsevna diagrama na slikah 11 in 12, zato povezave med gostoto in velikostjo cevk ne moremo potrditi.

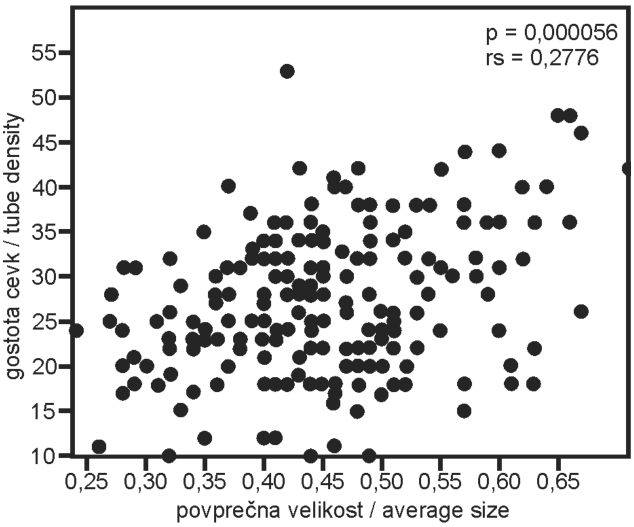
Razprava

Fosilne terebelide

Najstarejše aglutinirane cevke, ki jih pripisujejo redu Terebellida, so znane iz ordovicija in zgornjega devona (glej Zatoń & Bond, 2016). V Kantabrijskem gorovju v Španiji rod *Thartharella* sodeluje pri tvorbi skeletno-mikrobialitnih kop karbonske starosti (Samankassou, 2001; Samankassou et al., 2013). Cevke tvorijo krhko ogrodje, ki ga zapolnjujeta peloidni sediment in cement. Kope so domnevno nastajale v mirnem okolju pod globino dosega valov (Samankassou, 2001). Chesnel s sodelavci (2016, 2017) so aglutinirane cevke mnogoščetincev iz časa karbona našli predvsem v sedimentih zunanjega dela platforme in na pregibu platforme v pobočje, medtem ko so bile tiste v plitvejših delih platforme po smrti živali verjetno uničene. V triasnih kamninah Kuss (1988) omenja prisotnost rodu *Terebella* sp. v plitvomorskih zgornjeladinijskih in spodnjekarnijskih kamninah gore Sinaj v Egiptu. Cevke se nahajajo v življenjskem položaju in prispevajo k stabilizaciji sedimenta znotraj laminiranega mikritnega apnenca, ali pa so najdene preložene znotraj grainstone-a. Brandner s sodelavci (1991) so v Italijanskih Dolomitih posamične cevke našli v karbonatnih olistolitih, ki domnevno izvirajo z zgornjega ali srednjega dela pobočja zgornjeladinijske platforme. Fosilne terebelide v srednjetriasnih kamninah omenjajo še Bernecker (1996), Sánchez Beristain (2010) in Peybernes s sodelavci (2015). Gostejše populacije fosilnih mnogoščetincev so znane na zunanjih robovih in zgornjih delih pobočij norijsko-retijskih platform, kadar so te mejile na slabo prezračene ozke intraplatformne bazene (Iannace & Zamparelli, 1996; Cozzi & Podda, 1998; Cirilli et al., 1999; Iannace & Zamparelli, 2002; Iannace et al., 2005). Mnogoščetinci so obdani z mikrobialiti in so skupaj z njimi tvorili lečaste tvorbe pri razmeroma nizkoenergijskih pogojih (Iannace & Zamparelli, 1996). Cirilli s sodelavci (1999) ter Iannace in

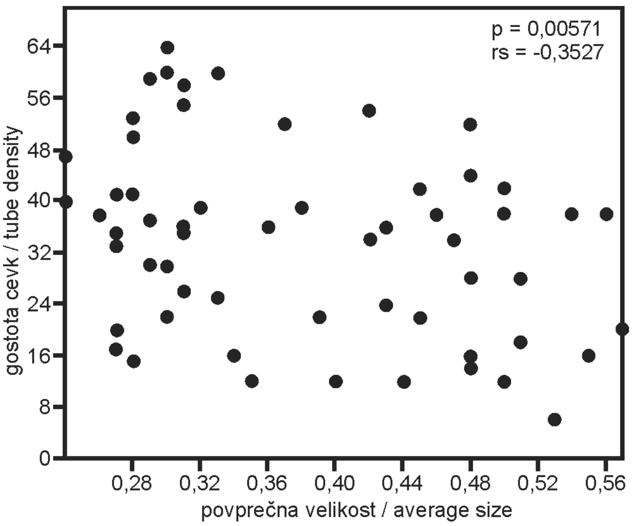
Tabela 1. Nekaj primerov fosilnih aglutiniranih cevk mnogoščetincev in primerjava s fosilnimi terebelidami iz Lesnega Brda.
Table 1. Some examples of fossil agglutinated polychaete tubes and their comparison with fossil terebellids from Lesno Brdo.

Vir / Reference	Ime / Name	Starost / Age	Okolje / Depo. environment	Zunanji premer / outer diameter (mm)	Notranji premer / inner diameter (mm)	Debelina stene / wall thick-ness (mm)	Velikost zrn v steni / incorporated grain size (mm)
Chesnel et al. (2017)	*Thartarella-Terebella* sp.	karbon / Carboniferous	celotna platforma / entire platform	0,25-0,50	/	/	/
Kuss (1988)	*Terebella* sp. (?*T. lapilloides* Münster)	zgornji ladinij in spodnji karnij / Upper Ladinian – Lower Carnian	plitvo morje / shallow marine	0,15-0,39	0,08-0,31	/	/
Climaco et al. (1997)	/	norij-retij / Norian-Rhaetian	rob platforme / platform margin	0,45	0,3	/	/
Cirilli et al. (1999)	/	norij / Norian	zunanji rob – zgornje pobočje / outer margin – upper slope	2,7	1,8	?0,9	/
Iannace & Zamparelli (2002)	*Porferitubus buseri* Senowbari-Daryan	zgornji trias / Upper Triassic	rob platforme / platform margin	13,5	7,3	3,8	/
Schlagintweit et al. (2006)	*Porferitubus lirimi* Schlagintweit, Gawlick & Berger	spodnja - srednja jura / Lower – Middle Jurassic	vrh platforme / platform top / outer margin – upper slope	0,145-0,6	0,008-0,29	0,03-0,145	/
	Porferitubus buseri Senowbari-Daryan	norij / Norian	zunanji rob – zgornje pobočje / outer margin – upper slope	0,4-0,75	0,17-0,5	/	/
Lazăr & Grădinaru (2014)	/	srednja jura / Middle Jurassic	odprti šelf / open shelf	0,42-6,4	0,64-8,85	variabilna / variabile	0,1-0,77
Zatoń et al. (2011)	/	srednja jura / Middle Jurassic	onkoidi in konkrecije; plitvo do globoko morje / oncoids and concretions; shallow to deeper marine	0,5-2,8 (povprečje / average 1,2-1,3)	/	/	0,25-1,0 (odvisno od premera cevke / depending on tube diameter)
Kaya & Altiner (2014)	*Terebella lapilloides* Münster	zgornja jura / Upper Jurassic	predgreben do zgornje pobočje - vznožje pobočja / fore reef to upper slope-base of slope	<1,125	0,13-0,68	0,04-0,25	/
Oloriz et al. (2003)	*Terebella lapilloides* Münster	zgornja jura / Upper Jurassic	spongijske bioherme; srednji del šelfa / sponge bioherms; middle shelf	<10	/	/	/
Schlagintweit & Ebli (1999)	*Terebella lapilloides* Münster	spodnja kreda / Lower Cretaceous	pobočje / slope	0,21-0,28 (tip 1 / type 1) 0,6-0,76 (tip 2 / type 2)	0,18-0,2 (tip 1 / type 1) 0,35-0,46 (tip 2 / type 2)	0.04	/
Vinn & Luque (2013)	Pectinariidae	zgornja kreda / Upper Cretaceous	/	7,7	/	/	0,34-1,13
Lesno Brdo	**Terebellida**	**spodnji karnij / Lower Carnian**	**zunanji rob platforme – zgornje pobočje / outer platform margin – upper slope**	**1,4-9**	**0,86-6**	**0,36-2,57**	**povprečje / average 0,05-0,08**



Sl. 11. Razporeditev povprečne velikosti in gostote cevk v prvi leči. rs: Spearmanov korelacijski koeficient; p: verjetnost.

Fig. 11. Plot of average size and density of tubes in lens 1. rs: Spearman rank-order correlation index; p: probability.



Sl. 12. Razporeditev povprečne velikosti in gostote cevk v drugi leči. rs: Spearmanov korelacijski koeficient; p: verjetnost.

Fig. 12. Plot of average size and density of tubes in lens 2. rs: Spearman rank-order correlation index; p: probability.

Zamparelli (2002) menijo, da je k nastanku tovrstnih bioherm botrovalo stresno okolje z nizko količino kisika, abnormalna slanost ali povečana evtrofnost. Te razmere so zavirale rast grebenov s prevlado metazojev, kakršne so bolj značilne za dobro prezračene robove platform tistega časa (glej Russo, 2005; Martindale et al., 2013). Geopetalne zapolnitve in zgodnjediagenetski izopahi cementi v prazninah med cevkami tvorb, ki so rasle na robovih Forni bazena v predgorju Karnijskih Alp (Cozzi & Podda, 1998), kažejo, da so vsaj nekatere od teh tvorb lahko prenesle močnejše vodne tokove ali valove in da je šlo za razmeroma toge strukture.

Iz spodnje- do srednjejurskih medplimskih karbonatov na Hrvaškem in v Albaniji so Schlagintweit s sodelavci (2006) opisali vrsto Porferitubus lirimi Schlagintweit, Gawlick & Berger. Fosilne aglutinirane cevke so prav tako poznane iz srednjejurskih kamnin Romunije. Lazăr in Grădinaru (2014) sta našla nizke biogene tvorbe iz mnogoščetincev in stromatolitov v razmeroma globokovodnih kamninah. K tvorbi stromatolitov so domnevno prispevale bakterije in glive v slabo prezračenem mikrookolju. Onkoidne in skorjaste tvorbe mnogoščetincev opisujejo tudi Zatón s sodelavci (2012) v srednjejurskih kamninah Poljske. Iz Švicarske Jure sta Dupraz in Strasser (1999) opisala združbo terebelidnih cevk in Tubiphytes mikroproblematike v plitvomorskih biohermah. Omenjena avtorja domnevata, da so živeli v disoksičnih ali anoksičnih razmerah. Terebella lapilloides Münster je bila najdena v zgornjejurskem nizkoenergijskem grebenskem faciesu Turčije (Kaya & Altiner, 2014), medtem ko Schmid s sodelavci (2001) omenjajo pogosto prisotnost rodu Terebella v nizkoenegijskih, po navadi globljemorskih okoljih. Schlagintweit in Ebli (1999) poročata o vrsti Terebella lapilloides Münster s pobočja spodnjekredne platforme. V globljih, nizkoenergijskih vodah nastopa skupaj z mikroproblematiko Tubiphytes Maslov. Združba je bila domnevno tolerantna na disaerobne pogoje. Vinn in Luque (2013) sta opisala en sam primerek mnogoščetinca družine Pectinariidae (red Terebellida) iz zgornje krede Kolumbije.

V oligocenskih kamninah Kalifornije Fischer s sodelavci (1989) opisujejo manjše zaplatne grebene, ki jih tvorijo tesno spojene aglutinirane cevke mnogoščetincev. Tvorbe so nastale v medplimskem pasu (Fischer et al., 1989). Garcin in Vachard (1987) sta opisala do 1 m visoke miocenske bioherme, ki so jih v medplimskem okolju ustvarile aglutinirane cevke družine Sabellariidae (red Terebellida).

Današnji mnogoščetinci z aglutiniranimi cevkami so pogosti v medplimskem in plitvem podplimskem pasu in prav tako lahko tvorijo obširne kope, ki se dvigajo do 1 m nad morsko dno (Bailey-Brock, 1976; Naylor & Viles, 2000; Rabaut et al., 2007; Fournier et al., 2010). Najdemo jih tako v tropskem (Bailey-Brock, 1976), kot tudi v zmernotoplem pasu (Fournier et al., 2010). Na plimskih ravnicah severne Evrope je pogosta vrsta *Lanice conchilega* (Pallas), ki živi v populacijah s po več tisoč osebkov na kvadratnem metru površine. Iz blatnega dna gledajo le vrhnji deli cevčic, med katere se useda drobnozrnat sediment. Akumulacija sedimenta počasi dvigne celotno populacijo nad morsko dno v obliki kope (Fournier et al., 2010). *Sabellaria alveolata* (Linné) po drugi strani v zmerno toplih vodah tvori nepravilne, do 1,5 m visoke bioherme ali do 0,3 m debele obrasti v turbulentnem okolju z nenehnim dotokom peščenih zrn (Naylor & Viles, 2000).

Interpretacija terebelidnih leč iz Lesnega Brda

Masivni »pisani lesnobrdski apnenec« se večinoma omenja kot grebenski apnenec (Buser et al., 1982; Buser, 1987; Grimšičar, 1987; Ramovš, 1987; Mirtič et al., 1999), ki bočno prehaja v dolomit z ostanki zelenih alg (Ramovš, 1987). Po Gale s sodelavci (2018) med biogene tvorbe spadajo le mikrobialitni boundstone in morda tudi terebelidne leče, preostanek masivnega apnenca pa predstavlja karbonatni mulj. Za ladinijske-spodnjekarnijske platforme je sicer značilna zgodnja litifikacija in obilica avtomikrita (glej Blendinger, 1994; Keim & Schlager, 1999; Russo, 2005; Marangon et al., 2011; Tosti et al., 2011), ki pa v primeru omenjenega faciesa ni dokazan.

Terebelidne leče bi lahko predstavljale alohtona nakopičenja cevk odmrlih mnogoščetincev, nastala ob krajši prekinitvi sedimentacije, kot nakopičenja nevihtnih ali drugih visokoenergijskih valov (Tucker, 2003). Za primer hiatusnih koncentracij nismo našli znakov vrtanja, obraščanja ali drugih znakov počasne sedimentacije. Prav tako nismo prepoznali tekstur značilnih za nevihtne valove, zaradi odsotnosti erozijskih kanalov pa ne moremo potrditi prenosa z močnimi tokovi. Proti tokovnemu ali valovnemu nakopičenju pričajo tudi nepravilne oblike (predvsem zgornjega dela) leč in relativna redkost terebelidnih cevk izven omenjenih leč.

Druga možnost je, da terebelidne leče predstavljajo in situ ohranjene populacije terebelid. V masivnem apnencu do sedaj nismo našli sledov vadozne diageneze, leče glinavca pa so morda povezane z zakrasevanjem ob glavni okopnitvi platforme, tako da dokazov za sedimentacijo v medplimskem pasu ni. Drobnozrnati apnenec sicer vsebuje veliko ostankov zelenih alg, ki pa so fragmentirane in morda prenesene s tokovi. Gale s sodelavci (2018) tako menijo, da je masivni apnenec nastal na zunanjem robu ali zgornjem pobočju karbonatne platforme, pri čemer so terebelidne leče analogne zgoraj omenjenim norijsko-retijskim terebelidno-mikrobialitnim biohermam. S spiranjem sedimenta v šibkem toku iz in situ populacij lahko razložimo lokalno prisotnost geopetalnih struktur med cevkami, rast obrobnega cement in hkrati ohranitev lečaste oblike. Ob domnevi, da so terebelidne populacije ohranjene in toto, statistična analiza dveh terebelidnih leč žal ne potrjuje povezave med velikostjo in gostoto osebkov v populaciji, čeprav na podlagi razporeditve gostote osebkov v prvi leči lahko sklepamo, da so cevke najbolj goste v spodnjem delu leče, proti robovom pa se njihova pogostnost zmanjšuje. Postopen upad števila cevk proti robovom leče lahko razložimo tako, da so robni deli populacije ščitili jedro pred preveliko količino sedimenta, zaradi česar tam najdemo več cevk. Prevelik vnos sedimenta bi skrčil obseg populacije, dokler ne bi bila ta povsem zasuta.

V primeru norijsko-retijskih tvorb so terebelide obrasle z mikrobialiti (Iannace & Zamparelli, 1996; Climaco et al., 1997; Cozzi & Podda, 1998; Cirilli et al., 1999), zaradi česar si laže predstavljamo, da so tvorile relief nad morskim dnom. V primeru terebelid masivnega apnenca Lesnega Brda je morda šlo bolj za biostrome, ki niso tvorile znatne izbokline. Terebelide so svoje cevke očitno zgradile iz materiala, ki jim je bil na voljo v okoliškem sedimentu. Čeprav sta Naylor in Viles (2000) za današnjo vrsto Sabellaria alveolata (Linné) ugotovila, da večji primerki vgrajujejo v steno večje delce, pri primerkih iz Lesnega Brda tega nismo potrdili. Vzrok bi lahko bil v tem, da v zbrusku opazujemo zgolj enega od prerezov cevke, ki je lahko pripadala še mlademu osebku, ali pa so bila za gradnjo cevke količinsko zadostna le zrna določene velikosti.

Vrstna pripadnost terebelid iz Lesnega Brda

Ker podobne aglutinirane cevke najdemo pri številnih družinah reda Terebellida, je primerjava fosilnih cevk iz Lesnega Brda z današnjimi rodovi in vrstami težavna. Na to opozarjata tudi Vinn in Luque (2013). Večina mezozojskih primerkov je bila umeščena v rod *Terebella* Linné in vrsto *Terebella lapilloides* Münster (Tabela 1). Primerki iz Lesnega Brda so občutno večji od primerkov, pripisanih vrsti *T. lapilloides*. Po velikosti so bližje norijsko-retijskim mnogoščetincem (Cirilli et al., 1999; Iannace et al., 2005), čeprav tipski material norijske vrste *Porferitubus buseri* Senowbari-Daryan kaže veliko manjši premer cevk. Prav tako je mnogo manjša spodnje/srednjejurska *Porferitubus lirimi* Schlagintweit, Gawlick & Berger. Rod *Porferitubus* ima sicer perforirano steno (Peybernes et al., 2015), medtem ko primerki iz Lesnega Brda perforacij nimajo.

Zaključki

Gosta nakopičenja terebelidnih cevk, ki nastopajo v obliki leč znotraj masivnega spodnjekarnijskega apnenca pri Lesnem Brdu, domnevno predstavljajo in situ ohranjene populacije fosilnih mnogoščetincev, ki so tvorile goste sestoje na zunanjem robu ali zgornjem pobočju nekdanje karbonatne platforme. Ena od dveh analiziranih leč kaže, da je bila populacija najgostejša ob poselitvi morskega dna. Na robovih leče se nato gostota populacije zmanjša na račun večjega vnosa sedimenta. Osebki niso bili selektivni pri izbiri vrste zrn, ki so jih vgrajevali v steno. Velikost zrn, ki gradijo steno, je prav tako neodvisna od velikosti cevk.

Extended summary

Polychaetes (phylum Annelida) are common in marine environments, and some produce carbonate or agglutinated tubes (Fauchald, 1977; Reish & Mason, 2003; Fournier et al., 2010; Vinn & Luque, 2013). Agglutinated tubes are relatively rarely preserved as fossils (Zatoń & Bond, 2016). The Lower Carnian massive limestone in a quarry near Lesno Brdo (fig. 1) contains up to 8 m wide and up to 1.75 m high accumulations of agglutinated worm tubes, attributed to polychaete order Terebellida (fig. 2). Our aim was to analyse two of the lenses (fig. 3) in terms of density, average size and maximum size of the tubes. In thin sections, we checked for relationships between grain composition in the tube walls and within the sediment, and between tube size and the average size of incorporated grains. We also compare the Lesno Brdo specimens with other known tubes from Triassic strata.

Terebellid lenses are surrounded by fine-grained limestone. Terebellid lenses comprise two varieties of microfacies: terebellid floatstone or bafflestone (depending on interpretation of tubes' position within the sediment), and terebellid rudstone. Early marine cements and geopetal structures are common in the latter. Tubes are mostly oriented sub-parallel to the former sea floor. The tubes themselves measure up to 1.75 cm in diameter and are composed of material reflecting composition of the matrix: peloids, measuring 0.05–0.08 mm in diameter are usually the most common grains utilized (fig. 4). There is no correlation between diameter of the tube and grain size. The distribution of density, average and maximum tube sizes is shown in figs. 5–10. The density of terebellid tubes in the first lens varies between 10 and 53 % (fig. 5), whereas in the second lens tubes occupy 6–64 % of the area (fig. 8). The highest density in the first lens seems to be in the lowest part of the lens, whereas tubes are sparse at the margins and at the top. The distribution of tube density in the second lens is irregular. We found no statistical support for correlation between density and size of the tubes (figs. 11, 12).

Irregular shape of the terebellid lenses, the absence of scour or channel structures, and the lateral discontinuity of lenses suggest that lenses are in situ preserved colonies of terebellid worms, biostromal colonies living on the outer margin or outer slope of the former carbonate platform under weak to moderate currents. The distribution of density of the tubes in the larger lens suggests that the most stable conditions for growth were in the inner part of the patch, while the outermost specimens were under greater sediment input. As conditions changed, so too did the population grow or diminish in lateral extent, producing irregular shape of the lens we see today in the quarry wall. Compared to other fossil worm tubes from Triassic (Table 1), we find no suitable analogue. Terebella lapilloides Münster seems to be much smaller in size (Kuss, 1988; Sánchez Beristain, 2010), whereas Porferitubus buseri Senowbari-Daryan and Porferitubus lirimi Schlagintweit, Gawlick & Berger (see Schlagintweit et al., 2006) possess perforated tube wall.

Zahvale

Raziskavo je omogočila finančna podpora Javne agencije za raziskovalno dejavnost Republike Slovenije (program P1-0011). Zahvaljujemo se družbi Mineral d.o.o., ki nam je dovolila dostop do kamnoloma in recenzentoma za temeljit pregled in konstruktivne pripombe.

Literatura

Bailey-Brock, J.H. 1976: Habitats of tubicolous polychaetes from the Hawaiian Islands and Johnston Atoll. Pacific Sci., 30: 69–81.

Bernecker, M. 1996: Upper Triassic reefs of the Oman Mountains: data from the South Tethyan margin. Facies, 34: 41–76.

Blendinger, W. 1994: The carbonate factory of Middle Triassic buildups in the Dolomites, Italy: a quantitative analysis. Sedimentology, 41: 1147–1159.

Brandner, R., Flügel, E. & Senowbari-Daryan, B. 1991: Microfacies of carbonate slope boulders: indicator of the source area (Middle Triassic: Mahlknecht Cliff, Western Dolomites). Facies, 25: 279–296.

Buser, S., Ramovš A. & Turnšek, D. 1982: Triassic reefs in Slovenia. Facies, 6: 15-24.

Buser, S. 1987: Pomembnost ugotavljanja starosti mezozojskih arhitektonsko-gradbenih kamenin v osrednji in južni Sloveniji. In: Pavlovec, R., Mikuž, V. & Pirc, S. (eds.): Arhitektonsko gradbeni kamen v Sloveniji in njegova uporaba. Geol. zbornik, 8: 45-49.

Chesnel, V., Samankassou, E., Merino-Tomé, Ó., Fernández, L.P. & Villa, E. 2016: Facies, geometry and growth phases of the Valdorria carbonate platform (Pennsylvanian, Northern Spain). Sedimentology, 63: 60-104.

Chesnel, V., Merino-Tomé, Ó., Fernárdez, L.P., Villa, E. & Smankassou, E. 2017: Spatial and temporal distribution of microbial carbonates, skeletal and non-skeletal grains in Pennsylvanian carbonate platform (Valdorria, Northern Spain). Palaeogeogr., Palaeoclimatol., Palaeoecol., 476: 106-139.

Cirilli, S., Iannace, A., Jadoul, F. & Zamparelli, V. 1999: Microbial-serpulid build-ups in the Norian-Rhaetian of the Western Mediterranean area: ecological response of shelf margin communities to stressed environments. Terra Nova, 11: 195-202.

Climaco, A., Boni, M., Iannace, A. & Zamparelli, V. 1997: Platform margins, microbial/serpulids bioconstructions and slope-to-basin sediments in the Upper Triassic of the "Verbicaro Unit" (Lucania and Calabria, Southern Italy). Facies, 36: 37-56.

Cozzi, A. & Podda, F. 1998: A platform to basin transition in the Dolomia Principale of the Pramaggiore area, Carnia Prealps, Northern Italy. Mem. Soc. Geol. It., 53: 387-402.

Dunham, R.J. 1962: Classification of carbonate rocks according to depositional texture. In: Han, W.E. (ed.): Classification of carbonate rocks, a symposium. Amer. Ass. Petrol. Geol. Mem., 108-121.

Dupraz, C. & Strasser, A. 1999: Microbialites and micro-encrusters in shallow coral bioherms (Middle to Late Oxfordian, Swiss Jura Mountains). Facies, 40: 101-130.

Fauchald, K. 1977: The polychaete worms: Definitions and keys to the orders, families and genera. Natural History Museum of Los Angeles County & Allan Hancock Foundation, University of Southern California. Science Series 28: 188 p.

Fischer, R., Galli Oliver, C. & Reitner, J. 1989: Skeletal structure, growth, and palaeoecology of the patch reef-building polychaete worm *Diplochaetetes mexicanus* Wilson, 1986 from the Oligocene of Baja California (Mexico). Geobios, 22: 761-775.

Flügel, E. 2004: Microfacies of carbonate rocks: Analysis, interpretation and application. Springer-Verlag, Berlin Heidelberg: 976 p.

Fournier, J., Etienne, S. & Le Cam, J.B. 2010: Inter- and intraspecific variability in the chemical composition of the mineral phase of cements from several tube-building polychaetes. Geobios, 43: 191-200.

Gale, L., Peybernes, C., Celarc, B., Hočevar, M., Šelih, S.V. & Martini, R. 2018: Biotic composition and microfacies distribution of Upper Triassic build-ups: new insights from the Lower Carnian limestone of Lesno Brdo, central Slovenia. Facies, 64: 17.

Garcin, M. & Vachard, D. 1987: Découverte d'hermelles fossils dans le Messinien de San Miguel de Salinas = Annélides du Miocène Supérieur du Sud-est de l'Espagne. Geobios, 20: 407-414.

Gerčar, D., Koceli, A., Založnik, A. & Rožič, B. 2017: Upper Carnian clastites from Lesno Brdo area (Dinarides, Central Slovenia). Geologija, 60/2: 279-295; doi: https://doi.org/10.5474/geologija.2017.020.

Grimšičar, A. 1987: Kamnine Robbovega vodnjaka v Ljubljani. In: Pavlovec, R., Mikuž, V. & Pirc, S. (eds.): Arhitektonsko gradbeni kamen v Sloveniji in njegova uporaba. Geol. zbornik, 8: 69-80.

Guido, A., Mastandrea, A., Rosso, A., San Filippo, R., Tosti, F., Riding, R. & Russo, F. 2014: Commensal symbiosis between agglutinated polychaetes and sulfate reducing bacteria. Geobiology, 12: 265-275, doi: https://doi.org/10.1111/gbi.12084.

Hammer, Ø. & Harper, D.A.T. 2006: Paleontological data analysis. Blackwell Publishing: 351 p.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D. 2001: PAST: Paleontological Statistics software for education and data analysis. Palaeont. Electronica 4: 9 p.

Iannace, A. & Zamparelli, V. 1996: The serpulid-microbialite bioconstructions of the 'Scisti Illiolitici' basin of Giffoni Vallepiana (Upper Triassic, Southern Apennines). Palaeopelagos, 6: 45-62.

Iannace, A. & Zamparelli, V. 2002: Upper Triassic platform margin biofacies and the paleogeography of Southern Apennines. Palaeogeogr., Palaeoclimatol., Palaeoecol., 179/1-2: 1-18, doi: https://doi.org/10.1016/S0031-0182(01)00362-5.

Iannace, A., Parente, M. & Zamparelli, V. 2005: The Upper Triassic platform margin facies of Southern Apennines and their Jurassic fate: state of the art. Bolletino della Societa Geologica Italiana, 124: 203-214.

Jelen, B. 1990: The Karnian bivalves (Mollusca) from Lesno brdo, Slovenia, NW Yugoslavia and their paleobiological significance. Geologija, 31/32: 11-127.

Kaya, M.Y. & Altiner, D. 2014: Terebella lapilloides Münster, 1833 from the Upper Jurassic-Lower Cretaceous İnaltı carbonates, northern Turkey: its taxonomic position and paleoenvironmental-paleoecological significance. Turkish J. Earth Sci., 23: 166-183.

Keim, L. & Schlager, W. 1999: Automicrite on steep slopes (Triassic, Dolomites, Italy). Facies, 41: 15-26.

Kuss, J. 1988: Microfacies and foraminifera of Middle Triassic limestones (Anisian-Carnian?) from Gebel Araif el Naqu (Sinai, Egypt). Facies, 19: 61-76.

Lazăr, I. & Grădinaru, M. 2014: Paleoenvironmental context and paleoecological significance of unique agglutinated polychaete worm tube-ferruginous microstromatolite assemblages from the Middle Jurassic of the Southern Carpathians (Romania). Facies, 60/2: 515-540, doi: https://doi.org/10.1007/s10347-013-0390-0.

Marangon, A., Gattolin, G., Della Porta, G. & Preto, N. 2011: The Latemar: A flat-topped, steep fronted platform dominated by microbialites and synsedimentary cements. Sed. Geol., 240/3-4: 97-114, doi: https://doi.org/10.1016/j.sedgeo.2011.09.001.

Martindale, R.C., Krystyn, L., Bottjer, D.J., Corsetti, F.A., Senowbari-Daryan, B. & Martini, R. 2013: Depth transect of an Upper Triassic (Rhaetian) reef from Gosau, Austria: Microfacies and community ecology. Palaeogeogr., Palaeoclimatol., Palaeoecol., 376: 1-21, doi: https://doi.org/10.1016/j.palaeo.2012.12.010.

Mirtič, M., Mladenovič, A., Ramovš, A., Senegačnik, A., Vesel, J. & Vižintin, N. 1999: Slovenski naravni kamen. Geološki zavod Slovenije & Zavod za gradbeništvo Slovenije & Naravoslovnotehniška fakulteta, Ljubljana: 131 p.

Naylor, L.A. & Viles, H.A. 2000: A temperate reef builder: an evaluation of the growth, morphology and composition of *Sabellaria alveolata* (L.) colonies on carbonate platforms in South Wales. In: Insalaco, E., Skelton, P.W. & Palmer, T.J. (eds.): Carbonate platform systems: components and interactions. The Geological Society, London, Special Publication, 178: 9-19.

Peybernes, C., Chablais, J. & Martini, R. 2015: Upper Triassic (Ladinian?-Carnian) reef biota from the Sambosan Accretionary Complex, Shikoku, Japan. Facies, 61: doi: https://doi.org/10.1007/s10347-015-0446-4.

Placer, L. 1998: Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides. Geologija, 41: 223-225, doi: https://doi.org/10.5474/geologija.1998.013.

Rabaut, M., Vincx, M. & Degraer, S. 2007: Do *Lanice conchilega* (sandmason) aggregations classify as reefs? Quantifying habitat modifying effects. Helgoland Marine Res., 63/1: 37-46, doi: https://doi.org/10.1007/s10152-008-0137-4.

Ramovš, A. 1987: Triasne gradbene in okrasne kamnine v severni Sloveniji. In: Pavlovec, R., Mikuž, V. & Pirc, S. (eds.): Arhitektonsko gradbeni kamen v Sloveniji in njegova uporaba. Geol. zbornik, 8: 25-35.

Reish, D.J. & Mason, A.Z. 2003: Radiocarbon dating and metal analysis of "fossil" and living tubes of *Protula* (Annelida: Polychaeta). In: Sigvaldadóttir, E., Mackie, A.S.Y., Helgason, G.V., Reish, D.J., Svavarsson, J., Steingrímsson, S.A. & Gudmundsson, G. (eds.): Advances in polychaete research. Hydrobiologia, 496: 371-383.

Russo, F. 2005: Biofacies evolution of the Triassic platforms of the Dolomites, Italy. Ann. Univ. Ferrara Mus. Sci. Natural., Vol. spec. 2005: 33-44.

Samankassou, E. 2001: Internal structure and depositional environment of Late Carboniferous mounds from the San Emiliano Formation, Cármenes Syncline, Cantabrian Mountains, Northern Spain. Sed. Geol., 145: 235-252.

Samankassou, E., Von Allmen, K. & Bahamonde, J.R. 2013: Growth dynamics of Pennsylvanian carbonate mounds from a mixed terrigenous-carbonate ramp in the Puebla de Lillo area, Cantabrian Mountains, Northern Spain. J. Sed. Res., 83/12: 1099-1112, doi: https://doi.org/10.2110/jsr.2013.84.

Sánchez Beristain, J.F. 2010: Paleoecological and geochemical studies on sponge/microencruster –bearing communities contained in selected Cipit Boulders from the St. Cassian Formation (Lower Carnian, Upper Triassic) of the Dolomites, Northeastern Italy). Dissertation. Mat.-Nat. Fak. Georg-August Univ. Göttingen, Götingen: 146 p.

Schlagintweit, F. & Ebli, O. 1999: New results on microfacies, biostratigraphy and sedimentology of Late Jurassic – Early Cretaceous platform carbonates of the Northern Calcareous Alps. Part I: Tressenstein Limestone, Plassen Formation. Abh. Geol. B.-A., 56: 379-418.

Schlagintweit, F., Gawlick, H.J. & Berger, P. 2006: *Porferitubus lirimi* n. sp., a new tubiferous microfossil incertae sedis (Cyanophyta?) from the Early/Middle Jurassic of the Adriatic-Dinaric carbonate platform (Croatia, Albania). In: XVIIIth Congress of Carpathian-Balkan Geological Association 2006: 522-526.

Schmid, D.U., Leinfelder, R.R. & Nose, M. 2001: Growth dynamics and ecology of Upper Jurassic mounds, with comparisons to Mid-Palaeozoic mounds. Sed. Geol., 145: 343-376.

Tosti, F., Guiso, A., Demasi, F., Mastandrea, A., Naccarato, A., Tagarelli, A. & Russo, F. 2011: Microbialites as primary builders of the Ladinian-Carnian platforms in the Dolomites: biogeochemical characterization. GeoAlp, 8: 156-162.

Tucker, M.E. 2003: Sedimentary rocks in the field (3rd edition). John Wiley & Sons Ltd., Chichester: 234 p.

Vinn, O. & Luque, J. 2013: First record of a pectinariid-like (Polychaeta, Annelida) agglutinated worm tube from the Late Cretaceous of Colombia. Cret. Res., 41: 107-110, doi: https://doi.org/10.1016/j.cretres.2012.11.004

Zatoń, M., Kano, Y., Wilson, M.A. & Filipiak, P. 2012: Unusual tubular fossils associated with microbial crusts from the Middle Jurassic of Poland: agglutinated polychaete worm tubes? Palaios, 27: 550-559, doi: https://doi.org/10.2110/palo.2012.p12-013r.

Zatoń, M. & Bond, D.P.G. 2015: Insight into tube-building behaviour and palaeoecology of some agglutinating worms from the Upper Devonian of Nevada, USA. Palaeogeogr., Palaeoclimatol., Palaeoecol., 445: 138-146, doi: https://doi.org/10.1016/j.palaeo.2015.12.020.

GEOLOGIJA 61/1, 101-110, Ljubljana 2018

https://doi.org/10.5474/geologija.2018.007

Results of the geointerpretation research in the frame of the Danube GeoTour project

Rezultati raziskave o geointerpretaciji v okviru projekta Danube GeoTour

Danijela MODREJ[1], Suzana FAJMUT ŠTRUCL[2] & Gerald HARTMANN[1]

[1]ARGE Geopark Karavanke/Karawanken, Hauptplatz 7, 9135 Bad Eisenkappel/Železna Kapla, Austria
[2]Podzemlje Pece, d.o.o., Glančnik 8, 2392 Mežica, Slovenia

Prejeto / Received 3. 5. 2018; Sprejeto / Accepted 20. 6. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Key words: geološka dediščina, geoparki, geointerpretacija, trajnostni razvoj, geoturizem, Geopark Karavanke/Karawanken, Danube GeoTour

Ključne besede: geological heritage, geoparks, geointerpretation, sustainable development, geotourism, Geopark Karavanke/Karawanken, Danube GeoTour

Abstract

Crossborder Karavanke/Karawanken UNESCO Global Geopark was established in 2011, and in 2013, it became a member of the European- (EGN) and Global Geopark Network (GGN). Its administrative boundary follows the boundaries of 14 municipalities on the Slovenian and Austrian sides. Since the early beginning, the sustainable tourism throughout the region has been developed. An important component of the Geopark activities is applying for various funding to support the regional development through the transnational cooperation between European Geoparks or through Geopark-specific projects. An example of the transnational cooperation is the project Valorisation of geo-heritage for sustainable and innovative tourism development of Danube Geoparks. Eight Geoparks of the Danube region participate in this project with the acronym Danube GeoTour, implemented in the INTERREG Danube Transnational Programme 2014-2020. The main goal of the project is establishment of the joint Danube GeoTour designed to strengthen cooperation between the regions' Geoparks and act as an innovative tourism product to accelerate visibility and tourist visits in the Geoparks. Common strategy for sustainable management of tourism pressures will form the basis for creating innovative geoproducts. Sharing experiences, testing pilot geotourism products and new interpretative approaches should increase local inhabitants' engagement, Geopark management capacities and lower the quality gap between Danube and other European Geoparks. Within the Danube GeoTour project, Karavanke/Karawanken UNESCO Global Geopark implemented a research "New competences in geoheritage interpretation". The aim of the project is to find out how to improve skills and quality of the heritage presentation in the participating Geoparks by transnational learning interaction, and to complement the uniqueness and character of the overall Danube GeoTour product. The main research objective was the introduction of new interpretation trends, techniques and methods which are used in the presentation of geoheritage, observed within and outside the participating Geoparks.

Izvleček

Čezmejni UNESCO-v globalni geopark Karavanke/Karawanken je bil ustanovljen leta 2011, z letom 2013 pa je postal član Evropske- (EGN) in Globalne mreže Geoparkov (GGN). Obsega območje 14 občin na slovenski in avstrijski strani. Že od samega začetka je prioriteta geoparka razvoj trajnostnega turizma v regiji; pomembna aktivnost je uporaba različnih finančnih skladov za podporo regionalnemu razvoju preko programov čezmejnega sodelovanja med evropskimi geoparki ali preko specifičnih projektov geoparka. Primer dobrega čezmejnega sodelovanja med evropskimi geoparki je projekt Valorizacija geodediščine za trajnostni in inovativni razvoj turizma v podonavskih geoparkih. V okviru programa čezmejnega sodelovanja Podonavje 2014–2020, v projektu z akronimom Danube GeoTour, sodeluje osem geoparkov z območja podonavske regije. Glavni cilj projekta je vzpostavitev skupne Podonavske poti Danube GeoTour, oblikovane z namenom krepitve sodelovanja med regijami z geoparki. Delovala bo kot inovativni turistični produkt za pospeševanje vidnosti in turističnih obiskov v geoparkih. Skupna strategija za trajnostno upravljanje turističnih obiskov bo osnova za ustvarjanje inovativnih geoproduktov. Izmenjava izkušenj ter preizkušanje pilotnih produktov geoturizma in novih interpretativnih pristopov bo povečala vključenost lokalnih prebivalcev, kapacitet geoparkov, in zmanjšala kakovostno vrzel med podonavskimi in drugimi evropskimi geoparki. V okviru projekta Danube GeoTour je UNESCO-v globalni geopark Karavanke/Karawanken izvedel raziskavo »Nove kompetence v interpretaciji geološke dediščine«. Namen projekta je ugotoviti, kako izboljšati predstavitev dediščine v sodelujočih geoparkih ter dopolniti edinstvenost in značaj celotnega Danube GeoTour produkta. Glavni cilj raziskave je preučitev novih interpretacijskih trendov, tehnik in metod, ki se uporabljajo pri predstavitvi geološke dediščine znotraj in zunaj sodelujočih geoparkov.

Introduction

Geology is a science concerned with the origin, history, composition and structure of our planet Earth. Without doubt this is one of the most important branches of Earth sciences, but often neglected, while geology-related topics are not appropriately visualized to general public. With the use of suitable presentation technique, we can make often too complicated geological phenomena more interesting and easier to understand.

In general, there are two reasons why we need presentation of geological heritage. Firstly, our geological heritage is important in underpinning the famous landscapes and biodiversity that we have. Despite this fact, the geological heritage is farther from the hearts and minds of the population than other more easily identifiable aspects of the natural heritage, namely the flora and fauna. However, similar to the biodiversity, the geological heritage is vulnerable to the activities of mankind, which may damage it. The damage is long-term and difficult to be remediated, often even impossible. Therefore, only those people and local communities who are aware of their geological heritage and can both identify with it and relate to it, can contribute to its conservation and sustainable development. Geological heritage presentation has a clear role in establishing the real links between the bio- and geodiversity and the need to preserve them both equally. The second reason for the requirement of geological presentation, is the opportunity the geodiversity offers in touristic efforts at local or national level. Good explanation and presentation of geological phenomena will enhance the visitor experience and help boost geotourism (Internet 1).

A significant role in the geo-presentation and geo-tourism have today Geoparks. Geopark is a territory with a great geological heritage, important not only at the national level, but also global. They are a relatively young establishment. The European Geoparks Network was established in the year 2000 by four Geoparks: Reserve Geologique de Haute-Provence (France), Natural History Museum of Lesvos Petrified Forest – Lesvos island (Greece), Geopark Gerolstein/Vulkaneifel (Germany) and Maestrazgo Cultural Park (Spain). In 2004, the Global Geoparks Network (GGN) was founded, when 17 European and 8 Chinese Geoparks came together. As of April 2018, 140 Geoparks in 38 Member States are currently members of the Global Geoparks Network. 70 Geoparks from 23 European Countries form today‘s European Geoparks Network (EGN).

UNESCO patronage on Geoparks began in 2001. In November 2015, the 195 Member States of UNESCO set-up the creation of a new label - the UNESCO Global Geoparks. According to the definition, UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development (Internet 2). Functioning in the same way as museums, zoos, parks and science centres, geoparks serve as centres for informal learning, providing visitors with geological, historical and cultural stories. They offer these opportunities through interpretation programmes, guided tours, exhibits, signage, brochures, lectures and online sites (Buhay et al., 2015).

In the last decade, the multi-medias increasingly impact the way of spreading the knowledge and represent a new modern approach in geo-presentation. Today, we live increasingly in a digital society. If we want to reach and engage wide audience, it is important to select the most appropriate means of communication. This does not mean abandoning old methods, but rather developing and introducing additional approaches. Digital technologies can provide off- and online presentation, as well as on- or offsite experiences. It is a major and growing trend in museums and education. Numerous recent digital heritage projects have demonstrated the usefulness of the information and communications technologies (Boile et al., 2014; Antlej, 2014). The new technologies enable the creation of virtual databases using virtual globes – e.g., Google Earth – and other personal-use geomatics applications (smartphones, tablets, PDAs) for accessing geological heritage information in “real time” for scientific, educational, and cultural purposes via a virtual geological itinerary. With these technologies, Geoparks and other relevant institutions can create mapped and georeferenced geosites (Martínez-Graña et al., 2013).

The development of the Geoparks goes hand in hand with the vision of Interpret Europe (European Association for Heritage Interpretation). High quality heritage presentation is the key to foster broader understanding of – and respect for – all natural and cultural heritage. This opens up new possibilities for cooperation in the field of environmental education and interpretation between Interpret Europe and the Geoparks, as well as the European Geoparks Network. Geoparks must look forward to developing new networks to foster creativity and to drive innovations in heritage presentation and the Geoparks must try to bring geo-presentation to the next level with the use of new technologies (multi-media, virtual reality, etc.), for visualisation and presentation of complex geological phenomena and processes, and popularisation of geological science (Hartmann et al., 2012; Bedjanič et al., 2014).

Eight Geoparks of the Danube region participate in the project Danube GeoTour - Valorisation of geo-heritage for sustainable and innovative tourism development of Danube Geoparks, implemented in the INTERREG Danube Transnational Programme 2014-2020. Karavanke/Karawanken UNESCO Global Geopark, as the coordinator of the Workpackage *Geointerpretation,* implements a research about *New competences in geoheritage interpretation*. The aims of the research were (a) the introduction of new approaches, which are used in the geoheritage presentation and are observed within and outside the participating Geoparks; (b) to improve skills and quality of the heritage presentation in the participating Geoparks by transnational learning interaction; (c) to complement the uniqueness and character of the overall Danube GeoTour product.

Research New competences in geoheritage interpretation - data collection tools

The main aim of the research *New competences in geoheritage interpretation* was to find out new trends and competences in geo-presentation and geo-communication as well as new specific presentation methods of 8 selected geological challenges in the Danube region, i.e. tectonics, volcanology, geohazards, geology over time, water in time, metamorphic processes and rocks, geomorphology and dialogue between Earth & humans. For this purpose, following data collection tools was used:

1. In order to gain better insight into existing presentation methods and technologies, used in participating Geoparks and into the quality of presentation the geological heritage, a Questionnaire concerning geo-presentation practices in project partners Geoparks was prepared. Questions were mainly related to the existing geological heritage presentation in Geopark - how does Geopark presents its geological heritage, which of selected geological processes/challenges are described in personal or non-personal geo-presentation, what kind of personal (guided tours in different trails and paths, training for guides/rangers/interprets, educational seminars for educational institutions, workshops for children, …) and non-personal (booklets/books, information panels, audio-visual equipment, info-points, info-centres, …) geo-presentation are used in Geopark, ...
2. With the objective to get a deep insight into the current developments in presentation of natural phenomena in other protected areas, several information centres in Austria have been visited, as the examples of best pactice in the geo-presentation (Nationalparkzentrum Hohe Tauern in Mittersill, Spring Water Museum in Wildalpen, Visitor centre Erz der Alpen) (fig. 1).

Fig. 1. Field visit of info centres in Austria.

3. An online research - *A screening of the most recent developments, technologies and best practices of interpretative methods applicable to Danube Geoparks*, was carried out, to find examples of best practice in the presentation of selected geological challenges all over the world. Each of the participating Geoparks addressed one geological presentation challenge (problem) that is common, well investigated and presented in the partner territory. At the same time, all selected challenges are typical for the Danube region Geoparks.

4. Data collection in the frame of the joint geo-presentation training - While one of the main ideas of the Danube GeoTour project is learning interaction between project partners, the joint geo-interpretation training was organised for key Danube Geopark personnel responsible for geoguide service and/or presentation (fig. 2). The training covered the following 3 topics: familiarizing with newest developments, methods and best practices - learning from others; exchange of different personal experiences and practices in the presentation of the selected top 8 interpretation challenges - this was implemented in the form of a workshop with a goal to learn from each other; modes of communicating complex geological facts in easy-to-understand language. As part of this topic, a vocabulary of English and all partners' language terms commonly used in geo-presentation was prepared.

Results and discussion

The research *New competences in geoheritage interpretation* geographically covers 7 countries in the Danube region. These represent territories of project partners who contributed best practices, experiences, as well as gained new skills. Moreover, best practices outside of the programme area were researched, being EU or third countries, which were gathered and exchanged at the various EGN/GGN international events. These countries are: Ireland, United Kingdom, Scotland, France, Germany, Italy, Greece, Denmark, Spain, Canada, United States, China and Japan. In total, research includes more than 70 cases of best practice examples in geo-presentation (Table 1 and Table 2).

The idea of the joint geointerpretation training was learning interaction and sharing concrete practical examples from other Geoparks and nature parks, which all lead to better insight into new presentation trends and improved practical presentation skills through learning new presentation and communication methods. This will significantly open perspectives as well as strengthen the competences of individual parks management and the Danube Geopark Tour partnership as a whole and in comparison to other more advanced Geoparks within the EGN and GGN Network.

In the frame of the joint geo-interpretation training, all participants (Geopark Idrija, Geopark Papuk, Geopark Hateg, Geopark Styrian Eisenwurzen, Balaton-Bakony Geopark, Bohemian Paradise Geopark, Geopark Karavanke) shared

Fig. 2. Geo-interpretation training in the Karavanke/Karawanken UNESCO Global Geopark on 20th of September 2017.

Table 1. Best practices from third countries.

No.	Best practice	Location	Type of presentation	Type of best practice
1	Dynamic Earth - Home of the Big Nickel - Earth sciences centre	Ontario, Canada	Exhibition Earthquakes of Canada, where visitors can create their own earthquake, use a seismometer to measure their impact	Best practice for direct linkage with scientific labs
2	Geologic Exhibit	Central Washington University Science II, United States of America	Model of the geologic timeline, built into the floor of a 58.5-meter-long corridor	Best practice for school workshop and digital interpretation
3	The Trail of Time	Grand Canyon, United States of America	A giant geologic timeline, where every meter along the trail, each of which is identified by a bronze marker, represents one million years of Earth's history	Best practice for interpretation route
4	Dynamic Earth - Home of the Big Nickel - Earth sciences centre	Ontario, Canada	Erosion Table; discover simple principles about erosion and water forces	Best practice for children interpretation and children workshops
5	Hong Kong Geopark app	Hong Kong UNESCO Global Geopark, China	An excellent interpretation example, which contains interpretation pictures, text, maps, and different videos	Best practice for mobile application

best practices and methods they use for presentation of geological heritage, especially for their selected geological challenge (tectonics, volcanology, geohazards, geology over time, water in time, metamorphic rocks and processes, geomorphology, dialogue between Earth and human) and visited a good practice example in the Karavanke/Karawanken UNESCO Global Geopark – visitor centre »World of geology« in Bad Eisenkappel/Železna Kapla with the presentation of different kinds of demonstration methods and applications – Geopuls System, Geoclock, GeoGames, etc. This visit was very good insight into the presentation of geological heritage through different kinds of methods and technologies; a combination of personal (guided visit) and non-personal (booklets/books, audio-visual equipment, info-centre) presentation of geological heritage was also presented.

The aim of the joint geo-interpretation training was that all participating Geoparks became familiarized with the modern methods and new trends in geo-presentation and with the best practices from all over the world. This transnational dimension of the training was very useful; each Geopark found out new approaches for geo-presentation through learning from other participants and also got new ideas for heritage presentation - some of the given approaches/ideas are presented below:

- Objects that can be weighed, touched, kept in hand are memorable elements of the presentation;
- gestures, tone of voice and expressive words, its magnitude and the events that accompanied it can make the explanation much more interesting, more fun and more memorable for the visitors;
- use not too much information and facts on the panels; a mix of maps, graphics and pictures with a good short information text is the best way;
- avoiding the overloading visitors with many scientific data in short period of time;
- it is important to connect/compare information with some familiar facts/events in the real life;
- active participation of visitors can not only enhance their experience but also helps them to remember important facts more easily;
- involve children and you will automatically involve adults;
- combination of personal (guided visits) and non-personal (use of illustrations, publications, audio-visual equipment, multi-media, etc.) presentation methods - although the geo-heritage presentation today uses a range of communications media and is delivered in many different ways, it is observed that the direct person-to-person contact is still the most efficient;
- ideally, presentation is carried out on two levels: for children and for adults, with different approaches;
- effective geo-presentation with the use of interactive, constructive learning, explaination of complex topics and ideas connected to a site's main themes in simple words and images that are easily accessible for non-expert audiences.

As the result of the geo-interpretation training, questionnaire, field trip (visits of several information centres in Austria) and on-line research, several recommendations were made, which should be followed when presenting geo-

Table 2. Best practices for 8 selected geological challenges.

No.	Best practice	Location	Type of presentation	Topic of geointerpretation / Geological challenge
1	Animation of plate tectonics and formation of Idrija territory	Idrija UNESCO Global Geopark, Slovenia	Animation at the 1511 Anno Domini exhibition	Tectonics
2	3D models, showing the types of faults and movements along different faults	Idrija UNESCO Global Geopark, Slovenia	Animation for interpretation of the Idrija territory formation and Idrija fault	Tectonic
3	Wooden 3D model	Idrija UNESCO Global Geopark, Slovenia	Didactical tool, used for presentation of movements along different types of faults	Tectonic
4	Interpretation point TIC Topla	Karavanke UNESCO Global Geopark, Slovenia/Austria	Didactic tools and interpretative boards showing tectonic plates boundaries and geological time-scale	Tectonic/ Geology over time
5	Visitors centre Cliffs of Moher	Burren and Cliffs of Moher UNESCO Global Geopark, Ireland	Multimedia exhibition, which enables to move in time and see distribution of tectonic plates throughout the Earths' geological history	Tectonic
6	Geological clock	Karavanke UNESCO Global Geopark, Slovenia/Austria	Special animation- clock, where the geological time is divided and presented in 12 hours	Tectonic/Geology over time/Water in time
7	High Definition 3D adventure cinema	Nationalparkzentrum Hohe Tauern in Mittersill, Austria	3D film, which shows the formation of the Alps and the Hohe Tauern window	Tectonic
8	Visitors center Our Dynamic Earth	Edinburgh, Scotland	Interactive exhibition, experience with erupting volcanoes and lava flow	Volcanology
9	Adventure park VULKANIJA	Grad, Slovenia	Power of volcanoes and their activity is presented through images, text and film, through play and interactive content	Volcanology
10	Vulcania theme park	Saint-Ours, Auvergne, France	Projections, special effects and mapping on the rock walls; exploring volcanoes and the planet Earth with attraction named Abyss explorer.	Volcanology
11	Illustrative tools used by geohike guides	Balaton-felvidéki National Park Directorate, Bakony–Balaton UNESCO Global Geopark, Hungary	Guiding a group of visitors on a field trip or on a geohike	Volcanology
12	Hegyestű Geological Visitor Site	Bakony–Balaton UNESCO Global Geopark, Hungary	Information panel of the evolution of volcanic remnant cones	Volcanology
13	Tapolca Lake Cave Visitor Centre	Bakony–Balaton UNESCO Global Geopark, Hungary	Model of volcanic remnant cones	Volcanology
14	Lavender House Visitor Centre	Bakony–Balaton UNESCO Global Geopark, Hungary	Geyser and thermal spring simulator	Volcanology
15	Lavender House Visitor Centre	Bakony–Balaton UNESCO Global Geopark, Hungary	Model of a volcano	Volcanology
16	Volcano Nature Trail	Bakony–Balaton UNESCO Global Geopark, Hungary	"Stone heaps": 4 models of the volcano cut into half	Volcanology
17	Volcano Nature Trail	Bakony–Balaton UNESCO Global Geopark, Hungary	"Stone map": model of Lake Balaton and the volcanoes around it	Volcanology
18	Volcano Nature Trail	Bakony–Balaton UNESCO Global Geopark, Hungary	"Stone wall": timeline of the volcanic activity in the area	Volcanology
19	Portable volcano model	Nógrád–Novohrad UNESCO Global Geopark, Hungary	Portable volcano model	Volcanology
20	Volcano simulator	Pannon Sea Museum, Geology and Natural History Exhibition of Herman Ottó Museum, Hungary	The simulator and the panels	Volcanology

No.	Best practice	Location	Type of presentation	Topic of geointerpretation / Geological challenge
21	Phreatomagmatic eruption simulator	Kemenes Vulcano Park, Celldömölk, Hungary	Simulator showing the process of the phreatomagmatic explosive eruption	Volcanology
22	Models of lava types	Kemenes Vulcano Park, Celldömölk, Hungary	Lifelike imitations of two interesting lava types: AA and pahoehoe lava	Volcanology
23	Simulations of volcanic processes	Kemenes Vulcano Park, Celldömölk, Hungary	Touchscreen, modelled volcano videos, like magma chamber processes, movement of the lava flows, simulation (2D, 3D) etc.	Volcanology
24	Models of volcano types	Kemenes Vulcano Park, Celldömölk, Hungary	Six major types of idealized volcanoes are displayed by professionally detailed and accurate relief models on a table	Volcanology
25	The House of Volcanoes	Hateg Country Dinosaurs UNESCO Global Geopark, Romania	An interpretation and education point with main interpretation theme - ancient volcanoes from the Cretaceous	Volcanology
26	Smrekovec – extinct giant	Karavanke UNESCO Global Geopark, Slovenia/Austria	The interpretation point reveals the geological story of Slovenia's only volcanic mountain range.	Volcanology
27	Seismic table simulator	Natural history museum of the Lesvos petrified forest, Lesvos Island UNESCO Global Geopark	Seismic table, which simulate the seismic movement of some of the most destructive earthquakes of the recent years.	Geohazards
28	Earthquake: Life on a Dynamic Planet	California academy of sciences, United States of America	Interactive exhibition with an earthquake simulator	Geohazards
29	Application of Modern Technologies in Popularization of the Czech Volcanic Geoheritage	Czech Republic	3D animation	Geohazards
30	Hiking tour "Hike to the seabed"	Karavanke UNESCO Global Geopark, Slovenia/Austria	Guided tour where the Geology over time is interpreted	Geology over time
31	Lavamünd Geopath	Karavanke UNESCO Global Geopark, Slovenia/Austria	Geopath with detailed explanations, where the history of the Earth from Devon to the Quaternary can be discovered	Geology over time
32	Children's book "Geological treasures of the Geopark Karavanke"	Karavanke UNESCO Global Geopark, Slovenia/Austria	Book, which include very interesting and easy to understandable geological time scale with illustrations	Geology over time
33	Family Geotime Trail	English Riviera UNESCO Global Geopark, Tourqay, United Kingdom	Very interesting and attractive geo trail where visitors can explore 4.600 million year long history of our planet	Geology over time
34	Geology park	St. Martin near Lofer, Austria	Walkable adventure trail	Geology over time
35	"Among rocks and flowers at Hleviše Hill"	Idrija UNESCO Global Geopark, Slovenia	Playground with detailed stratigraphic column and equipment arranged in the circle	Geology over time
36	"Journey through the time"	Slovenian Museum of Natural History (Ljubljana), Slovenia	Interactive publication for children aged 3 and up	Geology over time
37	A journey through time in Geopark Odsherred	Odsherred UNESCO Global Geopark, Denmark	3D technology - 3D graphics and augmented reality	Geology over time
38	Live timeline of Earth's history	Pannon Sea Museum, Geology and Natural History Exhibition of Herman Ottó Museum, Miskolc, Hungary	The 18 meters long timeline made live by the 5 round windows in which 4 characteristic paleogeographic environments can be rotated by the wheels next to the window	Geology over time
39	Centro de Interpretatcion de Geologica Nautilus	Basque Coast UNESCO Global Geopark, Mutriku, Spain	Special exhibition about fossils and the life in water over different time periods	Water in time

No.	Best practice	Location	Type of presentation	Topic of geointerpretation / Geological challenge
40	The OMIC Observatório Microbiano dos Azores	Azores UNESCO Global Geopark, Furnas, Portugal	The exhibition with various interactive stations, showing the changing microbiology in water within changing conditions and over various time periods	Water in time
41	Interpretation point Feistritzbach Stream	Karavanke UNESCO Global Geopark, Slovenia/Austria	Interpretation point explains the area's complex water network through animation, educates about water flora and fauna, and offers water-play facilities	Water in time
42	Spring Water Museum Wildalpen	Styrische Eisenwurzen UNESCO Global Geopark, Austria	The collection of the Museum comprises many original documents that enable visitors to understand the historical development of the drinking water system in Vienna	Water in time
43	Haus der Natur - Exhibition Salzach lifeline	Salzburg, Austria	Exhibition with the flight simulator	Water in time
44	Exhibition Gletscher. leben	Visitor Centre Kaiser-Franz-Josefs-Höhe, National Park Hohe Tauern, Austria	Interactive Station of the Pasterze glacier; Glacier.Life exhibition provides a deep insight into the glacier habitat, its origins and its influence on nature	Water in time
45	Exhibiton "Wasserleben"	Ökopark Hartberg, Styria, Austria	Partly outdoors exhibition with various interactive experiments	Water in time
46	A glance into the Hohe Tauern window	Neukirchen, Natioal Park Hohe Tauern, Austria	The thematic trail which shows how water is shaping landscapes	Water in time
47	Hexenwasser Hochsöll	Tyrol, Austria	The mountain adventure world with games of safe nature watching	Water in time
48	The Natural History Museum	London, United Kingdom	Different kind of panels with text and examples of rocks, describing and showing metamorphic processes and rocks; interactive installation where visitors can change metamorphic conditions with button	Metamorphic rocks and processes
49	Knocken Craig outdoor Visitor Centre	North West Highlands UNESCO Global Geopark, Scotland	Interpretation panels with examples from real life explaining process of metamorphism; interactive installation with micro and macro rock examples	Metamorphic rocks and processes
50	Assynt Visitor Center	United Kingdom	Rock boulders of metamorphic and other rocks with description and interactive panels	Metamorphic rocks and processes
51	Interpretation panels in Rokua Geopark	Rokua UNESCO Global Geopark, Finland	Interpretation panels in Rokua Geopark describing metamorphic rocks of the area	Metamorphic rocks and processes
52	Interpretation panels in Papuk Geopark	Papuk UNESCO Global Geopark, Croatia	Interpretation panels regarding to metamorphic rocks	Metamorphic rocks and processes
53	Itoigawa's GeoStation GeoPal	Itoigawa UNESCO Global Geopark, Japan	Geopark tourist information center	Geomorphology
54	Serra de Santa Bárbara Interpretation Centre	Terceira Natural Park, Azores UNESCO Global Geopark, Portugal	Interpretation center, explanation of geomorphological process of formation and evolution of the island and its relation to areas of high interest in terms of bio and geo-diversity	Geomorphology
55	Touchable glacier and Pasterze time wheel	Nationalparkzentrum Hohe Tauern, Mittersill, Austria	Information about the glaciers of the Hohe Tauern, about snow, corn snow and glacial ice, about the ice flowing and other peculiarities of the glaciers is given; the highlight is the real glacier, that is placed in the middle of the room	Geomorphology
56	Expo Postojna cave karst	Postojna, Slovenia	The biggest exposition of the karst and karst caves in the world	Geomorphology
57	Trail guide maps	Rokua UNESCO Global Geopark, Finland	The guides combine detailed explanations of the sites and a map that gives a good overall picture on the terrain and the location of sites of interest	Geomorphology

No.	Best practice	Location	Type of presentation	Topic of geointerpretation / Geological challenge
58	Rokua Geopark 3d Mobile app	Rokua UNESCO Global Geopark, Finland	In the mobile application visitors can explore landforms, attractions and tourism services with respect to their own positions in a three dimensional map view	Geomorphology
59	Levels of interpretation in the Geosite "Foz do Enxarrique"	Naturtejo UNESCO Global Geopark, Portugal	Interpretation panels, billboard, different thematic panels	Geomorphology
60	The Promenade Museum	Haute Provence UNESCO Global Geopark, France	Nature, contemporary art and geology which show the history of our planet during the last 300 million years.	Dialoque between Earth and human
61	The Natural History Museum of the Lesvos Petrified Forest	Lesvos UNESCO Global Geopark, Greece	Two permanent exhibitions presented through rare fossils and through impressive models and charts, geological phenomena and processes.	Dialoque between Earth and human
62	Visitor information center for the Messel fossil pit	Bergstraße-Odenwald UNESCO Global Geopark, Germany	Significant monolithic wall panels and the various exhibition rooms with effective architectural means such as confinement and expanse, light and dark effects, high and low ceilings.	Dialoque between Earth and human
63	Natural History Education Center Ulm	Swabian Albs UNESCO Global Geopark, Germany	The Natural history education center; scientific collections with over 60,000 objects	Dialoque between Earth and human
64	Exhibition Nature in human hands	Natural History Museum, Graz, Austria	Exhibition about the relationship Human - Nature	Dialoque between Earth and human
65	The Visitor Centre of the Troodos National Forest Park	Troodos UNESCO Global Geopark, Cyprus	Collection of rocks and minerals, a model of the geology of the area, depicting sites of geological importance and interest and informational panels	Dialoque between Earth and human
66	Mine of lead and zinc Mežica	Karavanke UNESCO Global Geopark, Slovenia/Austria	Numerous exhibited objects in the mine reveal the everyday work and lives of miners	Dialoque between Earth and human
67	Anthony's shaft – tourist mine in Idrija	Idrija UNESCO Global Geopark, Slovenia	Presentation of the hard daily work routine of miners, the precious cinnabar ore, drops of mercury and the unique and extraordinary underground chapel	Dialoque between Earth and human
68	Thematic tours and activities guided with local know-how and the travelling exhibition "When we went for ore"	Naturtejo UNESCO Global Geopark, Portugal	The travelling exhibition "When we went for Ore" is an open way to knowledge transfer between old miners and geologists that provide training to tour guides and educational monitors.	Dialoque between Earth and human
69	Footpath for everyone	Adamello Brenta UNESCO Global Geopark, Italy	Interpreted trail where visitors can learn how to read the landscape and the environment using their five senses	Dialoque between Earth and human
70	Intangible cultural heritage	Buzau Land Aspiring Geopark, Romania	Exhibitions, publications and a visitor centre	Dialoque between Earth and human

logical or any other (natural, cultural, technical, etc.) heritage to the audience in more efficient and quality way: Proper geo-presentation planning (Why are we doing this? Who is it for? What will we presented? How will we do it? How will it be managed? How will it be monitored and evaluated?); start of the geo-presentation with the basics; the combination of personal and non-personal presentation; personal contact; involvement of the audience; suitability and accessibility of the geo-presentation for different target groups; explanation of complex geological phenomena in simplified and interesting way, in easily understandable language, supported with illustrative materials, other interpretative tools or technologies; active training programmes for Geopark personnel and geotour guides; supportive infrastructure for comprehensive geo-presentation - visitors centres, interpretation points, learning path, etc.

Raising the multi-media and new technologies, such as QR codes and augemented reality simplifies the way of presentation of geological heritage to the public and helps scientists interpret difficult geological phenomena and processes. Geoparks need educated guides, and education for them has to be guaranteed. Geopark staff must be trained as geoguides and interpreters to assure high quality guiding and programmes, able to explain complex geological processes in easily understandable language. Good guide can encourage excitement and curiosity, link presentation to personal experiences from everyday life, disclosure of new insights and wider sense, using different and as effective communication tools as possible. New presentation approaches will increase local inhabitant´s engagement, Geopark management capacities and lower the quality gap between Danube and other European UNESCO Global Geoparks - this is beside the joint Danube GeoTour, designed to strengthen cooperations between the region´s Geoparks and creating innovative geo-tourism products to accelerate visibility and tourist visits in the Geoparks, one of the main Danube GeoTour project result.

Conclusions

The goal of the research was to improve the knowledge-base and exchange practices on quality geoheritage presentation in participating Geoparks with special focus on 8 selected geological challenges. The research provides a guideline in every day practice of Geoparks and other heritage sites within or outside Danube programme area. Participating partners identified contemporary presentation methods and technologies and also best practice examples of geo-presentation in their Geoparks and abroad. Through training and creative process, new ideas were born giving us sometimes completely different perspective to the presentation of the geological heritage.

In the frame of the research, we draw out lessons learnt, several recommendations and new trends that will be useful for project partners, as well as other Geoparks, natural protected areas and sites outside the project partnership designing presentation points or centres.

References

Antlej, K. 2014: 3D technologies in heritage interpretation: the Hungry Dragon fast food kiosk (K67). In: Lehnes, P. & Frost, S. (eds.): Interpret Europe: Conference proceedings 2014/2015. Interpert Europe: 14–24.

Bedjanič, M. & Rojs, L. 2014: Geo-interpretation: The interpretation of the geological heritage of Karavanke Geopark. In: Lehnes, P. & Frost, S. (eds.): Interpret Europe: Conference proceedings 2014/2015. Interpert Europe: 31–42.

Boile, M., El Raheb, K. & Toli, E. 2014: Valorisation of EU project results in the area of access to cultural content Grant D.1.2 – Stock-taking Analysis. Internet: http://www.ecultobservatory.eu/sites/ecultobservatory.eu/files/documents/eCultValue_D1.2_Stock-taking%20 Analysis_Final.pdf (02.07.2017).

Buhay, D. N. & Best, L. A. 2015: Informal Learning at Stonehammer and English Riviera Geoparks. Geoheritage, 7/2: 165–175, doi: https//doi.org/10.1007/s12371-014-0125-9.

Hartmann, G., Fajmut Štrucl, S., Bedjanič, M., Rojs, L. & Vodovnik, P. 2012: Osnutek načrta upravljanja Geoparka Karavanke-Karawanken. Mežica: Geopark Karavanke-Karawanken. Internet: https://www.geopark-karawanken.at/files/2012_01_06_upravljalski_nacrt_slo.pdf (02.07.2017).

Martínez-Graña, M., Goy, J. L. & Cimarra, C.A. 2013: A virtual tour of geological heritage: Valourising geodiversity using Google Earth and QR code. Computers & Geosciences, 61: 83-85, doi: https://doi.org/10.1016/j.cageo.2013.07.020.

Internet sources:

Internet 1: http://www.interpretacija.si/arhiv/geoloska_dediscina.pdf (02.07.2017)

Internet 2: http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/ (02.07.2017)

GEOLOGIJA *61/1*, 111-119, Ljubljana 2018

https://doi.org/10.5474/geologija.2018.008

Jaxea kuemeli Bachmayer, 1954 (Malacostraca, Gebiidea, Laomediidae) from the Middle Miocene of Tunjice Hills (central Slovenia)

Rak deseteronožec *Jaxea kuemeli* Bachmayer, 1954 (Malacostraca, Gebiidea, Laomediidae) iz srednjemiocenskih plasti Tunjiškega gričevja

Rok GAŠPARIČ[1,2] & Matúš HYŽNÝ[3,4]

[1]Oertijdmuseum De GroenePoort, Bosscheweg 80, 5293 WB Boxtel, the Netherlands; rok.gasparic@gmail.com
[2]Novi trg 59, SI-1241 Kamnik, Slovenija; rok.gasparic@gmail.com
[3]Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina G1, SK-842 15 Bratislava, Slovakia; hyzny.matus@gmail.com
[4]Geological-Paleontological Department, Natural History Museum Vienna, Burgring 7, A-1010 Vienna, Austria

Prejeto / Received 5. 6. 2018; Sprejeto / Accepted 8. 7. 2018; Objavljeno na spletu / Published online 20. 7. 2018

Key words: Decapoda, Miocene, Badenian, Central Paratethys, palaeoecology, Slovenia
Ključne besede: deseteronožci, miocen, badenij, Centralna Paratetida, paleoekologija, Slovenija

Abstract

In the present paper we report on several new specimens of *Jaxea kuemeli* Bachmayer, 1954 from the Middle Miocene laminated sandstones from Košiše in Tunjice Hills. New and well-preserved material from shallow water environment of Laško Formation allows the re-evaluation of *Jaxea* cheliped morphology. The report enhances our knowledge of the variability of tooth formula in the cheliped of *Jaxea kuemeli* and opens questions about interspecific variations connected to temporal or ecological factors. We also discuss the environmental preferences of the species which is so far known exclusively from the Paratethys Sea.

Izvleček

V pričujočem članku poročamo o novih primerkih deseteronožca vrste *Jaxea kuemeli* Bachmayer, 1954 iz srednjemiocenskih plasti nahajališča Košiše v Tunjiškem gričevju. Novi in dobro ohranjeni primerki, iz plitvovodnih plasti Laške formacije, omogočajo primerjavo morfologije škarnikov vrste *Jaxea kuemeli*. Opis novih primerkov razširja naše poznavanje razlik v zobni formuli škarnikov predstavljene vrste in odpira vprašanja o možni variabilnosti znotraj le-te, ki so lahko posledica časovnih ali okoljskih dejavnikov. V članku med drugim opredeljujemo tudi okoljske preference vrste, ki je do sedaj poznana le iz območja Paratetide.

Introduction

Miocene decapod crustaceans from Slovenia have been the subject of studies since the 19th century (Bittner, 1884; Glaessner, 1928). Recently, a renewed interest has brought a number of publications from this area describing various decapod assemblages (Mikuž, 2003, 2010; Mikuž & Pavšič, 2003; Hyžný & Gašparič, 2014; Gašparič & Halásová, 2015; Gašparič & Hyžný, 2015; Gašparič & Ossó, 2016; Gašparič & Križnar, 2017). In this respect, the decapod fauna of the Tunjice Hills is yet undescribed, despite the fact that over 300 specimens belonging to at least 10 species were collected in recent years by local collectors (Gašparič & Brajković, 2016). Among the taxa identified in the preliminary report by Gašparič and Brajković (2016), there is also *Jaxea kuemeli* Bachmayer, 1954, a known laomedi-id shrimp from the Miocene strata deposited in the ancient Paratethys Sea (Rögl, 1998; Popov et al., 2004; Harzhauser & Piller, 2007). The species was previously reported from the Lower Miocene deep-water sediments of Činžat on the northern slope of the Pohorje mountain range in north-east Slovenia (Gašparič & Hyžný, 2015), but remains largely understudied. Herein we aim for a more detailed report on *J. kuemeli* from the Tunjice Hills, where sediments deposited in a shallow-water environment are exposed.

Geological and stratigraphical settings

The area of the Tunjice Hills has been known for its wealth of fossil remains since the 19th century. In 1882 a well-known naturalists and local priest Simon Robič started collecting fossils and sent them to palaeontologists from the Natural History Museum in Vienna. Among these were also the first specimens of a brachyuran crab Cancer carniolicus Bittner, 1884, currently treated as Tasadia Müller in Janssen & Müller, 1984 (Schweitzer et al. 2010).

Here presented specimens of *Jaxea kuemeli* were recovered from the Middle Miocene (Badenian) sandstones and sandy limestone exposed in a road cut along the local road from Kamnik to Tunjice some 3 km northwest of the town of Kamnik near the village of Košiše (fig. 1).

The Tunjice Hills belong to the westernmost part of the Tunjice Syncline of the Sava Folds (Placer, 1999, 2008). In the south it borders with Triassic rocks of Trojane anticline and in the north to Teharje anticline and Menina mountain massif, both consisting of Triassic Dachstein limestone (Premru, 1983). The total thickness of the Miocene beds is estimated to approximately 1000 m (Žalohar & Zevnik, 2006).

The stratigraphic sequence of the Tunjice Hills starts with the Early Miocene (Burdigalian) Govce Formation. These strata consist of alternating conglomerates, sandstones, and fine-grained marls, as well as clays with lenses of sand and sandstones. Sediments of the Govce Fm. were deposited in a near-shore environment with variable terrestrial and marine influence (Vrabec, 2000) with the total thickness of 350 to 450 m (Premru, 1983). Marine fauna retrieved from marls also indicates near-coastal environment with common wood remains drilled by teredinid bivalves, carbonized pine cones, and rich mollusc fauna (Žalohar & Zevnik, 1998). Remains of decapod crustaceans are rare in the Govce Fm. and so far the only finds are a handful of specimens of *Retropluma slovenica* Gašparič & Hyžný, 2014 from sandy beds of this formation (Gašparič & Križnar, 2017).

Sediments of the Govce Fm. are discordantly overlapped by Middle Miocene (Langhian; Badenian) beds of the Laško Formation, which are exposed at Košiše locality discussed herein. The Laško Fm. consists of mudstones, sandstones, and limestone (Rijavec & Pleničar, 1979). Cyclic alterations of retrogradational sequences re-

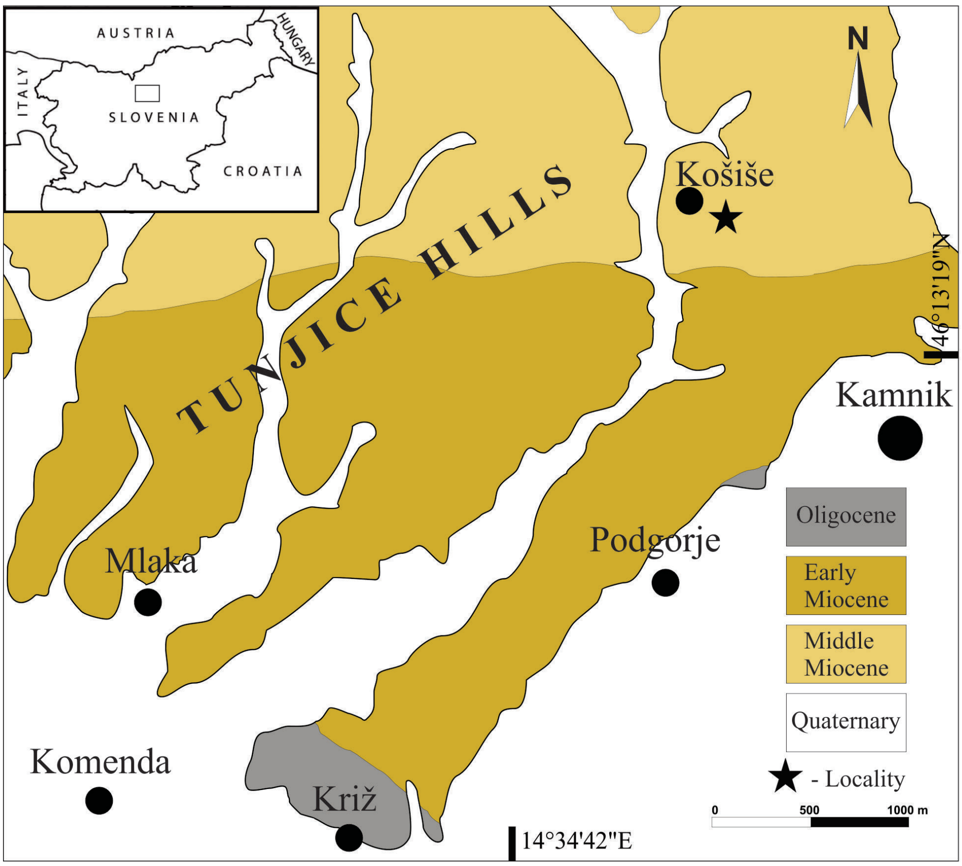


Fig. 1. Simplified geological map of Tunjice Hills, showing locality Košiše (modified after Gašparič & Križnar, 2017).

flect a rise in sea level or rapid subsidence of the terrain. Similarly to the underlying beds of the Govce Fm., sediments of the Laško Fm. were deposited in the shallow infralittoral environment (Vrabec et al., 2014). Sandstones and sandy limestone of the Laško Fm. are famous for their fossil molluscs (Mikuž & Pavšič, 2000) with commonly found and well-preserved bivalves belonging to genera *Glossus, Corbula, Anadara, Lucinoma, Thracia, Tellina, Cardium, Acanthocardia, Lutraria, Mytilus, Panopea,* and *Ostrea*, as well as gastropod genera *Xenophora, Trochus, Conus, Ancilla, Turritella, Lunatia,* and *Hinia* (Žalohar & Zevnik, 2006). Besides the mollusc fauna, rare whale remains represented by isolated vertebrae were also described (Gašparič & Križnar, 2014). Beds of the Laško Fm. also exhibit greater decapod diversity, with *Tasadia carniolica* as the dominant species (Mikuž & Pavšič, 2003), associated with frequent specimens of *Jaxea kuemeli* Bachmayer, 1954 (documented in detail further below) and rarer burrowing ghost shrimp *Calliax michelottii* (A. Milne Edwards, 1860) (Hyžný & Gašparič, 2014). In the upper part of the Laško Fm. increasing terrestrial influence is documented at the transition into the Serravallian (Sarmatian) Dol Formation (Vrabec et al., 2014). The fossil fauna of this formation indicates a fully marine environment (Horvat, 2003). Uppermost parts of the Dol Fm. suggest renewed shallowing of the environment, fresh-water influx, and periodic tectonic isolations of the Tunjice Basin (Žalohar & Hitij, 2014).

Material and methods

In total 30 specimens of *Jaxea kuemeli* from Košiše locality have been examined. Specimens were prepared using manual or pneumatic needle and studied under stereomicroscope Leica EZ4D. All specimens were measured, photographed using digital cameras Nikon Coolpix P340 and A900, and documented using computer graphic programmes (CoreDRAW X5, Adobe Photoshop CC). The material is deposited as a part of the "R. Gašparič Collection" in the Slovenian Museum of Natural History, Ljubljana, Slovenia (RGA/SMNH).

Systematics

The higher classification used herein follows De Grave et al. (2009).

Infraorder Gebiidea de Saint Laurent, 1979

Family Laomediidae Borradaile, 1903

Genus *Jaxea* Nardo, 1847

Type species. *Jaxea nocturna* Nardo, 1847, by original designation.

Diagnosis: Small firm exoskeleton, linea thalassinica straight anteroposteriorly, distinct and well developed (fig. 2). Abdominal segments approximately of same length, abdominal pleura 2-6 with minute serrations. Telson longer than wide, longitudinal dorsal ridges present, posterior border convex, median spine absent. Chelae equal and greatly developed, pereiopods P2-5 slender, simple. (After Ngoc- Ho, 2003; characters with low fossilization potential were omitted.)

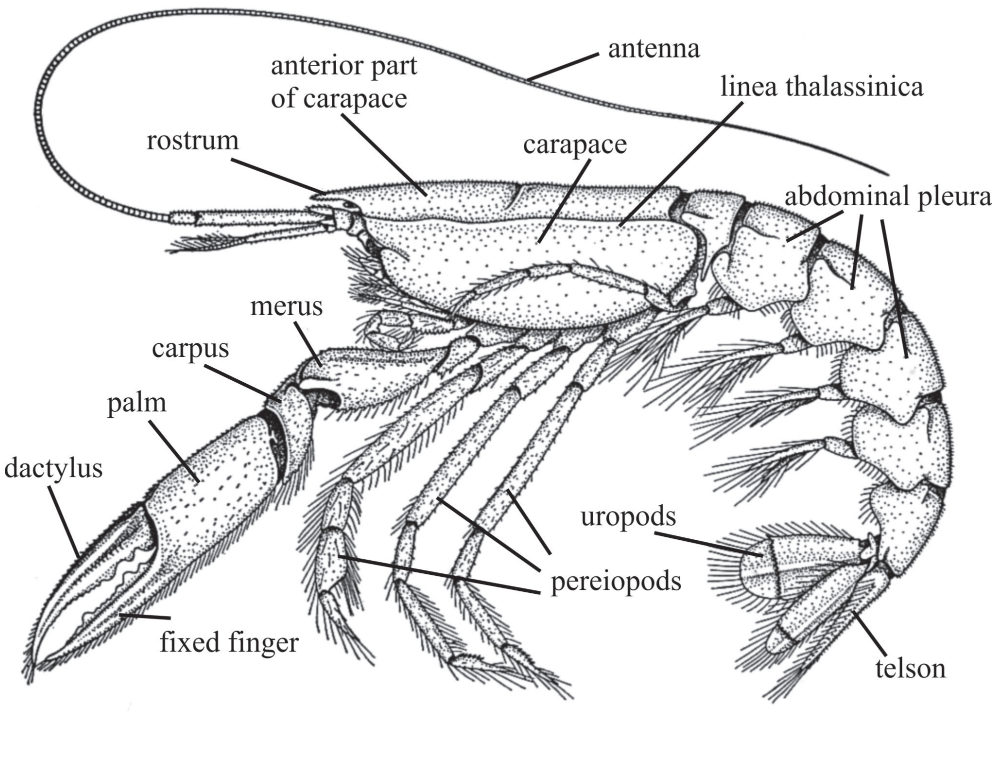


Fig. 2. Descriptive terminology used in the text showing basic morphology of *Jaxea novazealandiae* Wear & Yaldwyn, 1966 (modified after Wear & Yaldwyn, 1966).

Remarks: The genus *Jaxea* is represented by two extant species (known from adults), *Jaxea nocturna* Nardo, 1847 and *Jaxea novaezealandiae* Wear & Yaldwyn, 1966. *Jaxea nocturna* is represented also in the fossil record of the Mediterranean; well preserved remains have been reported from the Lower Pliocene of Italy (Delle Cave, 1988) and Spain (Mayoral et al., 1998; Garassino et al., 2009). *Jaxea kuemeli* Bachmayer, 1954 is known exclusively from the Miocene of Central Paratethys (Hyžný, 2011; Hyžný & Zorn, 2016).

Jaxea kuemeli Bachmayer, 1954

(Plate 1. A–G)

1954 *Jaxea kümeli* Bachmayer; p. 64, Pl. 1, Figs. 1–2.

1984a *Jaxea kuemeli* Bachmayer; Müller; p. 49.

1993 *Jaxea kuemeli* Bachmayer; Müller; p. 5.

1998 *Jaxea küumeli* Bachmayer; Mayoral et al.; p. 508.

1998 *Jaxea kuemeli* Bachmayer; Müller; p. 9.

2011 *Jaxea kuemeli* Bachmayer; Hyžný; p. 176, Figs 2–6.

2015 *Jaxea kuemeli* Bachmayer; Gašparič & Hyžný; p. 147, Figs. 8–9.

2016 *Jaxea kuemeli* Bachmayer; Hyžný & Zorn; p. 139, Pl. 17, Figs. 3–5.

Diagnosis: Cylindrical carapace with triangular rostrum with denticulate lateral margins; *linea thalassinica* and cervical groove well defined, not crossing each other. Telson slightly longer than wide with median longitudinal groove and two pairs of longitudinal ridges. First pereiopods chelate, equal or subequal, well developed, approximately as long as the cephalothorax; ischium and merus with spinules on entire lower margin; carpus with small lower distal spine; propodus granulate. Pollex with three or four larger round teeth positioned proximally followed with several smaller teeth, or with several round same sized teeth; large median triangular tooth positioned more proximally, usually composed from several smaller teeth; distal half of the cutting edge with numerous small round teeth. Dactylus with two or three larger round teeth positioned proximally followed with a broad notch and large median tooth. Second to fifth pereiopods simple. (After Hyžný, 2011.)

Material: In total 30 specimens of *Jaxea kuemeli* were collected and studied. The majority of the sample (25 specimens) represent cheliped remains (RGA/SMNH 0683, 0684, 0685, 0686, 0743, 0744, 0758, 0759, 0765, 0774, 0783, 0794, 0796, 0797, 1070, 1082, 1085, 1086, 1099, 1161, 1182, 1185, 1189, 1193, 1426). Additionally, there are some specimens with cheliped associated with fragmentary remains of dorsal carapace, abdominal pleura and telson (RGA/SMNH 0704), partial dorsal carapaces (RGA/SMNH 0676, 0682, 0760) and cheliped with pereipods (RGA/SMNH 1161).

Locality: The specimens studied herein were recovered from grey to yellowish Middle Miocene (Langhian/Badenian) laminated sandstones of the Laško Formation exposed at the Košiše locality (Sava folds Basin, Slovenia). Laško Formation beds of this locality consist of grey siltstones with concretions, interbedded with laminated grey to yellowish sandstones, overlain by poorly sorted bioturbated yellowish sandstones and sandstones with *Lithothamnium* fragments.

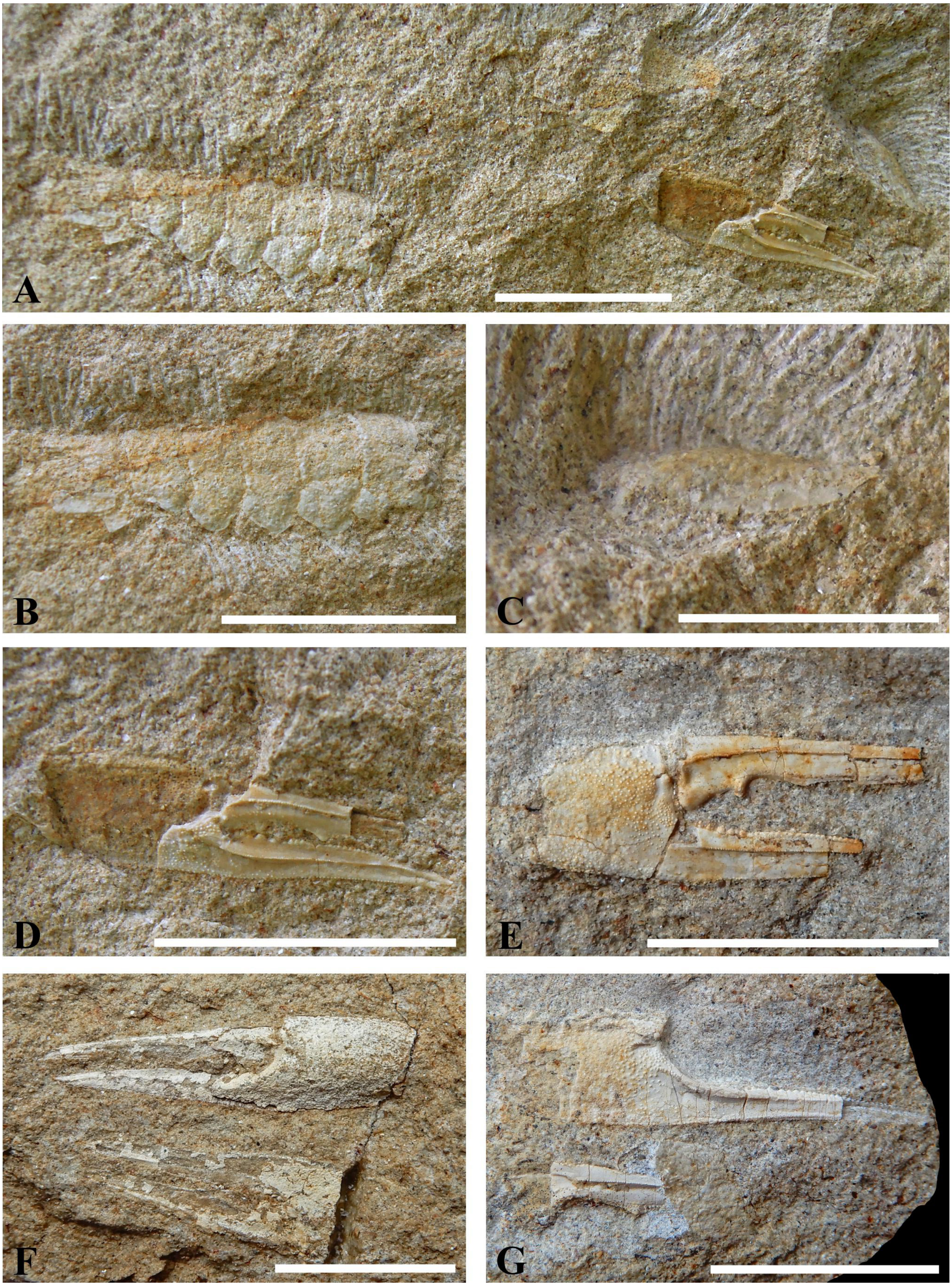
Laminated sandstones are more likely to contain macrofaunal fossil remains, including decapods, than other variations in lithology. Remains of *Jaxea kuemeli* were collected exclusively from bedding planes of grey to yellowish laminated sandstones.

Description: Dorsal carapace cylindrical, smooth and weekly calcified, with short, triangular rostrum (Pl. 1A, C). Abdomen well developed, abdominal pleurae 2-6 approximately of same

PLATE 1

Jaxea kuemeli Bachmayer, 1954. A–D RGA/SMNH 0704;
A - cheliped with scattered remains of dorsal carapace and abdomen;
B – close-up of abdomen with abdominal pleurae and fragmented telson;
C – close-up of anterior part of dorsal carapace with rostrum;
D - close-up of cheliped;
E - RGA/SMNH 0743, isolated cheliped, exhibiting strong tooth on dactylus;
F –RGA/SMNH 1193, chelipeds of fragmented specimen;
G –RGA/SMNH 1099, propodus, with occlusal margin of fixed finger.
All scale bars are 10 mm, except 1C scale bar is 5 mm.

PLATE 1



length, rounded, margins covered with minute spines, posterolateral margins concave. Telson longer than wide, posterior margin convex, dorsal surface with median longitudinal groove and two pairs of longitudinal ridges. Uropods equal in length to telson, with rounded posterior margin. Abdomen and telson weakly ornamented with small granules (Pl. 1B).

First pereiopods chelate, marginally subequal, one chela more slender, other robust. Both chelae well developed and strongly calcified, equal in length to carapace and strongly granulated. Manus rectangular, slightly longer than high. Dactylus slightly longer than fixed finger. Occlusal margin of both fingers adorned with row of teeth. Fixed finger with three to five larger, rounded teeth positioned proximally in concave part of occlusal margin. These are followed by row several smaller teeth, gradually diminishing in size in distal half, here occlusal margin slightly convex (Pl. 1G). Dactylus with two round teeth positioned proximally, first a small round tooth, followed by distinct strong tooth, knob like and proximally curved. Continuing distally follows a broad, unadorned notch and a large triangular median tooth (Pl. 1E). Distal half of dactylus occlusal margin slightly concave and adorned with equally small rounded teeth as on fixed finger. Termination of both fingers curved together and pincers-like. Two longitudinal ridges on dactylus, one throughout the finger, second less distinct and only present in proximal half. Fixed finger with one longitudinal ridge through the whole finger length. Ridges as well as outside margins of fingers evenly ornamented with small, spine like teeth (Pl. 1D). Pereiopods P2-5 simple, flattened and slender.

Remarks: Although Müller (1984b, 1993, 1998) and Mayoral et al. (1998) considered *J. kuemeli* to be possibly conspecific with extant species *Jaxea nocturna* Nardo, 1847, Hyžný (2011) argued for distinction between both taxa. Hyžný re-examined the type material of Bachmayer (1954) and additional specimens from Lower to Middle Miocene of Austria, Slovakia, and Hungary, and concluded that morphology of chelipeds expressed in unique tooth formula warrants keeping both species as separate. A major distinctive character is the position of the large median tooth on the occlusal margin of the fixed finger. In *J. kuemeli* this is located proximally relative to the position of the median tooth on the dactylus and less distinct, while it is positioned distally in *J. nocturna* and pronounced (Hyžný, 2011, p. 180, fig. 3).

Based on the cheliped morphology, the material from Košiše can be assigned to *Jaxea kuemeli*. The material confirms slight heterochely in the species as already documented (but not explored in detail) by Hyžný (2011). Additional intraspecific variation in the nature of the tooth formula is presented as well. Some specimens from Košiše do not show observable median tooth on the fixed finger or exhibits a different position of large proximal teeth on dactylus and constant rows of small rounded teeth in a distal half of fingers. These variations may be connected with temporal or ecological factors; more research, however, is needed to address these issues properly.

Taphonomy: Specimens of *Jaxea kuemeli* collected at the locality Košiše exhibit varying degrees of preservation. Only strongly mineralized chelipeds are commonly found due to the fragile cuticle of the dorsal carapace, abdomen, and pereiopods. Chelipeds are frequently found in pairs (Pl. 1F) and, where carapace or abdomen remains are recognized, these are always associated with chelipeds (Pl. 1A). Despite the fact that *Jaxea* representatives are active burrowers (Dworschak, 2004), described fossil remains are exclusively found on bedding plane and not in bioturbations present in the sediment. This type of preservation suggests limited post-mortem transport and rapid burial of remains, which likely represent moults rather than corpses (Glaessner, 1969).

Palaeoecology and environment

Modern representatives of *Jaxea* are reported exclusively from muddy substrates or sandy mud (Wear & Yaldwyn, 1966; Ngoc-Ho, 2003). Similarly, fossil occurrences come from fine-grained siliciclastic sediments (Hyžný, 2011; Garassino et al., 2009; Gašparič & Hyžný, 2015). *Jaxea* is considered an infaunal burrower in near-shore, shallow facies, which is supported by the palaeoenvironment of the Košiše locality. Interestingly, another report of *Jaxea kuemeli* from Slovenia (Gašparič & Hyžný, 2015) comes from deep-water sediments of the Lower Miocene (Karpatian) of north-east Slovenia. It appears *Jaxea kuemeli* is reported either from shallow water association with *Tasadia carniolica* (Bittner, 1884) (Hyžný & Zorn, 2016), as is also the case in specimens described herein, or found in association with a brachyuran *Styrioplax exiguus* Glaessner, 1928 (Hyžný, 2011; Gašparič & Hyžný, 2015) that is reported from deeper water settings. As for bathymetric preferences of modern *Jaxea*, it has been reported mainly from shallow-marine settings up to 100 m depth (Wear & Yaldwyn, 1966; Ngoc-Ho, 2003), although some occurrences are known from depth exceeding 400 m (Diez et al., 1994).

Conclusions

A number of specimens of a laomediid shrimp *Jaxea kuemeli* are reported from the Middle Miocene beds of the Laško Formation exposed in the Tunjice Hills, central Slovenia. The species was a dominant decapod taxon of the studied infaunal community, in co-occurrence with a crab *Tasadia carniolica*. Intraspecific variation in the nature of chelipeds has been observed in the studied material of *J. kuemeli*. The intraspecific variation of cheliped in the fossil *Jaxea* has not been evaluated yet; with the increasing number of specimens of this species from various localities, such study is now feasible. *Jaxea kuemeli* has been identified in decapod associations of both shallow as well as deep water environments, which is in accordance with the ecological preferences of modern representatives of *Jaxea*.

Acknowledgements

We thank Andreja Žibrat Gašparič (Faculty of Arts, University of Ljubljana) for linguistic support and proofreading of the manuscript. Research of MH has been supported by Slovak Research and Development Agency under contract no. APVV-16-0121, and by Hungarian Scientific Research Fund (OTKA K112708).

References

Bachmayer, F. 1954: Zwei bemerkenswerte Crustaceen-Funde aus dem Jungtertiär des Wiener Beckens. Sitzungsberichte der Österreichischen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse, Abteilung I, 163: 63–70.

Bittner, A. 1884: Beiträge zur Kenntniss Tertiärer Brachyuren Faunen. Denkschriften der Akademie der Wissenschaften, Mathematik und Naturwissenschaften. Cl., 48/2: 3–18 (15-30).

Borradaile, L. A. 1903: On the classification of the Thalassinidea. The Annals and Magazine of Natural History Sei 7/12: 534–551.

De Grave, S., Pentcheff, N. D., Ahyong, S. T., Chan, T. Y., Crandall, K. A., Dworschak, P. C., Felder, D. L., Feldmann, R. M., Fransen, C. H. J. M., Goulding, L. Y. D., Lemaitre, R., Low, M. E. Y., Martin, J. W., Ng, P. K. L., Schweitzer, C. E., Tan, S. H., Tshudy, D. & Wetzer, R. 2009: A classification of living and fossil genera of decapod crustaceans. The Raffles Bulletin of Zoology, Supplement, 21, 1–109.

Delle Cave, L. 1988: *Jaxea cf. nocturna* (Crustacea, Decapoda, Anomura) from the Early Pliocene of Tuscany, Italy. Bollettino della Società Paleontologica Italiana, 27/1: 3–10.

Diez, L. E., Garcia-Arberal, S. & Rallo A. 1994: Fauna bentica de los fondos de la fosa del Capbreton (Golfo de Vizcaya, Atlántico Oriental): Crustáceos Decápodos. Cuadermos de Investigacioón Biologica (Bilbao), 18: 45–54.

Dworcshak, P. C. 2004: Biology of Mediterranean and Caribbean Thalassinidea. Proceedings of the Symposium on Ecology of Large Bioturbators in Tidal Flats and Shallow Sublittoral Sediments - From Individual Behaviour to Their Role as Ecosystem Engineers, Nagasaki University, 15–22.

Garassino, A., Artal, P. & Pasini, G. 2009: *Jaxea nocturna* Nardo, 1847 (Crustacea, Thalassinidea, Laomediidae) from the Pliocene of Catalonia (Spain). Atti della Società italiana di Scienze naturali e del Museo civico di Storia naturale in Milano, 150: 69–76.

Gašparič, R. & Brajković, R. 2016: New decapod crustacean community from Neogene strata of Tunjice Hills (Central Slovenia). 6th Symposium on Mesozoic and Cenozoic Decapod Crustaceans, Villers-sur-Mer, France, Book of Abstracts, 30–34.

Gašparič, R. & Halásová, E. 2015: New reports of crab *Styrioplax exiguus* Glaessner, 1928 (Decapoda, Brachyura) from Miocene beds near Maribor, Slovenia, Geologija, 58/2: 201–212, doi: https://doi.org/10.5474/geologija.2015.016.

Gašparič, R. & Hyžný, M. 2015: An early Miocene deep-water Decapod Crustacean Faunule from the slovenian part of the Styrian Basin and its palaeoenvironmental and palaeobiogeographical significance. Papers in Palaeontology, 1/2: 141–166.

Gašparič, R. & Križnar, M. 2014: Nova najdba vretenca miocenskega morskega sesalca iz Tunjiškega gričevja. Kamniški zbornik, 22: 305–310.

Gašparič, R. & Križnar, M. 2017: Early Miocene decapod *Retropluma slovenica* Gašparič & Hyžný, 2014 from Govce beds of Tunjice Hills (Central Slovenia). Geologija, 60/1: 77–85, doi: https://doi.org/10.5474/geologija.2017.006.

Gašparič, R. & Ossó, A. 2016: New reports of decapod *Portunus monspeliensis* A. Milne Edwards, 1860 from Miocene beds of eastern Slovenia with notes on palaeoecology and palaeobiogeography. Geologija, 59/1: 55–66, doi: https://doi.org/10.5474/geologija.2016.005.

Glaessner, M. F. 1928: Die Dekapodenfauna des österreichischen Jungtertiärs. Jahrbuch der Geologischen Bundesanstalt, 78: 161–219.

Glaessner, M. F. 1969: Decapoda. In: Moore, R. C. (ed.): Treatise on invertebrate paleontology, Part R, Arthropoda 4/2. Geological Society of America and University of Kansas Press, 533 pp.

Harzhauser, M. & Piller, W. E. 2007: Benchmark data of a changing sea. – Palaeogeography, palaeobiogeography and events in the Central Paratethys during the Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology, 253/1-2: 8–31, doi: https://doi.org/10.1016/j.palaeo.2007.03.031

Horvat, A. 2003: Upper Badenian diatom paleoecology of the western part of Central Paratethys. Geologija, 46/2: 251–262, doi: https://doi.org/10.5474/geologija.2003.022.

Hyžný, M. 2011: Revision of *Jaxea kuemeli* Bachmayer, 1954 (Decapoda: Gebiidea: Laomediidae) from the Miocene of Europe, with remarks on the palaeobiogeography of the genus Jaxea Nardo, 1847. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 260: 173–184.

Hyžný, M. & Gašparič, R. 2014: Ghost shrimp *Calliax* de Saint Laurent, 1973 (Decapoda: Axiidea: Callianassidae) in the fossil record: systematics, palaeoecology and palaeobiogeography. Zootaxa, 3821: 37–57.

Hyžný, M. & Zorn, I. 2016: A Catalogue of the Type and figured Fossil Decapod Crustaceans in the Collections of the Geological Survey of Austria in Vienna. Jahrbuch der Geologischen Bundesanstalt, 156: 127–177.

Mayoral, E., Müller, P. & Muniz, F. 1998: Lower Pliocene Decapod crustaceans from the Southwestern Iberian Peninsula (Guadalquivir Basin, Sevilla, Spain). Geobios, 31/4: 505–510.

Mikuž, V. 2003: Miocenske rakovice iz okolice Šentilja v Slovenskih Goricah. (The Miocene crabs from vicinity Šentilj in Slovenske Gorice, Slovenia). Razprave IV. razreda SAZU, 44: 187–199.

Mikuž, V. 2010: Rakovice iz srednjemiocenskih plasti kamnolomov nad Trbovljami. Folia biologica et geologica, 51/1: 13–20.

Mikuž, V. & Pavšič, J. 2000: *Brotia (Tinnyea) escheri* (Brongniart) iz miocenskih plasti pri Tunjicah. Geologija, 43/1: 43–53, doi: https://doi.org/10.5474/geologija.2000.003.

Mikuž, V. & Pavšič, J. 2003: “Kranjska rakovica” iz srednjemiocenskih – badenijskih skladov kamnoloma Lipovica nad Brišami. Geologija, 46/2: 245–250, doi: https://doi.org/10.5474/geologija.2003.021.

Milne Edwards, A. 1860: Histoire des Crustacés podophthalmaires fossiles et Monographie des Décapodes Macroures de la famille des Thalassinens. Annales des Sciences Naturelles, 4e série, 14: 129–357.

Müller, P. 1984a: Description of the decapod fauna. In: Janssen, A. W. & Müller, P. (ed.): Miocene Decapoda and Mollusca from Ramsel (province of Antwerpen, Belgium), with a new crab genus and a new cephalopod species. Scripta Geologica, 75: 1–26.

Müller, P. 1984b: Decapod Crustacea of the Badenian. Geologica Hungarica, Series Palaeontologica, 42: 3–317.

Müller, P. 1993: Neogene decapod crustaceans from Catalonia. Scripta Musei Geologici Seminarii Barcinonensis, 225: 1–39.

Müller, P. 1998: Crustacea Decapoda. In: Flügel, H. W. (ed.): Catalogus Fossilium Austriae, 1–48.

Nardo, G. D. 1847: Sinonimia moderna delle specie registrate nell’opera intitolata: Descrizione de’Crostacei, de’Pesci che abitano Ie lagune e gulfo Veneto rappresentari in fugure, a chiaro-scuro ed a colori dell’ Abate Stefano Chiereghini, Ven. XI, Venezia: 127 pp.

Ngoc-Ho, N. 2003: European and Mediterranean Thalassinidea (Crustacea, Decapoda). Zoosystema, 25: 439–555.

Placer, L. 1999: Strukturni pomen Posavskih gub = Structural meaning of the Sava folds. Geologija, 41: 191–221, doi: https://doi.org/10.5474/geologija.1998.013.

Placer, L. 2008: Principles of the tectonic subdivision of Slovenia. Geologija, 51/2: 205–217, doi: https://doi.org/10.5474/10.5474/geologija.2008.021.

Popov, S. V., Rögl, F., Rozanov, A. Y., Steininger, F. F., Shcherba, I. G. & Kovác, M. 2004: Lithological paleogeographic maps of Paratethys. 10 Maps Late Eocene to Pliocene. Courier Forschungsinstitut Senckenberg, 250: 1–46.

Premru, U. 1983: Osnovna geološka karta SFRJ, 1:100000 – Tolmač lista Ljubljana = Basic geological map of Yugoslavia, 1:10.0000, Guidebook of sheet Ljubljana. Zvezni geološki zavod, Beograd.

Rijavec, L. & Pleničar, M. 1979: Neogene Beds in Slovenia. 16th European Micropaleontological Colloquium, 71–78.

Rögl, F. 1998: Paratethys Oligocene-Miocene stratigraphic correlation. In: Cicha, I., Rögl, F., Rupp, C. & Ctyroka, J. (eds.): Oligocene – Miocene foraminifera of the Central Paratethys. Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft, 549: 3–7.

Saint Laurent, M. De. 1979: Sur la classification et la phylogénie des Thalassinides: définitions de la superfamille des Axioidea, de la sous-famille des Thomassiniinae et de deux genres nouveaux (Crustacea Decapoda). Comptes Rendus hebdomadaires de Séances de l'Académie des Sciences, 288: 1395–1397.

Schweitzer, C. E., Feldmann, R. M., Garassino, A., Karasawa, H. & Schweigert, G. 2010: Systematic list of fossil decapod crustacean species. Crustaceana Monographs, 10: 1–222.

Vrabec, M. 2000: Govški peščenjak v profilu Doblič. Diplomsko delo. Ljubljana: 142 p.

Vrabec, M., Brajković, R. & Skaberne, D. 2014: Sedimentološke značilnosti terciarnih kamnin Tunjiškega gričevja. 4. slovenski geološki kongres, Ankaran.

Wear, R. G. & Yaldwyn, J. C. 1966: Studies on thalassinid Crustacea (Decapoda, Macrura Reptantia) with a description of a new Jaxea from New Zealand and an account of its larval development. Zoology Publications from Victoria University of Wellington, 41: 1–27.

Žalohar, J. & Hitij, T. 2014: Fossil seahorses and other biota from the Tunjice Konservat-Lagerstätte, Slovenia. University of Machester: 176 p.

Žalohar, J. & Zevnik, J. 1998: Terciarne plasti v okolici Kamnika. Kamniški zbornik, 14: 96–101.

Žalohar, J. & Zevnik, J. 2006: Miocenske plasti v Tunjiškem gričevju. Kamniški zbornik, 18: 289–301.

Poročila

Letno poročilo Slovenskega geološkega društva za leto 2017 in načrti za leto 2018

Matevž NOVAK

Geološki zavod Slovenije, Dimičeva ul. 14, SI–1000 Ljubljana; e-mail: matevz.novak@geo-zs.si

Slovensko geološko društvo (SGD) s sedežem na Dimičeva ul. 14 v Ljubljani je strokovno združenje slovenskih geologov. Društvo je bilo ustanovljeno leta 1951 in povezuje raziskovalce, učitelje, druge poklicne geologe in ljubitelje stroke. Cilj SGD s statusom društva, ki deluje v javnem interesu, je napredek znanosti in prakse na področju vseh vej geologije.

Društvo prireja javna predavanja, strokovne ekskurzije, razstave, znanstvene sestanke in delavnice, skrbi za popularizacijo geologije in za vključevanje geoloških ved v osnovnošolske in srednješolske učne programe, sodeluje pri prizadevanjih za varstvo okolja in pri izdelavi zakonskih aktov in normativov s področja geologije.

Skozi vsa leta društvo deluje v skladu z določili statuta in s programom dela, ki je sprejet na sejah IO društva v vsakem koledarskem letu. V letu 2017 je bila seja razširjenega Izvršnega odbora društva 14. junija. Večina postavk zastavljenega programa je bila realizirana. Najave in poročila o društvenih aktivnostih redno objavljamo na spletni strani www.geoloskodrustvo.si.

Strokovna predavanja

Bálazs Székely (Univerza Eötvös Loránd v Budimpešti), »*Attempts to integrate David with Goliath: lessons learnt on differential uplift in a flatland*«, 14. marec 2017 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Giovanni Monegato (Inštitut za geoznanosti in zemeljske vire italijanskega Nacionalnega raziskovalnega sveta), »**An** *updated overview of last glacial maximum on the southern side of the Alps: comparisons and climate considerations*«, 23. marec 2017 ob 18. uri v Ljubljani na Geološkem zavodu Slovenije, Dimičeva ul. 14. Predavanje je bilo izvedeno v soorganizaciji s Slovenskim nacionalnim odborom INQUA (SINQUA).

Vanja Kastelic (Italijanski nacionalni inštitut za geofiziko in vulkanologijo – INGV), »*Seizmotektonika, seizmičnost in potresna ogroženost centralnih Apeninov – kaj smo se naučili iz zadnjih močnih potresov in kaj ostajajo nadaljnji izzivi*«, 25. oktober 2017 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Bojan Djurić (Oddelek za arheologijo FF v Ljubljani), »*Rimska oskrba mest s kamnom – primer* Colonia Iulia Emona *(Ljubljana)*«, 15. november 2017 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Mihael Brenčič (Oddelek za geologijo NTF, GeoZS), »*Vasilij Nikitin, petrolog in mineralog – ob 150. obletnici rojstva*«, 7. december 2017 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Strokovne ekskurzije

Strokovna ekskurzija v soorganizaciji SGD in Društva SKIAH je bila izvedena 13. in 14. oktobra 2017. Teme ekskurzije so bile **mineralne vode, vulkaniti in geotermalna energija v SV Sloveniji in Z Madžarski**. Ogledali smo si globoke geotermalne vrtine in mofete v Slovenskih goricah, Doživljajski park Vulkanija na Goričkem, geotermalne vrtine v Moravskih Toplicah, sistem za pridobivanje zemeljskega plina v Lendavi-Petišovcih, termalno jezero Heviz in Pokrajinski muzej Balaton. Pri izvedbi so sodelovali tudi madžarski kolegi iz MFGI in zdravilišča Heviz. Ekskurzije se je udeležilo 30 članov obeh društev in 4 člani Hrvaškega geološkega društva.

Strokovna posvetovanja, seminarji in okrogle mize

SGD je bilo soorganizator **23. posvetovanja slovenskih geologov**, 31. marca 2017 v Ljubljani na Oddelku za geologijo NTF. Na posvetovanju je Društvo sodelovalo s predstavitvami mednarodnih projektov, v katere je vključeno.

SGD je skupaj s Kariernimi centri UL in Društvom študentov geologije organiziralo **Karierni dan za študente geologije**, 19. aprila 2017 med 13. in 15. uro na Oddelku za geologijo NTF. V okviru dogodka sta bila organizirana okrogla miza o možnostih zaposlovanja in mreženje s potencialnimi delodajalci.

SGD je bilo soorganizator **4. svetovnega foruma o zemeljskih plazovih** z naslovom »*Landslide Research and Risk Reduction for Advancing Culture of Living with Natural Hazards*«, med 29. majem in 2. junijem 2017 v Ljubljani. Odmevnega mednarodnega dogodka se je udeležilo več kot 600 udeležencev iz 51 držav.

SGD je sodelovalo kot sponzor pri organizaciji **3. regionalnega simpozija o zemeljskih plazovih v Jadransko Balkansko regiji (ReSyLAB)**, od 11. do 13. oktobra 2017 v Ljubljani v soorganizaciji Geološkega zavoda Slovenije, Fakultete za gradbeništvo in geodezijo ter Naravoslovnotehniške fakultete Univerze v Ljubljani.

SGD je skupaj z Društvom študentov geologije organiziralo delavnico z naslovom »Fosili skozi oči umetnika«. Delavnica o tehnikah paleontološke ilustracije je potekala 19. decembra 2017 v Ljubljani na Oddelku za geologijo NTF. Udeležilo se je je 13 študentov.

Delovna akcija čiščenja geološkega profila

V soboto, 25. marca 2017 smo v Naravnem spomeniku Dovžanova soteska izvedli tradicionalno delovno akcijo čiščenja zarasti na geoloških naravnih vrednotah v sodelovanju z Zavodom RS za varstvo narave (ZRSVN) in Občino Tržič. Akcije se je udeležilo 26 študentov, zaposlenih na ZRSVN, članov SGD in domačinov.

GeoTEK in GeoLOV

Slovensko geološko društvo je 5. oktobra 2017 organiziralo drugi tradicionalni **GeoTEK**, tokrat s Podpeškega jezera na Krim. Udeležilo se ga je 27 članov in simpatizerjev.

Poleg GeoTeka smo v letu 2017 uvedli še ekipno družabno akcijo, povezano z geološko vsebino – **GeoLOV (**»geocaching**«). Prvi** GeoLOV je bil v soboto, 8. aprila 2017 v okolici Lesnega Brda. Udeležilo se ga je 30 mladih geologov, razporejenih v 7 tekmovalnih skupin.

Sodelovanje na domačih dogodkih in druge aktivnosti

14. marca 2017 smo sodelovali na informativnem tehničnem dnevu Gimnazije Brežice, na katerem smo v delavnici predstavili uporabnost geoloških raziskav in poklic geologa.

18. marca 2017 smo sodelovali na **7. Kocenovi soboti** na Ponikvi s predstavitvijo njihovega pomembnega rojaka, pokojnega geologa, prof. dr. Stanka Buserja.

Z delavnico *Fizikalno in kemijsko preperevanje kamnin* smo sodelovali na tradicionalnih **Mednarodnih dnevih mineralov, fosilov in okolja MINFOS** v Tržiču, 13. in 14. maja 2017 v Dvorani tržiških olimpijcev.

Z delavnico *Vse o vulkanih* so člani SGD z GeoZS in Oddelkom za geologijo NTF sodelovali na prireditvi **Vrt eksperimentov**. Dogodek je organizirala Hiša eksperimentov v okviru 9. Znanstivala, 3. in 4. junija 2017 od 10. do 18. ure na Stritarjevi ulici v Ljubljani.

SGD je tudi v letu 2017, 9. junija, sodelovalo na dogodku »**BioBlitz – 24 ur z reko Muro**« v Veržeju v organizaciji Zavoda RS za varstvo narave, Območne enote Maribor. Izvedeni sta bili *Geološka delavnica o kamninah, mineralih in fosilih* ter hidrogeološka delavnica *Lastnosti podzemne in pitne vode*. Udeležilo se jih je skupaj skoraj 90 učencev. Društvo se je skupaj z Geološkim zavodom Slovenije in Oddelkom za geologijo NTF predstavilo tudi na stojnici.

26. avgusta 2017 je Društvo Fran Govekar Ig v sodelovanju z Inštitutom za arheologijo ZRC SAZU na Igu ponovno organiziralo **Koliščarski dan**. Z geološko delavnico *Vse o geoloških značilnostih Ljubljanskega barja in* **še čem** je SGD sodelovalo skupaj z Oddelkom za geologijo NTF, Geološkim zavodom Slovenije in ZRSVN.

Mednarodno delovanje SGD in članstvo v tujih in domačih zvezah

SGD je včlanjeno v tuje zveze: European Federation of Geologists (EFG), International Union for Quaternary Research (INQUA), European Association for the Conservation of the Geological Heritage (ProGeo), European Mineralogical Union (EMU) in International Mineral Association (IMA). Včlanjeni smo tudi v Slovensko inženirsko zvezo (SIZ).

Kot član **Evropskega združenja geologov** (European Federation of Geologists – EFG) SGD od leta 2015 sodeluje v evropskih projektih Obzorje 2020 (Horizon 2020). Skupaj z več drugimi nacionalnimi geološkimi društvi sodelujemo kot neodvisni partner preko pogodbe z EFG kot vodilnim projektnim partnerjem. V letu 2017 smo uspešno zaključili aktivnosti v projektu INTRAW – Mednarodno sodelovanje na področju oskrbe z mineralnimi surovinami (*International Cooperation on Raw materials*). Marca 2018 se bo zaključil projekt KINDRA – Zbirka znanja za hidrogeološke raziskave (*Knowledge Inventory for Hydrogeology Research*), nadaljuje pa se sodelovanje v projektih UNEXMIN – Podvodni raziskovalec potopljenih rudnikov (*An Autonomous Underwater Explorer for Flooded Mines*) in CHPM 2030 – Soproizvodnja toplotne in električne energije ter pridobivanje kovin (*Combined Heat, Power and Metal extraction from ultra-deep ore bodies*). V letu 2017 smo začeli sodelovati še v projektu INFACT – Inovativna, neinvanzivna in popolnoma sprejemljiva tehnologija raziskovanja (*Innovative, Non-Invasive* *and Fully Acceptable Exploration Technologies*). Član SGD, Marko Komac je član izvršniega sveta EFG kot External Relations Officer, več naših članov pa sodeluje v strokovnih svetovalnih telesih EFG.

Pod okriljem **Mednarodne zveze za raziskovanje kvartarja** (International Union for Quaternaty Research – INQUA) je med 9. in 12. novembrom 2017 potekalo 5. *regionalno znanstveno srečanje za kvartarno geologijo*, posvečeno geološko pogojenim nevarnostim. Organizatorji srečanja so Hrvaški nacionalni odbor INQUA (Hrvaška akademija znanosti in umetnosti, Oddelek za naravoslovje), Inštitut za kvartarno paleontologijo in geologijo, Slovenski nacionalni odbor INQUA, Slovensko geološko društvo, Geološki zavod Slovenije in Hrvaški geološki inštitut. Dvodnevno srečanje se je odvijalo v kraju Starigrad Paklenica na Hrvaškem, sledila pa mu je tridnevna ekskurzija v okolici Velebita. Srečanja se je udeležilo nekaj manj kot 50 znanstvenikov iz širše jadranske regije.

V letu 2017 smo ponovno vzpostavili sodelovanje z Delovno skupino za jugovzhodno Evropo **Evropske zveze za zaščito geološke dediščine** (European Association for the Conservation of the Geological Heritage – ProGEO). SGD je obnovilo članstvo v tej skupini, Martina Stupar (z ZRSVN) pa je naša predstavnica. V letu 2017 smo pripravili gradiva za predstavitev šestih slovenskih geoloških naravnih vrednot v knjigi o »*geosites*« **v JV evropski regiji.**

SGD je tudi član **Slovenske inženirske zveze** – SIZ. S tem je izpolnjen pogoj o obveznem članstvu SGD v SIZ za pridobitev naziva Evro inženir (EUR ING). Čakamo člane za pobude.

V letu 2018 so načrtovane in delno že izvedene naslednje dejavnosti društva:

Strokovna predavanja

Martin Gaberšek in **Klemen Teran** (Geološki zavod Slovenije), »*Prah – dragocen vir geokemičnih informacij o okolju*«, 22. marca 2018 ob 17.30 uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Tina Peternel (Geološki zavod Slovenije), »*Spremljanje pobočnih masnih premikov na primeru plazov Urbas in* **Čikla** *(SZ Slovenija)*«, 29. marca 2018 ob 17.30 uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Teja Čeru (Oddelek za geotehnologijo, rudarstvo in okolje NTF), »**Uporaba** *georadarja pri geomorfoloških raziskavah na krasu*«, 12. aprila 2018 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11

Lada Hylova (Univerza Palacky v Olomoucu, **Češka**), »*Upper Silesian basin*«, 19. aprila 2018 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Daniela Rehakova (Univerza v Bratislavi, Slovaška), »*Calcareous microplankton* **in the Upper Jurassic/Lower Cretaceous pelagic sediments of the Western Carpathians – a tool for** *stratigraphical and paleoenvironmental interpretation*«, 26. aprila 2018 ob 17. uri v Ljubljani na Oddelku za geologijo NTF, Privoz 11.

Timotej Verbovšek (Oddelek za geologijo NTF), predstavitev projekta UNEXMIN – *An Autonomous Underwater Explorer for Flooded Mines* bo predvidoma v sredini maja 2018.

Strokovne ekskurzije

V maju 2018 je predviden **ogled naravnega kamna na ljubljanskih ulicah** pod vodstvom Matevža Novaka.

Konec pomladi 2018 je predvidena **strokovna ekskurzija na Pohorje** pod vodstvom Mirijam Vrabec. Tema ekskurzije bo predstavitev novih dognanj o sestavi magmatskih in metamorfnih kamnin Pohorja.

Strokovna posvetovanja in okrogle mize

Slovenski nacionalni odbor INQUA (SINQUA), ki deluje pod okriljen SGD, organizira **1. srečanje SINQUA** v sredo, 18. aprila 2018, v Ljubljani, na Geološkem zavodu Slovenije, Dimičeva ulica 14.

5. slovenski geološki kongres

Slovensko geološko društvo je z Geološkim zavodom Slovenije soorganizator **5. slovenskega geološkega kongresa**. Kongres, ki bo potekal med 3. in 5. oktobrom 2018 v Velenju, bo za SGD največji in najpomembnejši dogodek leta 2018. Partnerji pri organizaciji so Premogovnik Velenje, Fakulteta za gradbeništvo in geodezijo, Slovensko rudarsko društvo inženirjev in tehnikov (SRDIT), Društvo slovenski komite mednarodnega združenja hidrogeologov (SKIAH) in Mestna občina Velenje. Kongres bo ob izmenjavi novih raziskovalnih rezultatov posvečen pomenu geoznanosti za širšo družbo in njen razvoj. Spremljalo ga bo veliko dogodkov v organizaciji SGD: Dan geologije z delavnicami in predavanji, GeoTEK in fotografski natečaj *Geoznanost za družbo*. Na kongresu bo tudi skupščina Slovenskega geološkega društva z volitvami novega vodstva in drugi organov. Vse informacije o kongresu bodo redno objavljene na spletni strani www.geo-zs.si/5SGK.

Dan geologije

Skupina za popularizacijo geologije v okviru SGD je pripravila idejno zasnovo in program za prvi **Dan geologije**, ki bo letos organiziran v okviru dejavnosti, ki bodo spremljale 5. slovenski geološki kongres v Velenju. Delavnice in predstavitve na temo *Geologija v vsakdanjem življenju* za učence in dijake osnovnih in srednjih šol bodo potekale dan pred kongresom, 2. oktobra 2018. Načrtujemo, da bi Dan geologije postal tradicionalen dogodek z vključevanjem čim večjega števila inštitucij.Slovensko geološko društvo je z Geološkim zavodom Slovenije soorganizator 5. slovenskega geološkega kongresa.

Fotografski natečaj

SGD je v okviru 5. slovenskega geološkega kongresa razpisalo nagradni fotografski natečaj *Geoznanost za družbo*. 24 najboljših fotografij po izboru komisije bo v velikem formatu razstavljenih v Galeriji na prostem v Velenju v času geološkega kongresa, skupaj pa tri mesece. 12 najboljših fotografij bo natisnjenih na koledarju, za najboljše tri fotografije pa bodo na zaključni kongresni slovesnosti podeljene nagrade.

GeoTEK in GeoLOV

Tretji tradicionalni **GeoTEK** Slovensko geološko društvo letos organizira v okviru dejavnosti, ki bodo spremljale 5. slovenski geološki kongres v Velenju. Trasa GeoTEKA, ki bo 2. oktobra 2018, sledi kolesarski stezi okrog Velenjskega jezera.

Drugi tradicionalni **GeoLOV**, tokrat na območju med Orlami in Škofljico, bo izveden predvidoma v začetku novembra 2018.

Obvestila članom Slovenskega geološkega društva

SGD je z Geološkim zavodom Slovenije nadaljevalo z aktivnostmi za <u>ureditev pravno-formalnega statusa "geološkega zakona"</u>. Pripravila smo osnutek dokumenta z opisom stanja, problematike ter predlogi za ureditev. Glavni poudarek je na reševanju problematike na področju zbiranja, hranjenja in razpoložljivosti geoloških podatkov oz. podatkov o geosferi. V teku je postopek usklajevanja in dopolnjevanja osnutka z izobraževalnimi inštitucijami, podjetji in strokovnimi združenji.

<u>Popularizacija geologije.</u> Znotraj SGD so se močno intenzivirale aktivnosti, namenjene promociji geološke znanosti. Skupina za popularizacijo geologije je na sestankih 10. 4. 2017 in 18. 12. 2017 posodobila program z jasno zastavljenimi cilji, s podrobnim načrtom lastnih akcij in objav v poljudnoznanstvenih revijah ter s koledarjem prireditev, na katerih bomo sodelovali. Skupina je v sodelovanju z Oddelkom za geologijo (UL, Naravoslovnotehniška fakulteta) pripravila geološke vsebine za **vključitev v Posodobitvene programe za učitelje** in v *Katalog programov nadaljnjega izobraževanja in usposabljanja strokovnih delavcev v vzgoji in izobraževanju*, ki se bodo izvajali na podlagi prijav na razpis programov KATIS. Skupina je opravila tudi prvo stopnjo temeljite **analize geoloških vsebin v učbenikih za osnovno in srednjo šolo**. Pregledali smo 101 učbenik za vse predmete, ki vsebujejo geološke vsebine in te vsebine evidentirali ter kritično ocenili. Naslednji korak bo pregled vsebin po tematikah in priprava priporočil za njihovo izboljšanje.

<u>Sodelovanje s sorodnimi društvi.</u> Iz poročila je razvidno, da smo močno okrepili ter vzpostavili nove stike s tujimi geološkimi društvi (predvsem Hrvaškim in Srbskim) ter z drugimi društvo s sorodnimi cilji (Geomorfološkim društvom Slovenije – GDS, Prirodoslovnim društvom Slovenije – PDS, Društvom slovenski komite mednarodnega združenja hidrogeologov – SKIAH).

<u>Sodelovanje s sorodnimi društvi.</u> SGD dobro sodeluje s tujimi geološkimi društvi (predvsem Hrvaškim in Srbskim) ter z drugimi društvi s sorodnimi cilji (Geomorfološkim društvom Slovenije – GDS, Društvom slovenski komite mednarodnega združenja hidrogeologov – SKIAH, Prirodoslovnim društvom Slovenije – PDS).

<u>Postavitev nove spletne strani.</u> SGD je še vedno sredi postopka temeljite posodobitve društvenega spletnega portala, ki bo omogočal hitrejše obveščanje o društvenih dogodkih, objavo koledarja dogodkov, izmenjavo mnenj registriranih uporabnikov ter naročanje na prejemanje teh obvestil. S tem želi društvo doseči večjo prepoznavnost društva in povečanje števila članov. Do dokončanja postavitve portala redno osvežujemo obstoječo spletno stran: www.geoloskodrustvo.si.

Navodila avtorjem

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

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

Avtorji z objavo prispevka v GEOLOGIJI potrjujejo, da se strinjajo, da je njihov prispevek odprto dostopen z izbrano licenco CC-BY.

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

Vrste prispevkov:

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

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

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

Diskusija in polemika
Prispevek, v katerem avtor ocenjuje ali komentira neko delo, objavljeno v GEOLOGIJI, ali z avtorjem strokovno polemizira.

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

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

Članek oddajte uredništvu vključno z vsemi slikami, tabelami in tablami v elektronski obliki po naslednjem sistemu:
- *Naslov članka (do 12 besed)*
- *Avtorji (ime in priimek, poštni in elektronski naslov)*
- *Ključne besede (do 7 besed)*
- *Izvleček (do 300 besed)*
- *Besedilo*
- *Literatura*
- *Podnaslovi slik in tabel*
- *Tabele, Slike, Table*

Citiranje: V literaturi naj avtorji prispevkov praviloma upoštevajo le objavljene vire. Poročila in rokopise naj navajajo le v izjemnih primerih, z navedbo kje so shranjeni. V seznamu literature naj bodo navedena samo v članku omenjena dela. Citirana dela, ki imajo DOI identifikator (angl. Digital Object Identifier), morajo imeti ta identifikator izpisan na koncu citata. Za citiranje revije uporabljamo standardno okrajšavo naslova revije. Med besedilom prispevka citirajte samo avtorjev priimek, v oklepaju pa navajajte letnico izida navedenega dela in po potrebi tudi stran. Če navajate delo dveh avtorjev, izpišite med tekstom prispevka oba priimka (npr. Pleničar & Buser, 1967), pri treh ali več avtorjih pa napišite samo prvo ime in dodajte et al. z letnico (npr. Mlakar et al., 1992). Citiranje virov z medmrežja v primeru, kjer avtor ni poznan, zapišemo (Internet 1). V seznamu literature navajajte po abecednem redu avtorjev.

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

Primeri citiranja članka:

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

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

Primer citirane knjige:

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

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

Primer citiranja poglavja iz knjige:

Turnšek, D. & Drobne, K. 1998: Paleocene corals from the northern Adriatic platform. In: Hottinger, L. & Drobne, K. (eds.): Paleogene Shallow Benthos of the Tethys. Dela SAZU, IV. Razreda, 34/2: 129–154, incl. 10 Pls.

Primer citiranja virov z medmrežja:

Če sta znana avtor in naslov citirane enote zapišemo:
Čarman, M. 2009: Priporočila lastnikom objektov, zgrajenih na nestabilnih območjih. Internet: http://www.geo-zs.si/UserFiles/1/File/Nasveti_lastnikom_objektov_na_nestabilnih_tleh.pdf (17. 1. 2010)

Če avtor ni poznan zapišemo tako:
Internet: http://www.geo-zs.si/ (22. 10. 2009)

Če se navaja več enot z medmrežja, jim dodamo še številko:
Internet 1: http://www.geo-zs.si/ (15. 11. 2000)
Internet 2: http://www.geo-zs.si/ (10. 12. 2009)

Slike, tabele in table: Slike (ilustracije in fotografije), tabele in table morajo biti zaporedno oštevilčene in označene kot sl. 1, sl. 2 itn., oddane v formatu TIFF, JPG, EPS ali PDF z ločljivostjo 300 dpi. Le izjemoma je možno objaviti tudi barvne slike, vendar samo po predhodnem dogovoru z uredništvom. Če avtorji oddajo barvne slike bodo te v barvah objavljene samo v spletni različici članka. Pazite, da bo tudi slika tiskana v sivi tehniki berljiva. Grafični materiali naj bodo usklajeni z zrcalom revije, kar pomeni, da so široki največ 172 mm (ena stran) ali 83 mm (pol strani, en stolpec) in visoki največ 235 mm. Večjih formatov od omenjenega zrcala GEOLOGIJE ne tiskamo na zgib, je pa možno, da večje oziroma daljše slike natisnemo na dveh straneh (skupaj na levi in desni strani) z vmesnim "rezom". V besedilu prispevka morate omeniti vsako sliko po številčnem vrstnem redu. Dovoljenja za objavo slikovnega gradiva iz drugih revij, publikacij in knjig, si pridobijo avtorji sami.

Če je članek napisan v slovenskem jeziku, mora imeti celotno besedilo, ki je na slikah in tabelah tudi v angleškem jeziku. Podnaslovi naj bodo čim krajši.

Korekture: Avtorji prejmejo po elektronski pošti članek v avtorski pregled. Popravijo lahko samo tiskarske napake. Krajši dodatki ali spremembe pri korekturah so možne samo na avtorjeve stroške.

Prispevki so prosto dostopni na spletnem mestu: http://www.geologija-revija.si/

Oddajanje prispevkov:

Avtorje prosimo, da prispevke oddajo v elektronski obliki na naslov uredništva:

GEOLOGIJA
Geološki zavod Slovenije
Dimičeva ulica 14, 1000 Ljubljana
bernarda.bole@geo-zs.si ali urednik@geologija-revija.si

Uredništvo Geologije

Instructions for authors

Scope of the journal: GEOLOGIJA publishes scientific papers which contribute to understanding of the geology of Slovenia or to general understanding of all fields of geology. Some shorter contributions on technical or conceptual issues are also welcome. Occasionally, a collection of symposia papers is also published.
All submitted manuscripts are peer-reviewed. When submitting paper, authors should recommend at least **three reviewers**. Note that the editorial office retains the sole right to decide whether or not the suggested reviewers are used. Authors should correct their papers according to the instructions given by the reviewers. Should you disagree with any part of the reviews, please explain why. Revised manuscript will be reconsidered for publication.

Author's declaration: Submission of a paper for publication in GEOLOGIJA implies that the work described has not been published previously, that it is not under consideration for publication elsewhere and that, if accepted, it will not be published elsewhere.
Authors agree that their contributions published in GEOLOGIJA are open access under the licence CC-BY.

Language: Papers should be written in English or Slovene, and should have both English and Slovene abstracts.

Types of papers:

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

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

Professional paper
Technical papers give information on research results that have already been published and emphasise their applicability.

Discussion paper
A discussion gives an evaluation of another paper, or parts of it, published in GEOLOGIJA or discusses its ideas.

Book review
This is a contribution that presents a content of a new book in the field of geology.

Style guide:
Submitted manuscripts should not exceed 20 pages of A4 format including figures, tables and plates. Only exceptionally and in agreement with the editorial board longer contributions can also be accepted.
Manuscripts submitted to the editorial office should include figures, tables and plates in electronic format organized according to the following scheme:
- *Title (maximum 12 words)*
- *Authors (full name and family name, postal address and e-mail address)*
- *Key words (maximum 7 words)*
- *Abstract (maximum 300 words)*
- *Text*
- *References*
- *Figure and Table Captions*
- *Tables, Figures, Plates*

References: References should be cited in the text as follows: (Flügel, 2004) for a single author, (Pleničar & Buser, 1967) for two authors and (Mlakar et al., 1992) for multiple authors. Pages and figures should be cited as follows: (Pleničar, 1993, p. 67) and (Pleničar, 1993, fig. 1). Anonymous internet resources should be cited as (Internet 1). Only published references should be cited. Manuscripts should be cited only in some special cases in which it also has to be stated where they are kept. Cited reference list should include only publications that are mentioned in the paper. Authors should be listed alphabetically. Journal titles should be given in a standard abbreviated form. A DOI identifier, if there is any, should be placed at the end as shown in the first case below.
Taxonomic names should be in italics, while names of the authors of taxonomic names should be in normal, such as *Clypeaster pyramidalis* Michelin, *Galeanella tollmanni* (Kristan), Echinoidea.

Articles should be listed as follows:

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

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

Books should be listed as follows:

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

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

Book chapters should be listed as follows:

Turnšek, D. & Drobne, K. 1998: Paleocene corals from the northern Adriatic platform. In: Hottinger, L. & Drobne, K. (eds.): Paleogene Shallow Benthos of the Tethys. Dela SAZU, IV. Razreda, 34/2: 129–154, incl. 10 Pls.

Internet sources should be listed as follows:

Known author and title:
Čarman, M. 2009: Priporočila lastnikom objektov, zgrajenih na nestabilnih območjih. Internet: http://www.geo-zs.si/UserFiles/1/File/Nasveti_lastnikom_objektov_na_nestabilnih_tleh.pdf (17. 1. 2010)
Unknown authors and title:
Internet: http://www.geo-zs.si/ (22.10.2009)

When more than one unit from the internet are cited they should be numbered:
Internet 1: http://www.geo-zs.si/ (15.11. 2000)
Internet 2: http://www.geo-zs.si/ (10.12. 2009)

Figures, tables and plates: Figures (illustrations and photographs), tables and plates should be numbered consecutively and marked as Fig. 1, Fig. 2 etc., and saved as TIFF, JPG, EPS or PDF files and submitted at 300 dpi. Colour pictures will be published only on the basis of previous agreement with the editorial office. If, together with the article, you submit colour figures then these figures will appear in colour only in the Website version of the article. Be careful that the grey scale printed version is also readable. Graphic materials should be adapted to the journal's format. They should be up to 172 mm (one page) or 83 mm wide (half page, one column), and up to 235 mm high. Larger formats can only be printed as a double-sided illustration (left and right) with a cut in the middle. All graphic materials should be referred to in the text and numbered in the sequence in which they are cited. The approval for using illustrations previously published in other journals or books should be obtained by each author.
When a paper is written in Slovene it has to have the entire text which accompanies illustrations and tables written both in Slovene and English. Figure and table captions should be kept as short as possible.

Proofs: Proofs (in pdf format) will be sent by e-mail to the corresponding author. Corrections are made by the authors. They should correct only typographical errors. Short additions and changes are possible, but they will be charged to the authors.

GEOLOGIJA is an open access journal; all pdfs can be downloaded from the website: http://www.geologija-revija.si/en/

Submission: Authors should submit their papers in electronic form to the address of the GEOLOGIJA editorial office:

GEOLOGIJA
Geological Survey of Slovenia
Dimičeva ulica 14, 1000 Ljubljana, Slovenia
bernarda.bole@geo-zs.si or urednik@geologija-revija.si

The Editorial Office

GEOLOGIJA
št.: 61/1, 2018
www.geologija-revija.si

ISSN 0016-7789
9 770016 778002

GeoZS
Geološki zavod
Slovenije