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Provenance and morphostratigraphy of the Pliocene-Quaternary sediments in the Celje and Drava-Ptuj Basins (eastern Slovenia)

Provenienca in morfostratigrafija pliocensko-kvartarnih sedimentov v Celjskem in Dravsko-Ptujskem bazenu (vzhodna Slovenija)

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Abstract

This study presents the results of the first systematic morphostratigraphic and provenance analyses of the Pliocene-Quaternary fluvial sediments in the Celje and Drava-Ptuj intramontane basins. Based on the degree of terrace preservation, the dip of the terrace surfaces and fans, and the composition and degree of weathering of the sediments, low-, middle- and high-level terrace groups were constrained and tentatively attributed to Late Pleistocene, Middle Pleistocene and Plio-Early Pleistocene, respectively. The provenance analysis focused on the sediments from the high-level terrace (Plio-Early Pleistocene) and encompassed clast lithological analysis and microfacies analysis of the clasts. The results indicate a local provenance with relatively short transport, which is consistent with the morphology of the clasts. The source rocks of the Plio-Early Pleistocene deposits in the Celje Basin are attributed to the formations outcropping in the southern Pohorje Massif and the Upper Savinja River Valley corresponding to the paleo-Savinja. The possibility of resedimentation of the clasts from Miocene clastic sedimentary rocks located north of the Celje Basin also needs to be considered. The sediments of the Drava-Ptuj Basin originate from the Pohorje Massif, the Kozjak mountain range, and the area south of the Pohorje Massif which were deposited by the paleo-Drava and paleo-Dravinja rivers. Our study indicates that the drainage systems of the paleo-Savinja, paleo-Drava and paleo-Dravinja during the Plio-Early Pleistocene roughly correspond to those of the present day.

Izvleček

Predstavljamo prve sistematične analize morfostratigrafije in provenience pliocensko-kvartarnih rečnih sedimentov na območju Celjskega in Dravsko-Ptujskega medgorskega bazena. Na podlagi stopnje ohranjenosti morfologije teras, naklona terasnih površin in sestave ter stopnje preperelosti sedimentov so bili opredeljeni trije terasni nivoji in interpretirane starosti teras in vršajev. Spodnjemu terasnemu nivoju je bila interpretativno določena poznopleistocenska starost, srednjemu terasnemu nivoju srednjepleistocenska, zgornjemu terasnemu nivoju pa plio-zgodnjepleistocenska starost. Analiza provenience je bila osredotočena na sedimente višjega terasnega nivoja (pliocen-zgodnji pleistocen) in je temeljila na litološki analizi klastov in analizi mikrofaciesov klastov. Rezultati nakazujejo, da gre za lokalno provenienco proda, kar dodatno potrjujejo sedimentološka opazovanja morfologije klastov. Izvor plio-zgodnjepleistocenskih sedimentov v Celjskem bazenu so domnevno formacije, ki izdanjajo na območju južnega Pohorja in Zgornjesavinjske doline, pri čemer pa moramo upoštevati

možnost resedimentacije nekaterih litologij iz miocenskih klastičnih sedimentnih kamnin, ki se nahajajo severno od bazena. Prod v Dravsko-Ptujskem bazenu pa verjetno prihaja z območja Pohorja, Kozjaka in območja južno od Pohorja. Ugotovljeno je bilo, da je plio-zgodnjepleistocenska rečna mreža generalno sovpadala z današnjo. Tako lahko rečemo, da so se plio-zgodnjepleistocenski sedimenti na območju Celjskega bazena odlagali s paleo-Savinjo in njenimi pritoki, sedimenti na območju Dravsko-Ptujskega bazena pa s paleo-Dravo, paleo-Dravinjo in njunimi pritoki.

Introduction

The Slovenian territory is located at the junction of the Alps, Dinarides and Pannonian Basin (Placer, 2008). The Cenozoic tectonic activity responsible for uplift of the Alps and Dinarides resulted in a morphologically diverse landscape and the formation of intramontane basins. These basins were rapidly filled due to intensive post-Neogene erosion related to the eustatic sea-level changes and Quaternary compression of the area. Plio-Early Pleistocene ("Plio-Quaternary" according to e.g. Buser, 2010 and other Slovenian authors) sediments mark the onset of the youngest terrestrial sedimentation active up to now in the area of South, East and Central Slovenia (Fig. 1A). According to current interpretations, these sediments represent informal stratigraphic unit named "Plio-Quaternary" comprised by i) the sediments that were filling the Pannonian Lake, ii) terrestrial sediments of intramontane basins and iii) sediments resulted from weathering of host rock and their subsequent resedimentation (Markič, 2009, and references within).

Plio-Early Pleistocene sediments of intramontane basins in the wider area of Maribor, Slovenj Gradec, Velenje, Nazarje, Celje, Črnomelj, Kočevje and Krško are composed of interlayered beds of gravel, sand, silt and clay (Mioč, 1978; Buser, 1979; Šikić et al., 1979; Premru, 1983; Bukovac et al., 1984; Mioč & Žnidarčič, 1989; Verbič, 2004) deposited in fluvial, swamp, and lacustrine environments. The gravel clasts are composed of igneous, metamorphic and sedimentary rocks. Rare previous provenance research points to i) local origin (Mioč, 1978), ii) non-local origin, sediments were transported by paleo-flows of current rivers (i.e. paleo-Sava; Verbič, 2004). Based on the relative and numeric data, the age of these sediments was defined only in the area of Velenje and Krško. In the Velenje Basin, a Plio-Early Pleistocene age of 2,6 to 3,5 million years (Villafranchian, mammal zone MN16: Debeljak, 2017) was determined based on the finding of fossil mastodonts (Drobne, 1967; Rakovec, 1968) and palaeontological findings in coal (Brezigar, 1987; Brezigar et al., 1987; Markič & Sachenhofer, 2010). In the Krško Basin, a Plio-Early Pleistocene age was determined

Uvod

Območje Slovenije leži na stičišču Alp, Dinaridov in Panonskega bazena (Placer, 2008). V obdobju kenozoika se je zaradi tektonskih procesov, ob katerih so se med drugim dvigale Alpe in Dinaridi, oblikovala reliefno razgibana pokrajina. Intenzivna poznoneogenska erozija, povezana tudi z evstatičnimi spremembami višine morske gladine, in kvartarna kompresija, sta znatno prispevali k povečani sedimentaciji v nastalih medgorskih bazenih. Plio-zgodnjepleistocenski (»pliokvartarni« v npr. Buser, 2010 ter v ostali dosedanji literaturi slovenskih avtorjev) sedimenti označujejo začetek najmlajše, še danes potekajoče terestrične sedimentacije na območju današnje osrednje, južne in vzhodne Slovenije (sl. 1A). Po trenutnih interpretacijah neformalno enoto »pliokvartar« tako predstavljajo: i) nanosi sedimentov, ki so zasipavali Panonski bazen, ii) terestrični sedimenti odloženi v medgorskih bazenih ter iii) sedimenti nastali s preperevanjem matične kamnine in njihovo kasnejšo resedimentacijo (Markič, 2009 z referencami).

Plio-zgodnjepleistocenske sedimente (»pliokvartar« po npr. Buser, 2010) medgorskih bazenov na širšem območju Maribora, Slovenj Gradca, Velenja, Nazarij, Celja, Črnomlja, Kočevja in Krškega predstavlja menjavanje nesprijetega proda, peska, melja in gline (Mioč, 1978; Buser, 1979; Šikić et al., 1979; Premru, 1983; Bukovac et al., 1984; Mioč & Žnidarčič, 1989; Verbič, 2004), ki so se odlagali v rečnih, močvirskih in jezerskih okoljih. Med prodniki najdemo različke magmatskih, metamorfnih in sedimentnih kamnin. Redke predhodne raziskave provenience kažejo, da so sedimenti lokalnega izvora (Mioč, 1978), oziroma prineseni s paleotokovi današnjih rek (npr. paleo-Sava; Verbič, 2004). Starost sedimentov je bila na podlagi relativnih in numeričnih metod določena le na območju Velenja in Krškega. V Velenjskem bazenu je starost plio-zgodnjepleistocenskih sedimentov določena na podlagi najdbe mastodonta (Drobne, 1967; Rakovec, 1968) in paleontoloških raziskav premoga (Brezigar, 1987; Brezigar et al., 1987; Markič & Sachenhofer, 2010) ter znaša od 2,6 do 3,5 milijona let (biokronološka enota spodnji villafranchij, sesalska cona MN 16;

based on paleontological correlations (Šikić et al., 1979), morphostratigraphy (Verbič, 2008) and numerical dating (Cline et al., 2016), indicating a minimal age of 1,79 million years.

Only few studies exsist on poorly investigated Plio-Early Pleistocene sediments in the area of Slovenia (Pleničar & Ramovš, 1954; Štern & Lapajne, 1974; Brezigar, 1987; Brezigar et al., 1987; Kralj, 2001; Markič & Rokavec, 2002; Verbič, 2004). The reasons are lack of outcrops and subsurface data, degraded and poorly preserved Plio-Early Pleistocene terraces and the fact that the sediments are usually strongly weathered. Therefore, the knowledge of Plio-Early Pleistocene sedimentary evolution represents a scientific gap not only in the area of Slovenia but also in a wider pan-Alpine realm.

This study focuses on composition and provenance of the Celje (CB) and Drava-Ptuj (DPB) basins (Fig. 1B). The study is based on systematic approach using morphostratigraphic and sedimentological methods established in the field of Quaternary geology. The aim of this research is to determine morphostratigraphy of terrace systems, to define provenance of Plio-Early Pleistocene sediments and to interpret the evolution of the fluvial system in the Plio-Early Pleistocene.

Geological Setting

Celje Basin (CB)

The CB is located north of the Sava Hills, east of the Menina planina and Dobrovlje, and south of the Vitanje-Konjice part of the Karavanke Mountains. The present-day fluvial system is governed by the river Savinja, originating in the Logarska Valley in the Kamnik-Savinja Alps, and running in a northwest–southeast direction. In addition to the river Savinja, smaller streams drain into the basin from the northern and southern rims. The northwestern rim of the CB borders the Smrekovec volcanic complex of Oligocene age (Kralj, 1996; Pamić & Balen, 2001; Premru, 1983). The wider area also comprises Carboniferous siliciclastic rocks, Permian carbonates, Triassic carbonate and volcanic rocks, Jurassic and Cretaceous carbonate rocks, as well as Neogene carbonate and siliciclastic sediments and sedimentary rocks (Buser, 2010). The mentioned Paleozoic and Mesozoic rocks structurally belong to the Southern Alps and the Dinarides, while sediments and rocks of Oligocene and Miocene age were deposited near the margins of the Pannonian Basin (Placer, 1999; 2008; Kováč et al., 2007). The Pliocene-Quaternary sediments of the CB comprise the 35 m thick "Plio–Quater-

Debeljak, 2017). V Krškem bazenu je bila starost plio-zgodnjepleistocenskih sedimentov določena na podlagi paleontoloških korelacij (Šikić et al., 1979), morfostratigrafije (Verbič, 2008) in numeričnih datacij (Cline et al. 2016). Slednje kažejo na minimalno starost 1,79 milijona let.

Plio-zgodnjepleistocenski sedimenti so na območju Slovenije sorazmerno slabo raziskani oziroma študije, ki se nanašajo nanje, tematiko opisujejo le obrobno (Pleničar & Ramovš, 1954; Štern & Lapajne, 1974; Brezigar, 1987; Brezigar et al., 1987; Kralj, 2001; Markič & Rokavec, 2002; Verbič, 2004). Temu botruje dejstvo, da so izdanki in globinski podatki redki, plio-zgodnjepleistocenske terase so pogosto slabo ohranjene in močno degradirane, sedimenti pa so pogosto močno prepereli. Slaba raziskanost zato predstavlja vrzel v kvartarni geologiji ne le na območju današnje Slovenije, temveč tudi v širšem predalpskem prostoru.

V tej študiji smo se osredotočili na sestavo in provenienco plio-zgodnjepleistocenskih sedimentov v Celjskem (CB) in Dravsko-Ptujskem bazenu (DPB) (sl. 1B). Raziskava temelji na sistematičnem pristopu z uporabo ustreznih morfostratigrafskih in sedimentoloških metod uveljavljenih v kvartarni geologiji, s katerimi smo opredelili morfostratigrafijo sistema teras, ovrednotili izvorna območja plio-zgodnjepleistocenskih sedimentov ter interpretirali razvoj rečne mreže v obdobju plio-pleistocena.

Geologija območja

Celjski bazen (CB)

CB se nahaja na severno od Posavskega hribovja, vzhodno od Menine planine in Dobrovelj ter južno od Vitanjsko-Konjiških Karavank. Današnja rečna mreža CB je pogojena z njenim glavnim vodotokom, Savinjo, ki izvira v Logarski dolini v Kamniško-Savinjskih Alpah in teče v smeri severozahod-jugovzhod. Poleg tega se v bazen drenirajo njeni manjši pritoki iz severnih in južnih obronkov kotline. Severozahodno obrobje bazena meji na Smrekovški vulkanski kompleks oligocenske starosti (Kralj, 1996; Pamić & Balen, 2001; Premru, 1983). Na širšem območju se nahajajo še karbonske klastične kamnine, permske karbonatne kamnine, triasne karbonatne in vulkanske kamnine, kredne in jurske karbonatne kamnine ter neogenske karbonatne in klastične kamnine ter sedimenti (Buser, 2010). Omenjene paleozojske in mezozojske kamnine strukturno pripadajo Južnim Alpam in Dinaridom, oligocenske in miocenske kamnine pa so se odložile v robnih delih Panonskega bazena (Placer, 1999,

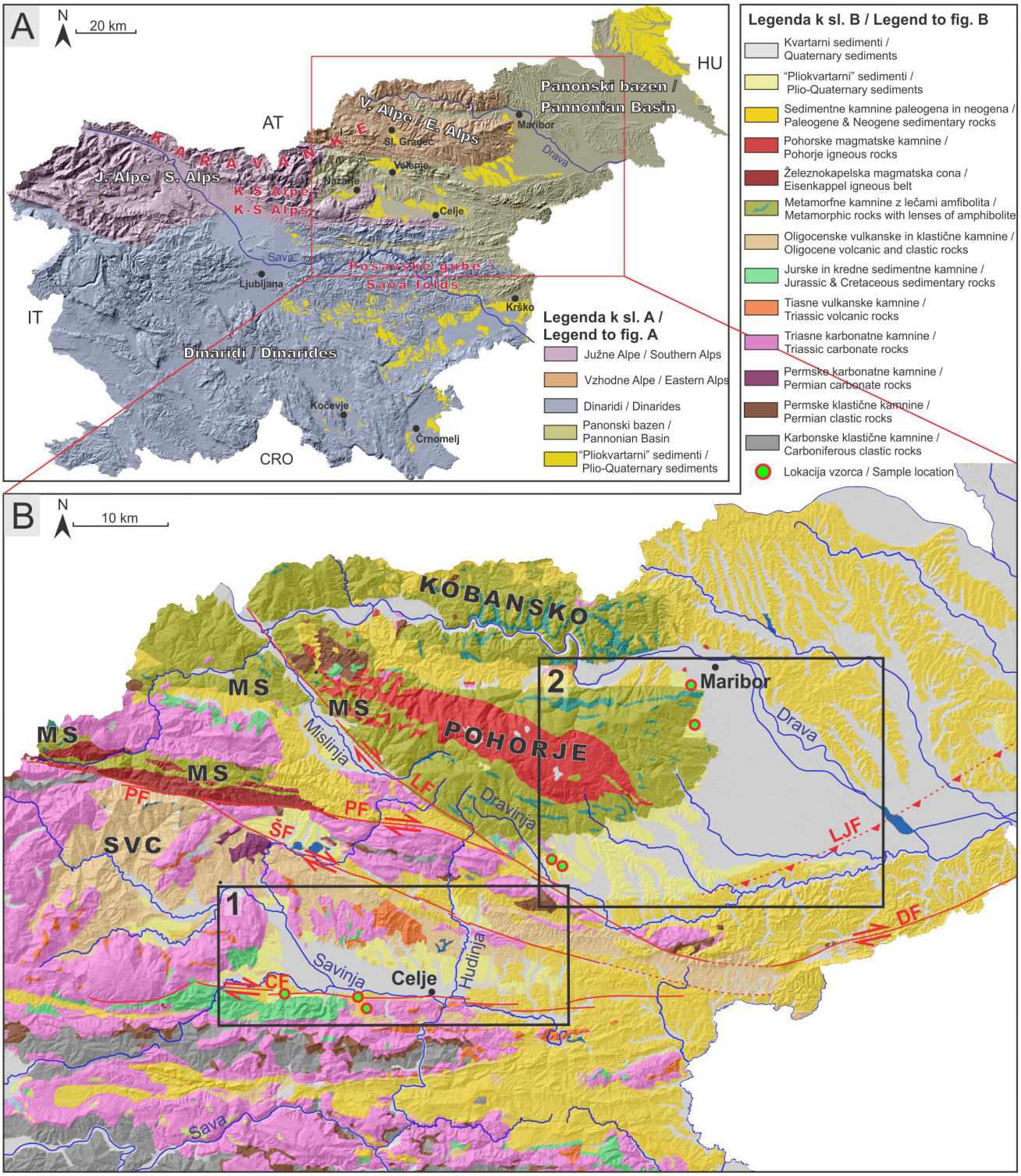

Fig. 1. Research area. (A) The area of Slovenia with geotectonic units marked (modified after Placer, 2008), and the spatial distribution of the Plio-Early Pleistocene sediments (so-called "Plioquaternary"). (B) Geological map of the Celje (1) and Drava-Ptuj (2) intramontane basins (modified after Buser, 2010). Abbreviations: MS: Magdalensberg series, SVC: Smrekovec volcanic complex, LF: Lavantall fault, ŠF: Šoštanj fault, CF: Celje fault, PF: Periadriatic fault, LJF: Ljutomer fault, DF: Donat fault.

Sl. 1. Območje raziskave. (A) Območje Slovenije z glavnimi geotektonskimi enotami (prirejeno po Placer, 2008) in pojavnostjo plio-zgodnjepleistocenskih sedimentov (t.i. »pliokvartarja«). (B) Geološka karta širšega območja Celjskega (1) in Dravsko-Ptujskega (2) medgorskega bazena (prirejeno po Buser, 2010). Na karti so označena glavna izvorna območja kamnin. Okrajšave: MS: Štalenskogorska serija, SVC: Smrekovški vulkanski kompleks, LF: Labotski prelom, ŠF: Šoštanjski prelom, CF: Celjski prelom, PF: Periadriatski prelom, LJF: Ljutomerski prelom, DF: Donački prelom.

nary" non-carbonate gravel, while the younger, Quaternary gravel deposits reach up to 25 m in thickness (Buser, 1979). The "Plio–Quaternary" deposits lie on Oligocene and Triassic basement (Fig. 1b; Buser, 1979). CB represents structurally the northernmost part of the Sava compressive wedge (Placer, 1998a, 1998b), which is reflected in the folding of its pre-Pliocene basement (the Celje syncline sensu Buser, 1977). The syncline's axis runs in an east–west direction, indicating post-Miocene compression in the north–south direction (Buser, 1977; Placer, 1998). According to Vrabec and Fodor (2006), the CB lies within the still active Periadriatic dextral transpressive fault system, experiencing local transtension between the faults running along the basin's margin.

Drava-Ptuj Basin (DPB)

The Drava-Ptuj Basin (DPB) is situated southeast of the Pohorje Massif and north of the Sava Hills. Its present-day fluvial system comprises the main river Drava, running in a north-northwest–south-southeast direction, and numerous smaller tributaries, following the direction of the Drava river, or generally flowing from the (north)west to the (south)east. The pre-Quaternary basement of the DPB belongs to several geological units (Fig. 1b). West to northwest of the DPB lies the Pohorje Massif built of low-, medium-, to (ultra) high-metamorphic rocks of the Pohorje metamorphic complex, overthrusted by very low-grade metamorphic rocks of the Magdalensberg series, unconformably overlain by Permo-Triassic, Cretaceous, and Miocene rocks and sediments (Mioč, 1978; Hinterlechner-Ravnik, 1971, 1973, 1982; Janák et al., 2004; Janák et al., 2005; Vrabec et al., 2012). The central part of the Pohorje Massif is formed of a pluton and sub-volcanic varieties of granodioritic to tonalitic composition, emplaced during the Miocene (Zupančič, 1994a, 1994b; Altherr et al., 1995; Fodor et al., 2008; Trajanova et al., 2008; Trajanova, 2013). From the structural point of view, the pre-Neogene rocks belong to the Eastern Alps. Miocene sediments and sedimentary rocks of the Maribor subbasin near the western margin of the Central Paratethys sea, filling the depression of the Pannonian Basin (Jelen & Rifelj, 2011; Trajanova, 2013). The deposition of Plio–Early Pleistocene sediments in this area started after the final regression of the Central Paratethys (Markič, 2009). According to Mioč and Žnidarčič (1989), the Plio–Early Pleistocene sediments in the DPB reach thickness up to 65 m, while the Quaternary deposits are only 30 m thick. The latter comprise four river terraces (Mioč & Žnidarčič, 2008; Kováč et al., 2007). Pliocensko-kvartarni sedimenti v CB obsegajo »pliokvartarni« nekarbonatni prod v skupni debelini 35 m, medtem ko mlajši, karbonatni kvartarni prod dosega debeline do 25 m (Buser, 1979). Podlago »pliokvartarja« v sami kotlini predstavljajo oligocenske in triasne kamnine (sl. 1b; Buser, 1979). V ožjem strukturnem smislu je po nekaterih interpretacijah kotlina še del Savskega kompresijskega klina (Placer, 1998a, 1998b), na kar kaže sinklinalna upognjenost predpliocenskih kamnin in sedimentov (Celjska sinklinala po Buser, 1977). Os sinklinale, ki poteka v smeri vzhod-zahod, kaže na post-miocensko kompresijo v smeri sever-jug (Buser, 1977; Placer, 1998). Po aktualnejših interpretacijah se kotlina nahaja znotraj aktivnega desno transpresivnega Periadriatskega sistema prelomov, kjer se odvija rotacija strižnih leč, pri čemer je območje CB verjetno podvrženo lokalni transtenziji med posameznimi prelomi, ki ga obkrožajo (Vrabec in Fodor, 2006).

Dravsko-Ptujski bazen (DPB)

DPB se nahaja jugovzhodno od Pohorja in severno od Posavskega hribovja. Rečna mreža današnjega DPB obsega glavni vodotok Dravo, ki teče v smeri sever-severozahod-jugovzhod, ter številne manjše pritoke, ki sledijo smeri glavnega toka ali tečejo generalno v smeri (severo)zahod-(jugo)vzhod. Predkvartarna podlaga DPB obsega več različnih geoloških enot (sl. 1b). Zahodno do severozahodno od DPB se nahaja Pohorje, ki je sestavljeno iz nizko, srednje do (ultra) visoko-metamorfnih kamnin Pohorskega kompleksa, na katere so narinjene zelo šibkometamorfozirane kamnine Štalenskogorske serije in diskordantno odložene permo-triasne, kredne ter miocenske kamnine in sedimenti (Mioč, 1978; Hinterlechner-Ravnik, 1971, 1973, 1982; Janák et al., 2004; Janák et al., 2005; Vrabec et al., 2012). V osrednjem delu Pohorja se nahajajo pluton in subvulkanski različki granodioritne do tonalitne sestave, ki so bili vtisnjeni v miocenu (Zupančič, 1994a, 1994b; Altherr et al., 1995; Fodor et al., 2008; Trajanova et al., 2008; Trajanova, 2013). V strukturnem smislu predneogenske kamnine uvrščamo k Vzhodnim Alpam. Miocenske kamnine in sedimenti Mariborskega podbazena so se odlagali na zahodnem robu Centralne Paratetide (sistem Panonskega bazena) (Jelen & Rifelj, 2011; Trajanova, 2013). Usedanje plio-zgodnjepleistocenski sedimentov na tem območju se je pričelo odlagati po končnem umiku Centralne Paratetide (Markič, 2009). Na snovi predhodnih podatkov so v DPB debeli do 65 m, kvartarni sedimenti pa

1989). In a structural sense, the DPB coincides with the Ptuj-Ljutomer syncline, which is bounded by the Ormož-Selnica anticline to the south (Mioč & Markovič, 1998). The later formed due to tectonic activity within the Donat fault zone. The most important faults of the latter are the dextral transpressive Donat fault and the reverse Ljutomer fault (Fodor et al., 1998, 2002).

Methods

The methodology for investigating the Plio-Early Pleistocene sediments was following guidelines from Stokes et al. (2012). Field observations were supported with geomorphological, sedimentological and microfacies analyses. Geomorphological analyses itself focused not only on Plio-Early Pleistocene sedimentary bodies, but also other younger sedimentary bodies from Pliocene-Quaternary succession.

The spatial extent of Plio-Early Pleistocene unit was constrained from Basic Geological Map, sheets Celje and Maribor (Buser, 1977; Žnidarčič & Mioč, 1988) and modified by analyzing the high-resolution digital elevation model derived from lidar data (Ministry of the Environment and Spatial Planning, Slovenian Environment Agency, 2011). Units mapped by means of remote sensing were field checked at the selected locations. Geomorphological analysis was carried out in GIS environment and encompassed analysis of topographic profiles, shaded relief map, topographic contours with 1 m equidistance, slope degree and slope aspect maps. Results of analysis are presented on two geomorphological maps, showing Plio-Early Pleistocene and other Quaternary terraces and fans in the studied basins (Figs. 2, 3). Geomorphological maps present the spatial extent of preserved surfaces of sedimentary bodies (surface forms). Therefore, oldest sediments are mostly occurring in greater spatial extent than their geomorphologically mapped present surface form (terrace or fan), i.e. the sediments at the surface occur also in the areas where their surface form is not preserved and mapped.

Seven sedimentary sections were logged: in CB these were Miklavž (MI), Šešče (SE) and Griže (GR), and in DPB Nova vas (NV), Hoče (HO), Radana vas (RA) and Škalce (SKA). Classification of lithofacies by Evans and Benn (2004) was used for logging. Sections height range from 1.5 to 5.5 m. Clasts from individual sections were sieved to 16-63 mm fraction. This fraction was chosen because it is appropriate for macroscopic identification of lithotypes of individual clasts, as well as for preparation of thin-sections.

30 m. V slednjih so vidne štiri terase (Mioč & Žnidarčič, 1989). DPB v strukturnem smislu sovpada s Ptujsko-Ljutomersko sinklinalo, na jugu pa ga omejuje Ormoško-Selniška antiklinala (Mioč & Markovič, 1998). Dviganje slednje je pogojeno z aktivnostjo Donačke prelomne cone, v kateri sta najpomembnejša potencialno aktivna desno transpresivni Donački prelom ter reverzni Ljutomerski prelom (Fodor et al., 1998, 2002).

Metode

Metodologija raziskovanja plio-zgodnjepleistocenskih sedimentov je sledila smernicam povzetih po Stokesu in sodelavcih (2012), pri čemer so bila terenska opazovanja podprta z geomorfološkimi, sedimentološkimi in mikrofaciesnimi analizami. Sama geomorfološka analiza je poleg analize plio-zgodnjepleistocenskih sedimentacijskih teles zajemala tudi mlajša sedimentacijska telesa iz pliocensko-kvartarnega zaporedja. Prostorska razširjenost enote plio-zgodnjepleistocenskih sedimentov je bila ugotovljena s pomočjo uporabe Osnovne geološke karte lista Celje in Maribor (Buser, 1977; Žnidarčič & Mioč, 1988) ter na analizi visokoločljivostnega digitalnega modela reliefa izdelanega na podlagi lidarskih podatkov (Ministrstvo za okolje in prostor, Agencija RS za okolje in prostor). Enote izdvojene z metodami daljinskega zaznavanja so bile na izbranih lokacijah preverjene s terenskim delom. Geomorfološke analize so bile izvedene v GIS okolju in so obsegale analizo topografskih profilov in kart senčenega reliefa, izohips z ekvidistanco 1 m, naklonov pobočij ter usmerjenosti pobočij. Izdelani sta bili geomorfološki karti, ki prikazujeta plio-zgodnjepleistocenske in ostale kvartarne terase in vršaje obravnavanih bazenov (sl. 2, 3). Geomorfološki karti prikazujeta razprostranjenost ohranjenih površin sedimentacijskih teles (površinske oblike). Predvsem za starejše sedimente zato velja, da je njihov obseg pojavljanja sicer večji od kartiranega obsega njihove današnje površinske oblike (terase ali vršaja), saj se sedimenti danes nahajajo tudi tam, kjer sama površinska oblika ni ohranjena.

Posnetih je bilo sedem sedimentoloških profilov, in sicer v CB Miklavž (MI), Šešče (SE) in Griže (GR) ter v DPB Nova vas (NV), Hoče (HO), Radana vas (RA) in Škalce (SKA), pri čemer je bila uporabljena klasifikacija litofaciesov po Evans in Benn (2004). Dolžina profilov znaša od 1,5 do 5,5 m. Prodniki iz posamičnih profilov so bili presejani na frakcijo od 16 do 63 mm. Ta velikost je ustrezna za makroskopsko litološko določitev klastov in za izdelavo zbruska.

Clast lithological analysis was following guidelines from Walden (2004), Lindsey et al. (2007) and Gale and Hoare (2011), adapted for the purpose of our study. 98-299 clasts were analyzed per sample from CB and 173-346 clasts per sample from DPB. 53 thin sections were prepared and examined with a polarizing microscope. Clast lithological analysis is traditionally performed on the macroscopic level (e.g. Bridgland et al., 2012), however, during our study it turned out that identification of weathered clasts is often wrong, and that microscopic analysis of the clasts significantly increases the reliability of the results. Due to lack of data on microfacies of Triassic volcanic rocks in the CB area, we additionally sampled their outcrops in the vicinity.

Results

Pliocene-Quaternary sediments of the CB and DPB are preserved in alluvial terraces and fans, following the terrace staircase model, which is typical in areas affected by relative surface uplift and erosional base lowering (e.g. Bridgland, 2000; Bridgland & Maddy, 2002; Bridgland & Westaway, 2008a; Bridgland & Westaway, 2008b; Doppler et al., 2011; van Husen & Reitner, 2011; Westaway, 2002). The oldest sediments are preserved in the highest terraces.

Pliocene-Quaternary sediments of the Celje Basin

The stratigraphy of alluvial terraces and fans in the CB is shown in the profile P1 (Fig. 2B and Table 1). Based on geomorphological mapping, five Pliocene-Quaternary terrace levels were distinguished (T0, T1, T3, T4, T5). Lithofacies and lithological analysis of gravels and clasts, respectively, were focused on Plio-Early Pleistocene sediments located on western and southern side of the basin (Fig. 2). Sediments of terrace levels T4 and T5 were analyzed in detail (Figs. 2, 4). Section MI (46,2394737°, 15,0395998°, 317 m a.s.l.) and SE (46,2307163°, 15,1398659°, 278 m a.s.l.) are located on the terrace level T4, and section GR (46,2196692°, 15,1520658°, 347 m a.s.l.) on terrace level T5.

Pliocene-Quaternary sediments of the Drava-Ptuj Basin

The stratigraphy of alluvial terraces and fans in the DPB is shown in profile P2 and P3 (Figs. 3B, 3C and Table 2). Six Pliocene-Quaternary terrace levels were distinguished (T0, T1, T2, T3, T4, T5). Lithofacies and lithological analysis of

Za litološko analizo klastov so bile upoštevane in prilagojene smernice avtorjev Walden (2004), Lindsey in sodelavcev (2007) ter Gale in Hoare (2011). V CB je bila litološka analiza izvedena na 98 do 299 klastih na vzorec, v DPB pa na 173 do 346 klastih na vzorec. Izdelanih in pregledanih je bilo 53 zbruskov klastov; 20 v CB in 33 v DPB. Tradicionalno je litološka analiza klastov izvedena makroskopsko (npr. Bridgland et al., 2012), vendar je bilo tekom študije ugotovljeno, da so napake pri identifikaciji preperelih kamnin pogoste in da mikroskopska analiza znatno pripomore k večji zanesljivosti rezultatov. Zaradi pomanjkanja podatkov o mikrofaciesu triasnih vulkanskih kamnin na območju CB, so bili dodatno vzorčeni tudi njihovi bližnji izdanki.

Rezultati

Pliocensko-kvartarni sedimenti CB in DPB so ohranjeni v terasah in vršajih, ki sledijo modelu inverzne terasne stratigrafije (ang. terrace staircase), ki je značilen za območja relativnega dvigovanja površja in zniževanja erozijske baze (npr. Bridgland, 2000; Bridgland & Maddy, 2002; Bridgland & Westaway, 2008a; Bridgland & Westaway, 2008b; Doppler et al., 2011; van Husen & Reitner, 2011; Westaway, 2002). Pri tem so najstarejši sedimenti ohranjeni na najvišje ležečih terasah.

Pliocensko-kvartarni sedimenti Celjskega bazena

Stratigrafija teras in vršajev v CB, ugotovljena s to študijo, je prikazana na profilu P1 (sl. 2B in Tabela 1). Na podlagi geomorfološkega kartiranja je bilo ugotovljenih pet pliocenski-kvartarnih terasnih nivojev (T0, T1, T3, T4, T5). Litofaciesna in litološka analiza prodov in klastov je bila osredotočena le na plio-zgodnjepleistocenske sedimente, ki se nahajajo na zahodni in južni strani bazena (sl. 2). Sedimenti so bili podrobneje analizirani na terasnem nivoju T4 in T5 (sl. 2, 4). Profila MI (46,2394737°, 15,0395998°, 317 m n.v.) in SE (46,2307163°, 15,1398659°, 278 m n.v.) se nahajata na terasnem nivoju T4, profil GR (46,2196692°, 15,1520658°, 347 m n.v.) pa na terasnem nivoju T5.

Pliocensko-kvartarni sedimenti Dravsko-Ptujskega bazena

Stratigrafija teras in vršajev v DPB, ugotovljena s to študijo, je prikazana na profilu P2 in P3 (sl. 3B, 3C in Tabela 2) pri čemer je bilo ugotovljenih šest pliocensko-kvartarnih terasnih nivojev (T0, T1, T2, T3, T4, T5). Litofaciesna in litološka ana-

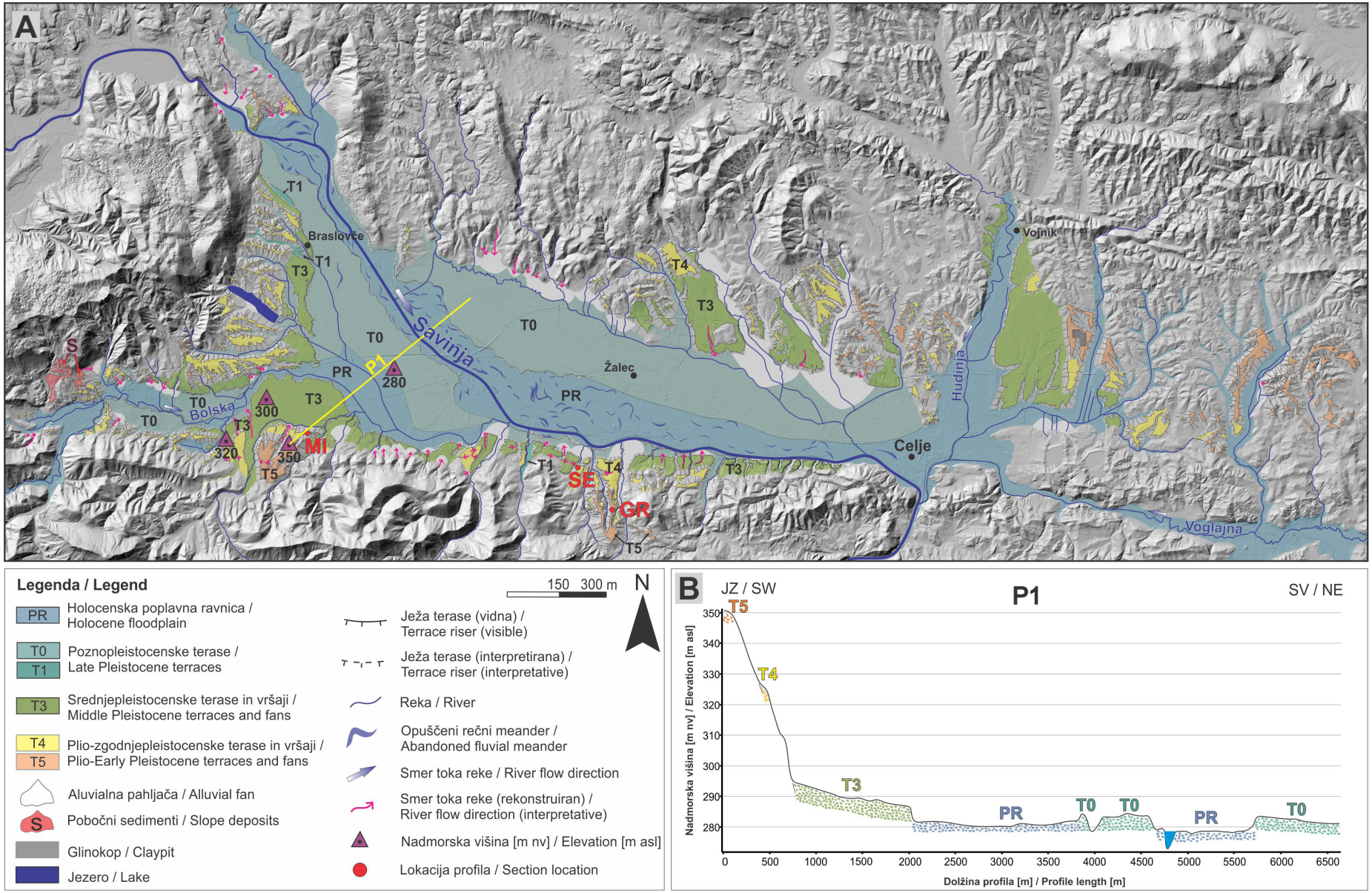

Fig. 2. Geomorphological analysis of the Pliocene-Quaternary surfaces of the Celje Basin. (A) Geomorphological map of the Plio-Early Pleistocene, Middle Pleistocene, Late Pleistocene and Holocene terraces and fans with locations of the studied sections marked (MI, SE, GR). (B) Topographic profile P1 with present-day elevations of the terraces and fans.

Sl. 2. Geomorfološka analiza pliocensko-kvartarnih površinskih oblik Celjskega bazena. (A) Geomorfološka karta plio-zgodnjepleistocenskih, srednjepleistocenskih, poznopleistocenskih in holocenskih teras in vršajev z označenimi lokacijami profilov (MI, SE, GR). (B) Topografski profil P1 z današnjimi višinami teras in vršajev.

Table 1. Basic geomorphological characteristics of the terrace system in the Celje Basin.
Tabela 1. Osnovne karakteristike sistema teras v Celjskem bazenu.

Terrace level / Terasni nivo	**Elevation [m a.s.l.] / Višina [m n.v.]**	**Height above the floodplain [m] / Relativna višina nad poplavno ravnico [m]**	**Thickness / Debelina [m] (after / po Buser, 1979)**	**Morphology of the unit / Morfologija enote**	**Composition of the sediments / Sestava sedimentov**	**Age / Starost (after / po Buser, 1979)**
Floodplain / Poplavna ravnica	236 - 304	/	25	Very well-preserved former channel pattern / Zelo dobro ohranjena morfologija rečnih meandrov	Carbonate gravel / Karbonatni prod	Quaternary / Kvartar
T0	238 - 309	2 - 5		Very well-preserved terrace morphology, rare and not well visible former channel meanders / Morfologija terase zelo dobro ohranjena, redki slabo ohranjeni rečni meandri		Quaternary / Kvartar
T1	279 - 308	7 - 8	35	Well-preserved terrace morphology, however the terrace surfaces are smaller and present only in a few places within the basin / Morfologija terase dobro ohranjena vendar terase ne zavzemajo velikih površin in so prisotne le na nekaj mestih znotraj bazena		Identified as single "Plio-Quaternary" terrace / Identificirano kot enotna »pliokvartarna« terasa
T3	245 - 324	9 - 14		Well-preserved terrace and fan morphology, present at basin boundaries / Morfologija teras in vršajev dobro ohranjena, prisotnost ob robovih bazena		
T4	258 - 338	15 - 22		Terrace and fan erosional remnants with degraded morphology incised by the drainage network / Morfologija teras in vršajev degradirana – erozijski ostanki teras, pogosto vrezovanje manjših potokov	Non-carbonate gravel / Nekarbonatni prod	
T5	262 - 366	42 - 124				

Table 2. Basic geomorphological characteristics of the terrace system in the Drava-Ptuj Basin.
Tabela 2. Osnovne značilnosti sistema teras v Dravsko-Ptujskem bazenu.

Terrace level / Terasni nivo	**Elevation [m a.s.l.] / Višina [m n.v.]**	**Height above the floodplain [m] / Relativna višina nad poplavno ravnico [m]**	**Thickness / Debelina [m] (after / po Buser, 1979)**	**Morphology of the unit / Morfologija enote**	**Composition of the sediments / Sestava sedimentov**	**Age / Starost (after / po Mioč & Žnidarčič, 1989)**
Floodplain / Poplavna ravnica	216 - 266	/	up to 30 m / do 30 m	Very well-preserved former channel pattern / Zelo dobro ohranjena morfologija rečnih meandrov	Carbonate gravel / Karbonatni prod	Quaternary / Kvartar
T0	224 - 284	7		Well-preserved former channel pattern, very well-preserved terrace morphology / Dobro ohranjena morfologija rečnih meandrov, morfologija terase zelo dobro ohranjena		Quaternary / Kvartar
T1	228 - 288	9 - 12		Moderately-preserved former channel pattern, very well-preserved terrace morphology / Srednje dobro ohranjena morfologija rečnih meandrov, morfologija terase zelo dobro ohranjena		Quaternary / Kvartar
T2	232 - 278	13 - 14		Very well-preserved terrace morphology / Morfologija terase zelo dobro ohranjena		Quaternary / Kvartar
T3	251 - 333	15 - 23	25 - 40	Well-preserved terrace and fan morphology, but the terrace surfaces are present only in a few places within the basin / Morfologija teras in vršajev dobro ohranjena, vendar terase ohranjene le na nekaj mestih znotraj bazena		Identified as single "Plio-Quaternary" terrace / Identificirano kot enotna »pliokvartarna« terasa
T4	231 - 437	15 - 50		Terrace and fan remnants with degraded morphology incised by the drainage network / Morfologija teras in vršajev degradirana – ostanki teras, pogosto vrezovanje manjših potokov		
T5	277 - 450	40 - 100				

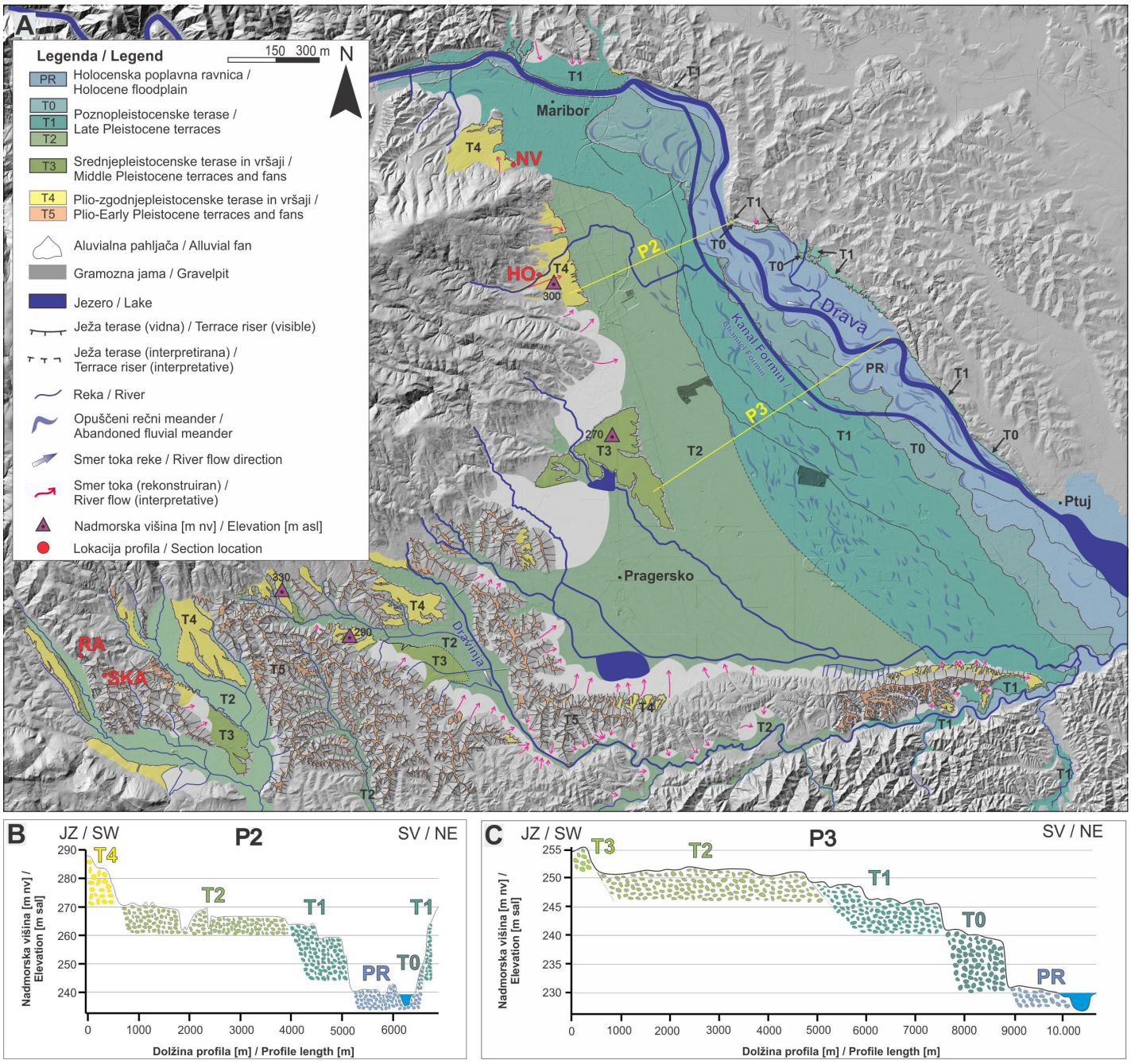

Fig. 3. Geomorphological analysis of the Pliocene-Quaternary surfaces of the Drava-Ptuj Basin. (A) Geomorphological map of the Plio-Early Pleistocene, Middle Pleistocene, Late Pleistocene and Holocene terraces and fans with locations of the studied sections marked (NV, HO, RA, SKA). (B, C) Topographic profiles P2 and P3, with present-day elevations of the terraces and fans.

Sl. 3. Geomorfološka analiza pliocensko-kvartarnih površinskih oblik Dravsko-Ptujskega bazena. (A) Geomorfološka karta plio-zgodnjepleistocenskih, srednjepleistocenskih, poznopleistocenskih in holocenskih teras in vršajev z označenimi lokacijami profilov (NV, HO, RA, SKA). (B, C) Topografska profila P2 in P3 z današnjimi višinami teras in vršajev.

gravels and clasts, respectively, were focused on Plio-Early Pleistocene sediments of terrace level T4 in sections NV (46.532506°, 15.615964°, 293 m a.s.l.) and HO (46.495161°, 15.626824°, 319 m a.s.l.), and sediments of terrace level T5 in sections SKA (46,3627381°, 15,416756°, 404 m a.s.l.) and RA (46,3691538°, 15,4047645°, 389 m a.s.l.).

liza prodov in klastov je bila osredotočena na plio-zgodnjepleistocenske sedimente na terasnem nivoju T4 v profilih NV (46.532506°, 15.615964°, 293 m n.v.) in HO (46.495161°, 15.626824°, 319 m n.v.) ter sedimente na terasnem nivoju T5 na lokacijah SKA (46,3627381°, 15,416756°, 404 m n.v.) in RA (46,3691538°, 15,4047645°, 389 m n.v.).

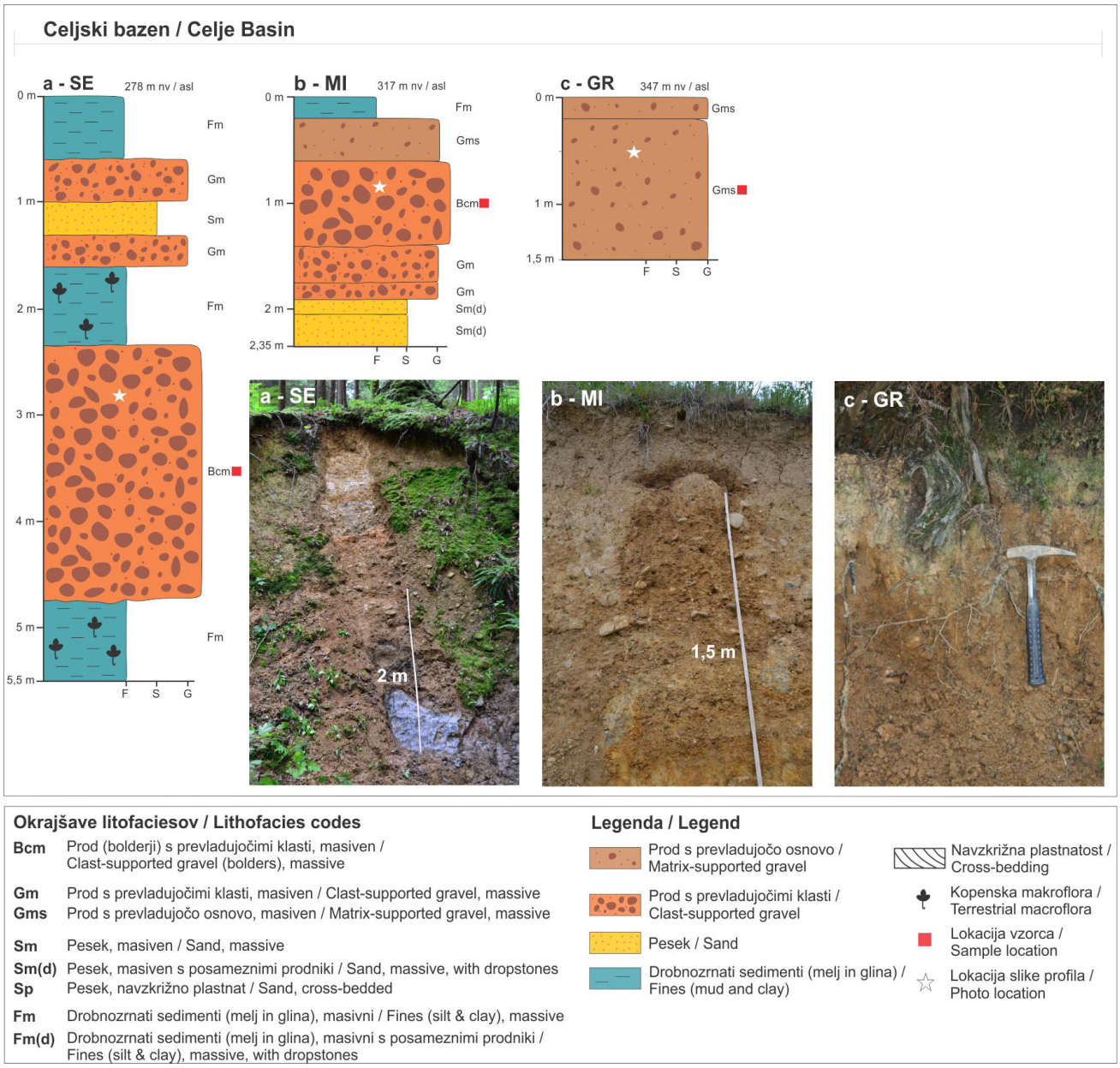

Fig. 4. Lithofacies of the Plio-Early Pleistocene sediments of the Celje Basin in sections Šešče (SE), Miklavž (MI) and Griže (GR). White stars indicate the parts of the sections presented in the photographs.

Sl. 4. Litofaciesi plio-zgodnjepleistocenskih sedimentov Celjskega bazena v profilih Šešče (SE), Miklavž (MI) in Griže (GR). Bele zvezde označujejo fotografirane dele profilov.

Lithofacies analysis of the sections and clast lithological analysis

In seven sections, eight different gravely, sandy and muddy lithofacies were recognized (Table 3). Contacts between the layers are gradual or in parts erosional. The thickness of the layers varies laterally and reach values from a few centimeters to approximately two meters. The sediments partly occur in lenses. Cross-lamination is present in some of the sandy layers and coalified plant fragments up to a few centimeters in size are present in fine-grained layers.

Litofaciesna analiza profilov in litološka analiza klastov

V skupno sedmih profilih je bilo ugotovljenih osem različnih litofaciesov (Tabela 3). Prisotni so prodnati, peščeni in muljasti sedimenti. Kontakti med posameznimi litofaciesi so postopni, mestoma tudi erozijski. Debelina plasti variira od nekaj centimetrov do približno dva metra ter se lateralno spreminja. Sedimenti se ponekod pojavljajo v lečah. Mestoma se v peščenih plasteh pojavlja navzkrižna plastnatost. Ponekod so bili v drobnozrnatih plasteh najdeni poogleneli fragmenti kopenskih rastlin veliki do nekaj centimetrov.

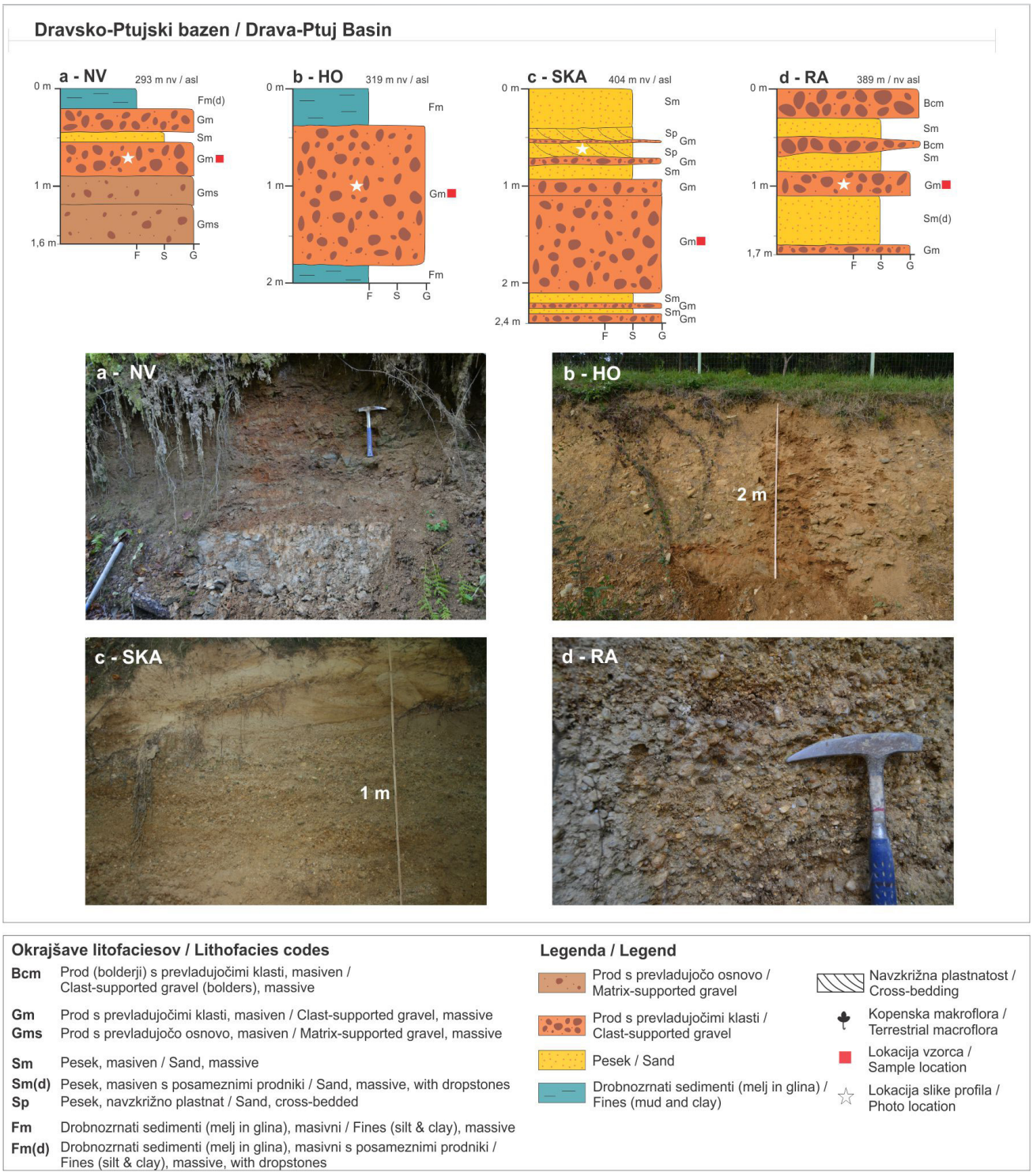

Fig. 5. Lithofacies of the Plio-Early Pleistocene sediments of the Drava-Ptuj Basin in sections Nova vas (NV), Hoče (HO), Škalce (SKA) and Radnana vas (RA). White stars indicate the parts of the sections presented in the photographs.

Sl. 5. Litofaciesi plio-zgodnjepleistocenskih sedimentov Dravsko-Ptujskega bazena v profilih Nova vas (NV), Hoče (HO), Škalce (SKA) in Radnana vas (RA). Bele zvezde označujejo fotografirane dele profilov.

The results of the clast lithological analysis are presented in tables 4 and 5 and on figures 6 and 7. In the CB, clasts of metamorphic, volcanic, volcaniclastic and clastic rocks occur, whereas in the DPB, metamorphic, volcanic, volcaniclastic and carbonate clasts are present (Fig. 8).

Rezultati litološke analize klastov so predstavljeni v tabelah 4 in 5 ter na slikah 6 in 7. Slika 8 podaja primerjavo litoloških analiz klastov obeh bazenov. V CB prevladujejo metamorfne, vulkanske in vulkanoklastčne ter klastične kamnine, v DPB pa metamorfne, vulkanske in vulkanoklastične ter karbonatne kamnine.

Table 3. Lithofacies codes and descriptions, interpretation of depositional setting and occurrences within the sections.
Tabela 3. Okrajšave in opisi litofaciesov, interpretacija sedimentacijskega okolja in pojavnost v profilih.

Litofacies code and definition / Okrajšava in definicija litofaciesa (Evans & Benn, 2004)		**Additional lithofacies description / Dodaten opis litofaciesa**	**Interpretation / Interpretacija**	**Occurrence in the sections / Pojavnost v profilih**
Bcm	Clast-supported gravel (bolders), massive / Prod (balvani) s prevladujočimi klasti, masiven	Well-sorted gravel, well-rounded clasts / Dobro sortiran prod, klasti dobro zaobljeni	Channel lag deposits and gravel (gravely-sandy) dunes; coarse-grained sediments in alluvial fans / Sedimenti korita in prodnate (prodnato-peščene) sipine; grobozrnati sedimenti v aluvialnih pahljačah	RA, SE
Gm	Clast-supported gravel, massive / Prod s prevladujočimi klasti, masiven	Sub- to well-rounded clasts, gravel locally highly weathered / Slabo do dobro zaobljeni klasti, v posameznih profilih prod močno preperel		NV, HO, SKA, RA, SE, MI
Gms	Matrix-supported gravel, massive / Prod s prevladujočo osnovo, masiven	Poorly- to moderately-sorted, angular to well-rounded clasts, locally highly weathered / Slabo do srednje sortiran prod, oglati do dobro zaobljeni klasti, mestoma močno prepereli		NV, MI, GR
Sm	Sand, massive / Pesek, masiven	In parts marmorized and pedogenized / Mestoma marmoriziran in pedogeniziran	Sand dunes / Peščene sipine	NV, SKA, RA, SE
Sm(d)	Sand, massive, with dropstones / Pesek, masiven, s posameznimi prodniki	In parts marmorized, sub-angular to well-rounded clasts / Mestoma marmoriziran, klasti pol-oglati do dobro zaobljeni		RA, MI
Sp	Sand, cross-bedded / Pesek, navzkrižno plastnat	/		SKA
Fm	Fines (silt and clay), massive / Drobnozrnati sedimenti (melj in glina), masivni	In parts marmorized and pedogenized with plant remains / Mestoma marmoriziran in pedogeniziran z rastlinskimi ostanki	Floodplain sediments and finegrained sediments in alluvial fans / Sedimenti poplavne ravnice in drobnozrnati sedimenti v aluvialnih pahljačah	HO, SE, MI
Fm(d)	Fines (silt and clay), massive with dropstones / Drobnozrnati sedimenti (melj in glina), masivni, s posameznimi prodniki	In parts marmorized and pedogenized; clasts sub- to well-rounded / Mestoma marmoriziran in pedogeniziran; klasti slabo do dobro zaobljeni		NV

Table 4. Microfacies of clasts of Plio-Early Pleistocene sediments and interpretation of the provenance in the Celje Basin. The term keratophyre was used in the Basic geological map (Buser, 1979; Premru, 1983). Although the term is outdated, we herein retain it, since the provenance analysis is based on the Basic geological map.

Tabela 4. Mikrofacies prodnikov plio-zgodnjepleistocenskih sedimentov in interpretacija provenience v Celjskem bazenu. Izraz keratofir je povzet po terminologiji Osnovne geološke karte (Buser, 1979; Premru, 1983). Ker primerjava provenience klastov temelji na Osnovni geološki karti, smo izraz obdržali kljub zastarelosti.

Lithogroup / Lito-skupina	**Lithotype / Litotip**	**General description / Splošni opis**	**Provenance interpretation / Interpretacija provenience**	**Key feature for provenance interpretation / Ključna lastnost za določitev provenience**
Metamorphic rocks / Metamorfne kamnine	Phyllitoid mica schist / Filitoidni sljudnat skrilavec	The rock consists of sparse lenticular augen of perthitic feldspar and quartz. Quartz and white mica are the main constituents. Very frequent are opaque minerals (mostly secondary) concentrated along foliation and cleavage. Tourmaline is sparsely present. / Kamnina vsebuje redka lečasta očesa perthitnega glinenca in kremena. Prevladujejo kremen in minerali sljud. Zelo pogosti so neprosojni minerali (večinoma sekundarnega izvora), ki so koncentrirani vzdolž foliacije in klivaža. Redek je turmalin.	Source rocks eroded (similar facies outcrop on the S Pohorje area (Hudinja stream drainage) / Izvorne kamnine erodirane (podobni faciesi izdanjajo na območju J Pohorja – potok Hudinja)	Metamorphic degree and facies / Stopnja metamorfoze in facies
Volcanic and volcaniclastic rocks / Vulkanske in vulkanoklastične kamnine	Keratophyre / Keratofir	The rock consists of glassy groundmass and phenocrysts of albitized plagioclases and biotite. Volcanic glass is altered to microcrystalline quartz, chlorite, sericite and locally calcite. / Kamnina vsebuje steklasto osnovo z vtrošniki albitiziranih plagioklazov, alkalnih glinencev, kremena, plagioklazov in biotita. Vulkansko steklo je spremenjeno v mikrokristalen kremen, albit, klorit, sericit in mestoma kalcit.	Triassic volcanic and volcanoclastic rocks (N, W and S slopes of the CB) / Triasne vulkanske in vulkanoklastične kamnine (S, Z in J pobočja CB)	Visible diagenesis, compact texture of the rock, typical mineral alteration / Vidni znaki diageneze, kompaktna struktura kamnine, značilne spremembe v mineralizaciji
	Fine- to coarse-grained tuff / Drobno do debelo-zrnati tuf	The rock consists of tuffaceous matrix altered to microcrystalline quartz, chlorite, sericite, muscovite, epidote and albite(?). It contains crystal grains of quartz, feldspars, oxidized mafic minerals, volcanic rock fragments and rare lapilli. / Kamnina je sestavljena iz tufske osnove, ki je spremenjena v mikrokristalen kremen, klorit, sericit, muskovit, epidot in albit(?). Vsebuje kristaloklaste kremena, glinencev in oksidiranih mafičnih mineralov ter vulkanske litične drobce in redke lapile. Kamnina je pogosto močno preperela.		
	Fine-grained vitric tuff / Drobno zrnati vitrični tuf	The rock consists of fine-grained tuffaceous matrix and glass shards of crystal grains. Volcanic glass is altered to microcrystalline quartz, phyllosilicate minerals and zeolites(?). Crystal grains belong to feldspars and subordinately quartz. Rare biotite is chloritized. / Kamnina vsebuje drobnozrnato tufsko osnovo in koščke stekla. Vulkansko steklo je spremenjeno v mikrokristalen kremen, filosilikatne minerale in zeolite(?). Kristalna zrna pripadajo glinencem in v manjši meri kremenu. Redek biotit je kloritiziran.	Oligocene Smrekovec series (wider area N and W from the CB) / Oligocenska Smrekovška serija (širše območje S in Z od CB)	Rock texture (without indicators of diagenesis), presence of glass shards / Struktura kamnine (ni znakov diageneze), dacitna sestava, vidne črepinjice stekla. (Kralj, 2016a, Kralj, 2016b)
Clastic rocks / Klastične kamnine	Siltstone to slate / Meljevec do skrilavi glinavec	The main constituents are white micas uniformly aligned along slaty cleavage. Sparse biotite is present. Sericite-chlorite aggregates are aligned transverse to slaty cleavage. The rock is strongly hydroscopic and impregnated by limonitic pigment. / Kamnina ima izrazito poudarjeno usmerjeno teksturo. Prevladuje bela sljuda, ki je orientirana vzdolž skrilave teksture. Redek je biotit. Sericitno-kloritni agregati so orientirani pravokotno na usmerjeno teksturo. Kamnina je močno higroskopična in impregnirana z limonitnim pigmentom.	Carboniferous (S slopes of the CB) / Karbon (J obronki CB)	Structure, texture, metamorphic degree and facies / Tekstura, struktura, stopnja metamorfoze in facies
	Very weakly metamorphosed quartz sandstone / Zelo nizko metamorforiziran kremenov peščenjak	The rock contains quartz, rare fragments of lithic grains (slate) and rare muscovite. Accessory minerals are opaque minerals, and rare rutile, tourmaline and zircon. Quartz-sericite matrix is recrystallized, often with directed growth and is intergrown with quartz grains on the rims. Anastomosing slaty cleavage developed with concentrations of opaque non-migrative component. / Kamnino sestavljajo kremen, redki odlomki litičnih zrn (glinastega skrilavca) in redek muskovit. Akcesorni so neprosojni minerali ter redek rutil, turmalin in cirkon. Kremenovo-sericitno vezivo je rekristalizirano, pogosto usmerjeno raščeno in se obodno prerašča s kremenovimi klasti. Med klasti je nastal povijajoč klivaž, v katerem je koncentrirana nemigrativna neprosojna komponenta.	Carboniferous (S slopes of the CB) / Karbon (J obronki CB)	Metamorphic degree and facies / Stopnja metamorfoze in facies

Table 5. Microfacies of clasts of Plio-Early Pleistocene sediments and interpretation of the provenance in the Drava-Ptuj Basin. The term keratophyre was used in the Basic geological map (Buser, 1979; Premru, 1983) and is for this reason retained, despite being outdated.

Tabela 5. Mikrofacies prodnikov plio-zgodnjepleistocenskih sedimentov in interpretacija provenience v Dravsko-Ptujskem bazenu. Izraz keratofir je povzet po terminologiji Osnovne geološke karte (Buser, 1979; Premru, 1983). Ker primerjava provenience klastov temelji na Osnovni geološki karti, smo izraz kljub zastarelosti obdržali.

Lithogroup / Lito-skupina	**Lithotype / Litotip**	**General description / Splošni opis**	**Provenance interpretation / Interpretacija provenience**	**Key feature for provenance interpretation / Ključna lastnost za določitev provenience**
Metamorphic rocks / Metamorfne kamnine	Amfibolitna skupina (epidotno amfibolski skrilavci do amfiboliti) / Amphibolitic group (epidote amphibole schists to amphibolites)	The rock consists of hornblend, epidote, clinozoisite, chlorite, feldspar and quartz (in some of the samples). Accessory minerals are rutile, titanite and opaque minerals. Some of the samples have pronounced foliation, others pronounced porphyroclastic texture. / Kamnina je sestavljena iz rogovače, epidota, klinozoisita, kloria, redko glinenca in kremena (v nekaterih vzorcih). Akcesorni so rutil, titanit in neprosojni minerali. Nekateri vzorci imajo izraženo foliacijo, drugi pa izrazito porfiroklastično strukturo.	Pohorje and Kozjak (W and N from the DPB) / Vzhodne Alpe - Pohorje in Kozjak (Z in S od DPB)	Typical facies of the Pohorje metamorphic complex / Značilen facies pohorskega metamorfnega kompleksa (Hinterlechner Ravnik 1971, 1973)
	Mica schists / Blestniki in muskovitni skrilavci	The rock consists of muscovite, quartz, garnet (mostly its relicts), chlorite, rare biotite (in parts chloritized), zoisite/clinozoisite, traces of accessory zircon, titanite, rutile, and opaque minerals). Schistose structure with pronounced foliation is present. / Kamnino sestavljajo muskovit, kremen, granati (večinoma njihovi relikti), klorit, redek biotit (mestoma kloritiziran), zoisit/klinozoisit, sledovi akcesornih mineralov cirkona, titanita, rutila in neprosojnih mineralov. Tekstura je skrilava z izrazito foliacijo. Nekateri vzorci so močno prepereli.	Eastern Alps (Pohorje and Kozjak area, also the surroundings of Ravne na Koroškem) (most probably eastern Pohorje and north of Maribor) / Vzhodne Alpe (najverjetneje vzhodno Pohorje in severno od Maribora)	Typical facies / Značilen facies
	Slate / Glinast skrilavec	Macroscopic texture seems massive. Microscopically, the rock has pronounced cleavage, expressed as preferred orientated sericite and chlorite. In-between them are grains of clastic quartz, feldspar, infrequent opaque minerals of primary and secondary origin, tourmaline, traces of zircon, apatite and epidote(?). Some sericite-chlorite aggregates and larger white mica flakes are oriented transverse to foliation. / Makroskopsko je kamnina videti masivna. Mikroskopsko je močno izražen klivaž poudarjen z usmerjenimi listki sericita in klorita. Vmes so zrna kremena, glinencev, redkih neprosojnih mineralov (primarnega in sekundarnega izvora), turmalina, sledovi cirkona, apatita in epidota(?). Posamezni sericitno-kloritni agregati in večji listki sljud so usmerjeni prečno na foliacijo.	Štalenskogorska serija (Z Kozjak in/ali SZ del Pohorja)/ Magdalensberg series (W Kozjak and/or NW part of the Pohorje area)	Typical facies / Značilen facies
	Quartzite of very low-grade metamorphism / Kvarcit zelo nizke stopnje metamorfoze	The rock contains of mineral clasts of quartz, tourmaline, opaque minerals rutile, titanite and zircon. It contains infrequent lithic grains of slate and phylite. Quartz grains have undulose extinction and serrated grain boundaries with small quantity of recrystallized matrix in between. The source rock of the quartzite represents "dirty" quartz sandstone presumably formed from Carboniferous clastic rocks from the zone of stronger dynamometamorphism. / Kamnina je sestavljena iz mineralnih klastov kremena, turmalina, neprosojnih mineralov, rutila, titanita in cirkona. Redka so litična zrna glinastega skrilavca in filita. Zrna kremena valovito potemnijo in se pogosto zobčasto preraščajo med seboj in z vmesnim vezivom. Kvarcit nastal iz nečistega kremenovega peščenjaka v coni močnejših dinamometamorfnih sprememb, predvidoma nastal iz karbonskih klastitov.	Carboniferous (Dravinja drainage, S from Slovenske Konjice) / Karbon (drenaža Dravinje, J od Slovenskih Konjic)	Typical facies / Značilen facies
Volcanic and volcaniclastic rocks / Vulkanske in vulkanoklastične kamnine	Keratophyre / Keratofir	The rock is extensively altered. The former glassy groundmass is altered to microcrystalline quartz and phyllosilicate minerals. Phenocrysts of feldspars and mafic minerals can only be anticipated by shape remains. The rock is impregnated with Fe-oxides and hydroxides. / Kamnina je močno spremenjena. Nekdanja steklena osnova je spremenjena v mikrokristalen kremen in filosilikate. Oblika popolnoma preperelih vtrošnikov nakazuje na glinence in mafične minerale. Kamnina je popolnoma oksidirana, impregnirana z železovimi oksidi in hidroksidi.	The rock does not outcrops in the today's drainage area of the sampling locality SKA (lack of detail geological map or eroded outcrops?) / Triasne vulkanske in vulkanoklastične kamnine. Kamnina ne izdanja v današnjem drenažnem območju vzorčne lokacije SKA (manjka natančna geološka karta ali pa so izdanki popolnoma erodirani)	Visible diagenesis, compact texture of the rock, typical mineral alteration / Vidni znaki diageneze, kompaktna struktura kamnine, značilne spremembe v mineralizaciji.
	Keratophyre tuff / Keratofirski tuf	The rock consists of fragments of altered feldspars, biotite and volcanic lithic fragments. The matrix is altered to microcrystalline quartz, Fe-oxides and kaolinite. Some of the samples contain welded glass shards. / Kamnino sestavljajo fragmenti spremenjenih glinencev, biotita in vulkanskih litičnih drobcev. Osnova je spremenjena v mikrokristalen kremen, železove okside in kaolinit. Nekateri vzorci vsebujejo nataljene črepinjice stekla.		

Carbonate rocks / Karbonatne kamnine	Limestone breccia / Apnenčeva breča	Polimiktna apnenčeva breča (*Tubiphytes obscurus* Maslov, *Calcitornella/Tuberitina,* Schwagerinidae, *Epimastopora* sp., *Anthracoporella spectabilis* Pia); klasti apnenca in peščenjaka, v vezivu tudi fuzulinide / Polymict limestone breccia (*Tubiphytes obscurus* Maslov, *Calcitornella/Tuberitina,* Schwagerinidae, *Epimastopora* sp. , *Anthracoporella spectabilis* Pia); limestone and sandstone clasts, isolated fusulinid foraminifera	Lower Permian breccia: Dovžanova soteska and Trogkofel Formations (west of the DPB; the area of Slovenske Konjice) / Spodnjepermska breča: Dovžanosoteška in Trogkofelska formacija (zahodno od DPB; okolica Slovenskih Konjic)	*Tubiphytes*-like microproblematica / Tubifitna mikroproblematika (*Tubiphytes obscurus* Maslov), foraminifera / foraminifere (*Calcitornella/Tuberitina,* Schwagerinidae), algae /alge (*Epimastopora* sp. in *Anthracoporella spectabilis* Pia)
	Marly limestone / Laporast apnenec	Bioclastic wackstone with terregenous admixture / Bioklastični wackstone s terigeno primesjo	Upper Permian or Lower Triassic limestone / Zgornjepermski ali spodnjetriasni apnenec	/
	Micritic limestone / Mikritni apnenci	Mudstone with dessication voids, intraclastic wackstone and calcimicrobial boundstone (with foraminifera *Endotriadella* or *Ammobaculites*, *"Trochammina"* sp.), bioclastic wackstone and packstone (*Agathammina* sp., *Aulotortus* ex gr. *sinuosus* Weynschenk, ?*Aulotortus friedli* (Kristan-Tollmann)). / Mudstone z izsušitvenimi porami, intraklastični wackstone in kalcimikrobni boundstone (s foraminiferami *Endotriadella* ali *Ammobaculites*, »Trochammina« sp.,), bioklastični wackstone in packstone (s foraminiferami *Agathammina* sp., *Aulotortus* ex gr. *sinuosus* Weynschenk, ?*Aulotortus friedli* (Kristan-Tollmann))	Ladinian to lower Carnian shallow marine facies / Ladinijski do spodnjekarnijski plitvomorski faciesi	foraminifera / foraminifere »Trochammina« sp., ?*Variostoma pralongense* Kristan-Tollmann, *Aulotortus* ex gr. *sinuosus* Weynschenk, ?*Aulotortus friedli* (Kristan-Tollmann); microproblematica / mikroproblematika (*Tubiphytes obscurus* Maslov)
	Calcarenite / Kalkarenit	Bioclastic-intraclastic grainstone (foraminifera *Glomospira* sp., *Reophax* sp., ?*Variostoma pralongense* Kristan-Tollmann, microproblematica *Tubiphytes obscurus* Maslov) / Bioklastični-intraklastični grainstone (foraminifere *Glomospira* sp., *Reophax* sp., ?*Variostoma pralongense* Kristan-Tollmann, mikroproblematika *Tubiphytes obscurus* Maslov)		
	Partly recrystallized limestone / Delno rekristaliziran apnenec	Bioclastic packstone or wackstone / Bioklastični packstone ali wackstone		
	Dolomite / Dolomit	Crystalline dolomite / Kristalinični dolomit		
	Micritic limestone / Mikritni apnenec	Radiolarian wackstone, radiolarian-filament wackstone / Radiolarijski wackstone, radiolarijski-filamentni wackstone	Middle to Upper Triassic (alternatively Jurassic or Cretaceous?) open marine facies / Srednje- do zgornjetriasni (ali jurski in kredni?) odprtomorski faciesi	Radiolarians and/ or thin-shelled bivalves / Radiolariji in/ali tankolupinaste školjke
	Calcarenite / Kalkarenit	Intraclastic grainstone (resediment?) / Intraklastični grainstone (resediment?)		
	Partly recrystallized limestone / Delno rekristaliziran apnenec	Peloid filament grainstone / Peloidni filamentni packstone		
	Limestone breccia / Apnenčeva breča	Intraclastic rudstone / Intraklastični rudstone		
	Calcarenite / Kalkarenit	Oolithic grainstone / Ooidni grainstone	Mesozoic oolithic limestones / Mezozojski ooidni apnenci	/
	Calcarenite / Kalkarenit	Rudist packstone and bioclastic packstone (*Cuneolina*?, *Moncharmontia*) / Rudistni packstone in bioklastični packstone (*Cuneolina*?, *Moncharmontia*)	Upper Cretaceous shallow water rudist limestone from Gossau group (W of the PB; the area of Zreče) / Zgornjekredni plitvomorski rudistni apnenec Gossauske grupe (Z od DPB; okolica Zreč)	rudist fragments, foraminifera / Fragmenti rudistnih školjk, foraminifere (*Cuneolina*?, *Moncharmontia*)

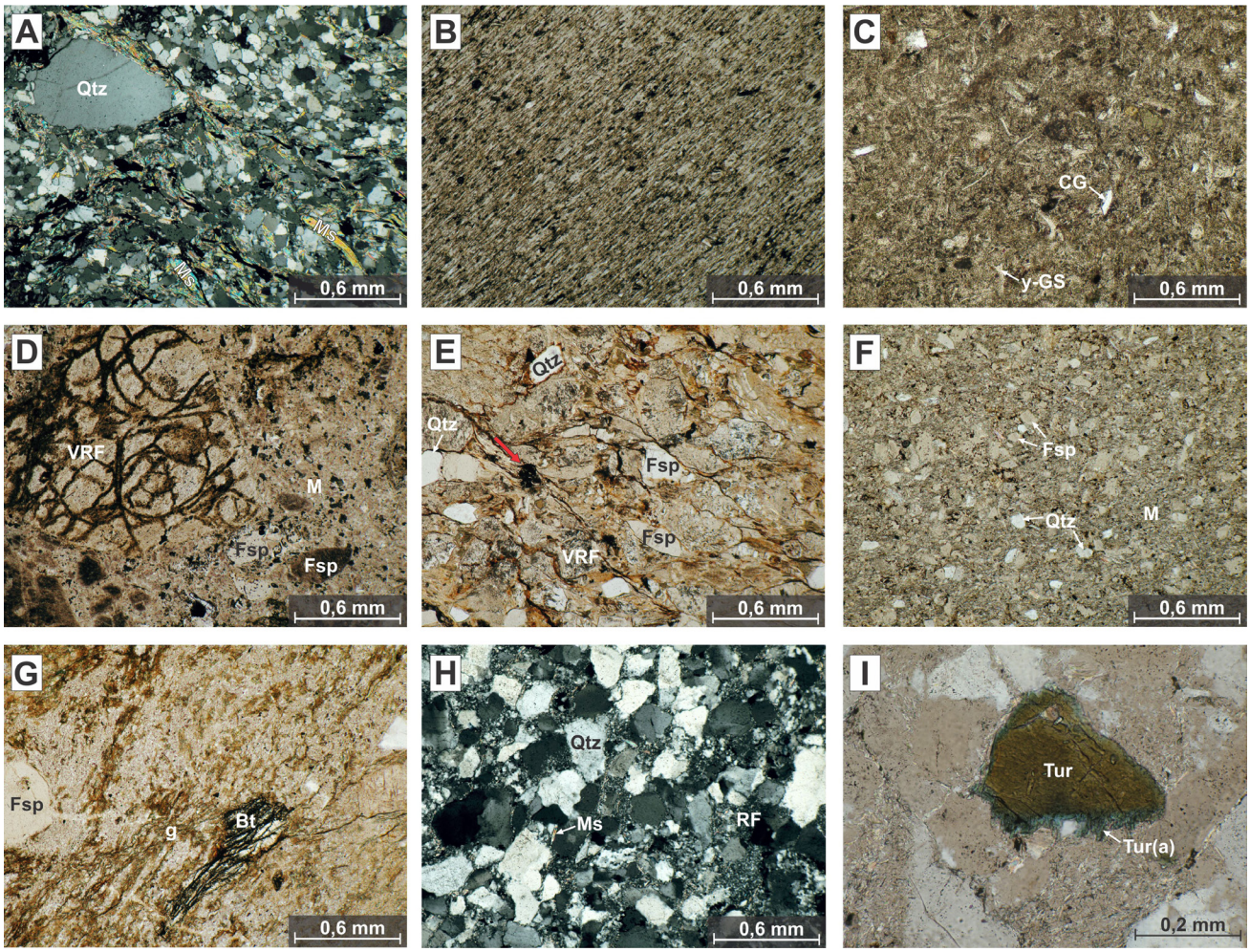

Fig. 6. Microfacies of the clasts in the Plio-Early Pleistocene sediments in the Celje Basin. (A) Slate with quartz and white mica as the main constituents. Rare quartz porphyroblasts are characteristic. (B) Foliated siltstone to shale with uniform preferred orientation of white mica forming continuous cleavage. (C) Fine-grained vitric (dacitic) tuff from the Oligocene Smrekovec series. (D) Glassy volcanic lithic fragment with perlitic texture in the sample of keratophyre lapilli tuff (Triassic). Some of the feldspars are extremely altered. (E) Coarse-grained (meta)tuff with incipient clevage marked with red arrow (Triassic). (F) Fine-grained tuff (Triassic). (G) Weathered (oxidized) biotite phenocryst in glassy groundmass altered to chlorite and microcrystalline quartz in keratophyre (Triassic). (H) Low-grade metamorphic heterogranular quartz sandstone. (I) Authigenic growth of tourmaline in the sample of slightly metamorphosed quartz sandstone. Abbreviations: Qtz – quartz, Ms - muscovite, CG – crystal grains, y-GS – y-shaped glass shards, VRF – volcanic lithic fragment, Fsp – feldspar, M – tuffaceous matrix, Bt – biotite, g – glassy groundmass, RF – rock fragment, Tur – tourmaline, Tur(a) -authigenic tourmaline.

Sl. 6. Mikrofaciesi klastov plio-zgodnjepleistocenskih sedimentov v Celjskem bazenu. (A) Filitoidni sljudnat skrilavec (peščeni metameljevec); v sestavi prevladujetakremen in muskovit. Značilni so redki porfiroklasti kremena. (B) Skrilav meljevec do glinavec s prednostno orientacijo mineralov belih sljud, ki oblikujejo kontinuiran klivaž – predvidena starost: karbon. (C) Drobnozrnat vitrični (dacitni) tuf iz Smrekovške serije oligocenske starosti. (D) Steklen vulkanski litični drobec s perlitno strukturo v vzorcu keratofirskega lapilnega tufa (trias). Nekateri K-glinenci so popolnoma prepereli. (E) Debelozrnati (meta) tuf z neizrazitim klivažem označenim z rdečo puščico (trias). (F) Drobnozrnati tuf (trias). (G) Preperel (oksidiran) vtrošnik biotita v steklasti osnovi, ki je spremenjena po kloritu in mikrokristalnem kremenu v keratofirju (trias). (H) Šibko metamorfoziran heterozrnat kremenov peščenjak. (I) Avtigena rast turmalina v neznatno metamorfoziranem heterozrnatem kremenovem peščenjaku. Okrajšave: Qtz – kremen, Ms - muskovit, CG – kristalna zrna, y-GS – črepinjice vulkanskega stekla y oblike, VRF – vulkanski litični drobec, Fsp – K-glinenec, M – tufska osnova, Bt – biotit, g – steklena osnova, RF – litični drobec, Tur - turmalin, Tur(a) -avtigeni turmalin.

Discussion

Sedimentary environment and morphostratigraphy

Pliocene-Quaternary sediments of the CB and DPB were deposited in alluvial environment, as indicated by lithofacies analysis of sections (Figs. 4, 5 and Table 3) and geomorphological analysis of sedimentary bodies (Figs. 2 , 3). Based on the results of sedimentological and geomor-

Diskusija

Okolje sedimentacije in morfostratigrafija

Pliocensko-kvartarni sedimenti so se na območju CB in DPB odlagali v aluvialnemokolju, kar je razvidno iz facielne analize profilov (sl. 4, 5 in Tabela 3) in geomorfološke analize sedimentacijskih teles (sl. 2, 3). Na podlagi rezultatov sedimentološke in geomorfološke analize interpretiramo, da so bili na območju CB vzorčeni rečni

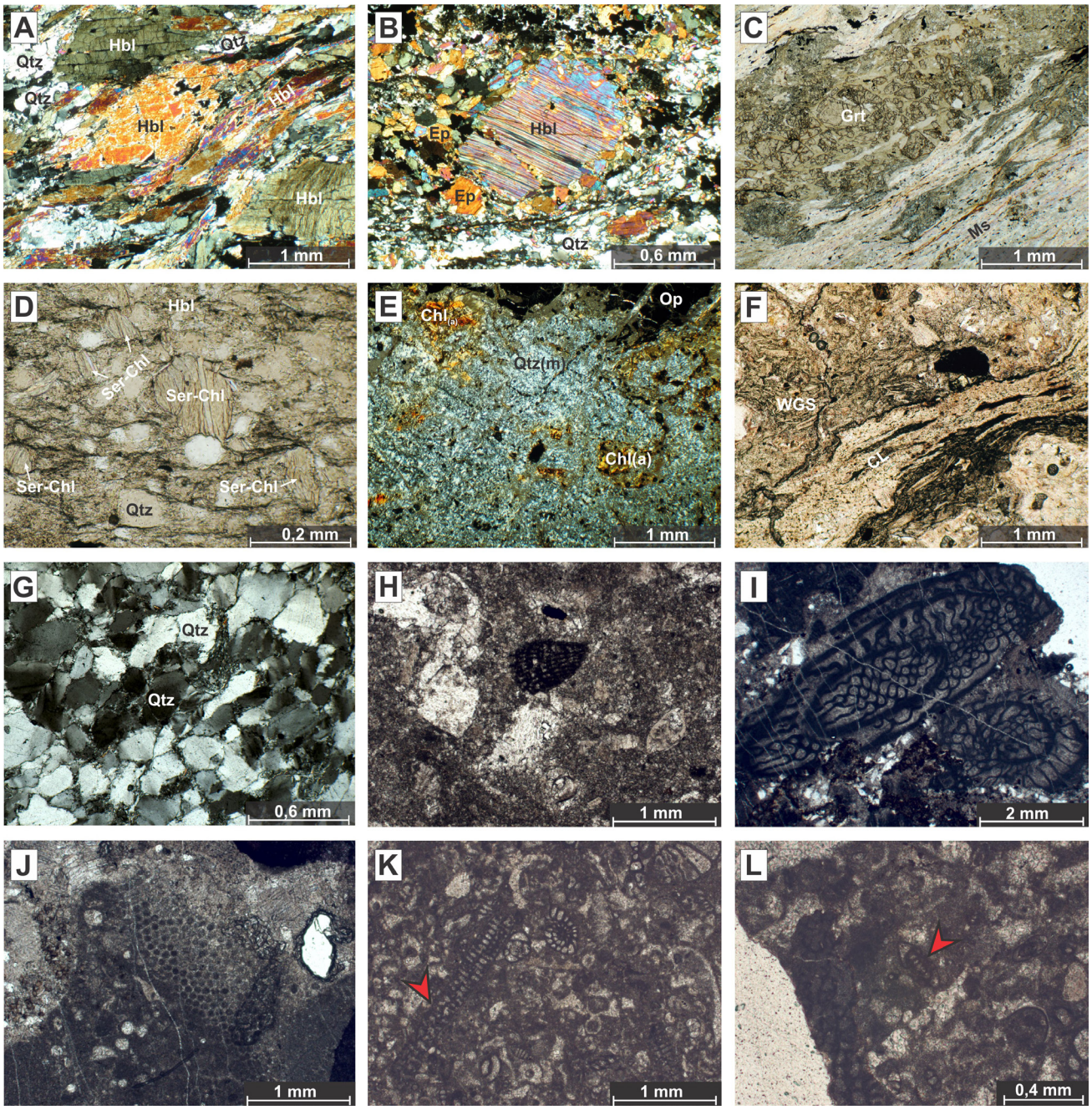

Fig. 7. Microfacies of the clasts in the Plio-Early Pleistocene sediments in the Drava-Ptuj Basin. (A) Lenticular and streched blasts of hornblende oriented along foliation plains in medium- to coarse-grained amphibolite. (B) Deformational lamellae in porphyroclast of hornblende embedded in fine-grained hornblende, plagioclase, epidote, quartz and opaque minerals in epidote amphibole schist. (C) Disintegrated and chloritized garnet surrounded by muscovite and some quartz in retrograde altered (mylonitized) mica schist. (D) Sericite-chlorite aggregates oriented transverselyl to anastomosing cleavage in slate. (E) Altered glassy keratophyre (Triassic). (F) Elongated collapsed lapilli in the sample of welded keratophyre tuff (Triassic). (G) Undulose extinction of quartz in the sample of low-grade metamorphic quartz sandstone. (H) Fragment of foraminifera Cuneolina sp. in rudist packstone (Upper Cretaceous). (I) Foraminifera of the family Schwagerinidae (Paraschwagerina? sp.) in the intergranular space in breccia (lower Permian). (J) Alga Anthracoporella spectabilis Pia in a breccia clast (lower Permian). (K) Foraminifera Cuneolina (marked with the arrowhead) and undetermined foraminifera in bioclastic packstone (Upper Cretaceous). (L) Foraminifera Moncharmontia sp. in bioclastic packstone (Upper Cretaceous). Abbreviations: Qtz – quartz, Qtz(m) – microcrystalline quartz, Hbl – hornblende, Ep – epidote, Grt – garnet, Ms – muscovite, Ser – sericite, Chl – chlorite, Chl(a) – altered chlorite, Op – opaque mineral, WGS – welded glass shards, CL – collapsed lapilli.

Sl. 7. Mikrofaciesi klastov plio-zgodnjepleistocenskih sedimentov v Dravsko-Ptujskem bazenu. (A) Lečasti blasti rogovače in vlaknata rogovača vzdolž foliacije v srednje do debelozrnatem amfibolitu. (B) Deformacijske lamele v porfiroklastu rogovače obdane z drobno rogovačo, plagioklazom, epidotom, kremenom in neprosojnimi minerali v vzorcu epidotno amfibolskega skrilavca. (C) Zdrobljen in kloritiziran granat obdan z muskovitom in malo kremena v vzorcu retrogradno spremenjenega (milonitiziranega) blestnika. (D) Sericitno-kloritni agregati orientirani pravokotno na povijajoči klivaž v vzorcu glinastega skrilavca. (E) Preperel steklast keratofir (trias). (F) Močno razpotegnjen lapil s porušeno strukturo v vzorcu nataljenega keratofirskega tufa (trias). (G) Valovita potemnitev kremena v šibko metamorfoziranemu kremenovemu peščenjaku (H) Fragment foraminifere Cuneolina sp. v rudistnem packstone-u (zgornja kreda). (I) Foraminifere družine Schwagerinidae (Paraschwagerina? sp.) v vezivu breče (spodnji perm). (J) Alga Anthracoporella spectabilis Pia v klastu znotraj apnenčeve breče (spodnji perm). (K) Foraminifera Cuneolina (označena velika hišica na levi) in številne druge nedoločene vrste v bioklastičnem packstone-u (zgornja kreda). (L) Foraminifera rodu Moncharmontia v bioklastičnem packstone-u (zgornja kreda). Okrajšave: Qtz – kremen, Qtz(m) – mikrokristalen kremen, Hbl – rogovača, Ep – epidot, Grt – granat, Ms – muskovit, Ser – sericit, Chl – klorit, Chl(a) – preperel klorit, Op – neprosojni mineral, WGS – nataljene črepinjice stekla, CL – lapil s porušeno strukturo.

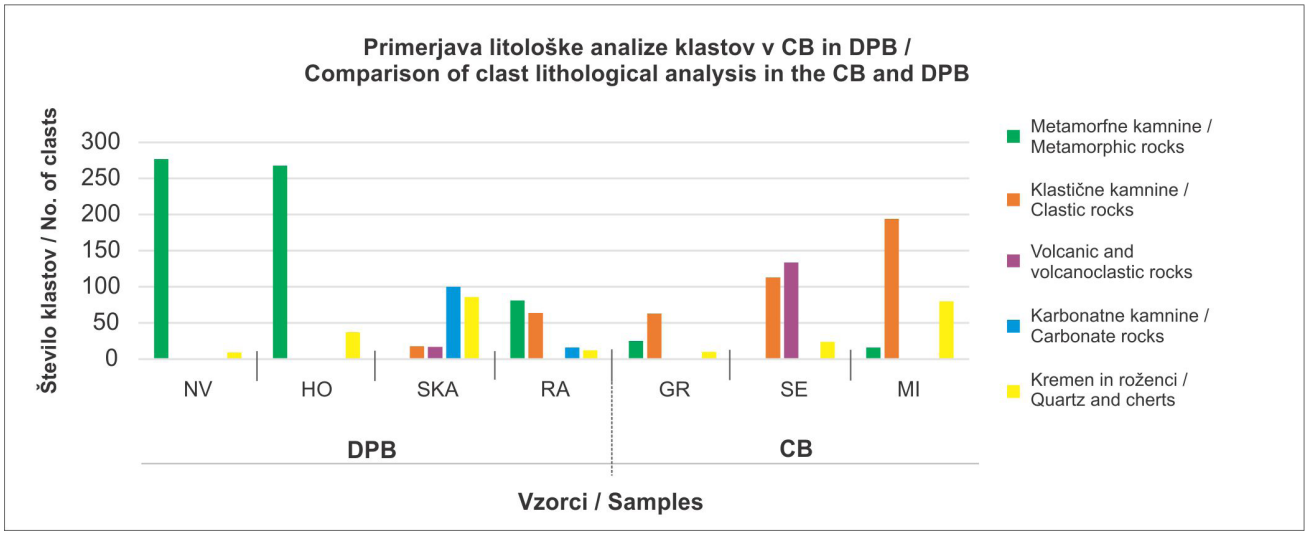

Fig. 8. Comparison of the clast lithological analysis of the Plio-Early Pleistocene sediments in the Celje (CB) and Drava-Ptuj Basin (DPB). Lithogroups correspond to those in tables 4 and 5.

Sl. 8. Primerjava litološke analize klastov plio-zgodnjepleistocenskih sedimentov v Celjskem (CB) in Dravsko-Ptujskem bazenu (DPB) pri čemer lito-skupine kamnin ustrezajo skupinam v tabelah 4 in 5.

phological analyses, we interpret sediments from CB (sections GR, SE, MI) as river sediments and from DPB as river sediments (sections RA and SKA) and alluvial fan sediments (sections NV and HO). Lithofacies Bcm, Gm and Gms were deposited in river channels and alluvial fans. Sandy lithofacies Sm, Sm(d) and Sp are present in sand dunes, while the finest sediments Fm and Fm(d) are floodplain sediments and fine-grained part of alluvial fans. Coarse-grained and poorly sorted facies with subangular to well-rounded clasts suggest relatively short transport, which agrees with the results of clast provenance analysis (see the following section of the discussion).

Alluvial sediments in CB and DPB were depositing simultaneously with the erosional base lowering and relative surface uplifting, as suggested by the inverse terrace staircase (Fig. 9). The floodplain surface (PR) in CB and DPB has well visible morphology with abandoned river meanders that are very well preserved indicating braided river system active prior to regulation of Savinja and Drava river channels. The estimated age of this floodplain deposits is Holocene. The age of higher terrace levels was interpreted based on traditional morphostratigraphy (Buser, 1979; Mioč & Žnidarčič, 1989), comparison with other basins in the region (e.g.: Krško Basin: Verbič, 2004; Velenje Basin: Drobne, 1967, and Rakovec, 1968; Ljubljana Basin: Pavich & Vidic, 1993) and on new observations from this study.

Low-level terrace group encompasses terraces T0 and T1 in CB and terraces T0, T1 and T2 in DPB, which are up to 8 m above the floodplain in

sedimenti (profili GR, SE, MI), na območju DPB pa rečni sedimenti (profila RA in SKA) ter sedimenti aluvialnih pahljač (profila NV in HO). Litofaciesi Bcm, Gm in Gms so se odlagali v rečnih koritih ter v nanosih aluvialnih pahljač. Peščeni litofaciesi Sm, Sm(d) in Sp predstavljajo peščene sipine, najbolj drobnozrnati sedimenti Fm in Fm(d) pa sedimente poplavnih ravnic ter drobnozrnate nanose aluvialnih pahljač. Debelozrnati in slabo sortirani prodnati faciesi s slabo do dobro zaobljenimi klasti nakazujejo relativno kratek transport, kar je v skladu z rezultati analize provenience klastov (glej nadaljevanje diskusije).

Odlaganje aluvialnih sedimentov v CB in DPB se je odvijalo sočasno z zniževanjem erozijske baze in relativnim dvigovanjem površja, kar se odraža v inverzni stratigrafiji teras (sl. 9). Površina poplavne ravnice (PR) v CB in DPB ima jasno razvidno morfologijo in zelo dobro ohranjene opuščene rečne meandre, ki nakazujejo na prepletajoč rečni sistem Savinje in Drave pred regulacijo strug. Ocenjena starost poplavne ravnice je holocen. Višje ležečim terasnim nivojem in vršajem so pripisane interpretativne starosti na podlagi tradicionalne morfostratigrafije (Buser, 1979; Mioč & Žnidarčič, 1989), primerjave z drugimi bazeni v regiji (npr.: Krški bazen: Verbič, 2004; Velenjski bazen: Drobne, 1967; Rakovec, 1968; Ljubljanski bazen: Pavich & Vidic, 1993) ter na podlagi novih opazovanj, ki so predmet te študije.

Spodnji terasni nivo obsega terasi T0 in T1 v CB ter terase T0, T1 in T2 v DPB, ki se nahajajo

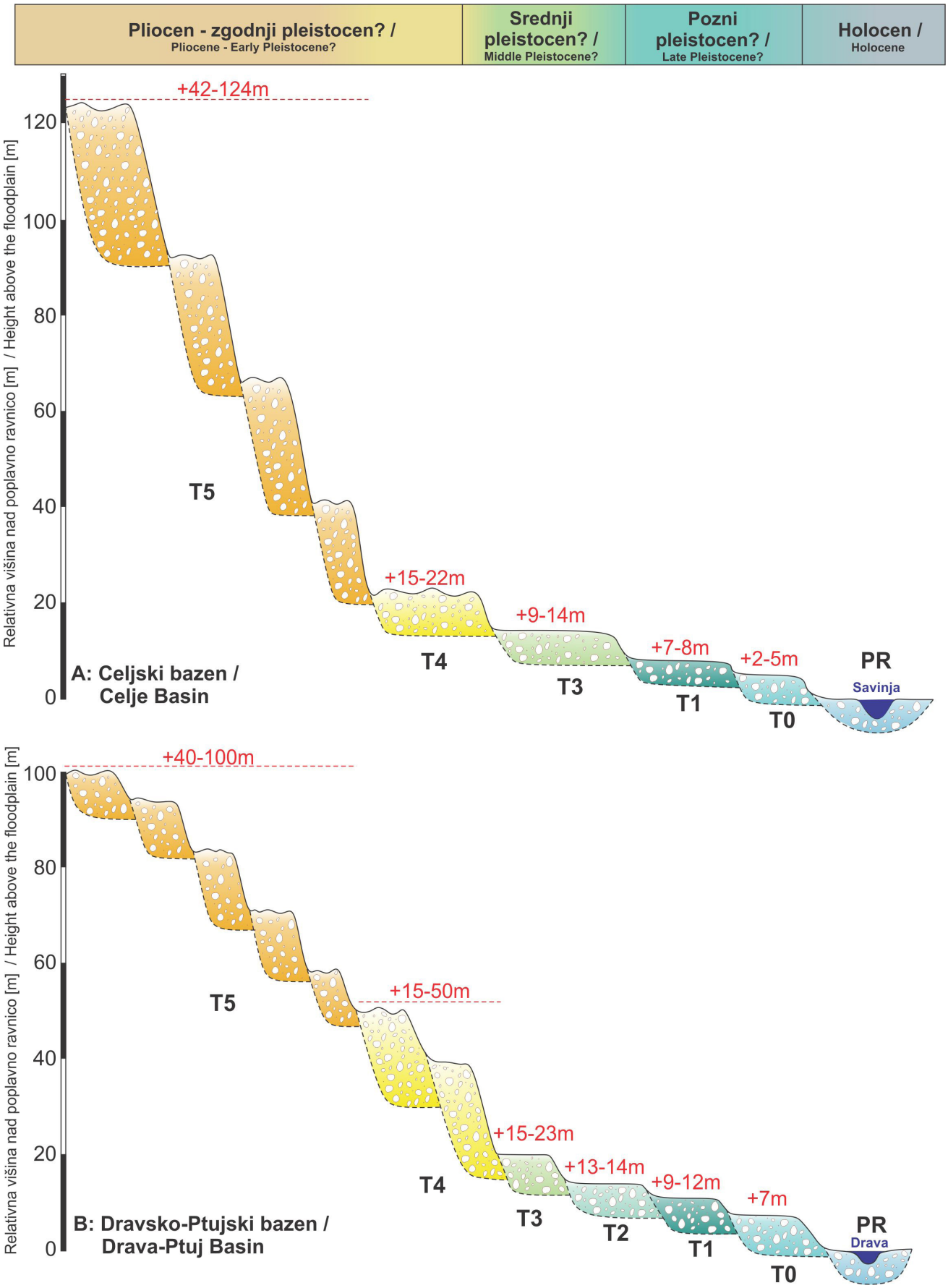

Fig. 9. Schematic profile of the terrace and fan systems in the (A) Celje Basin and (B) Drava-Ptuj Basin with levels (T0, T1, T2, T3, T4 in T5) marked, together with their relative heights above the Holocene floodplain (PR).

Sl. 9. Shematska profila sistema teras in vršajev v (A) Celjskem in (B) Dravsko-Ptujskem bazenu z označenimi nivoji (T0, T1, T2, T3, T4 in T5) ter njihovimi relativnimi višinami nad holocensko poplavno ravnico (PR).

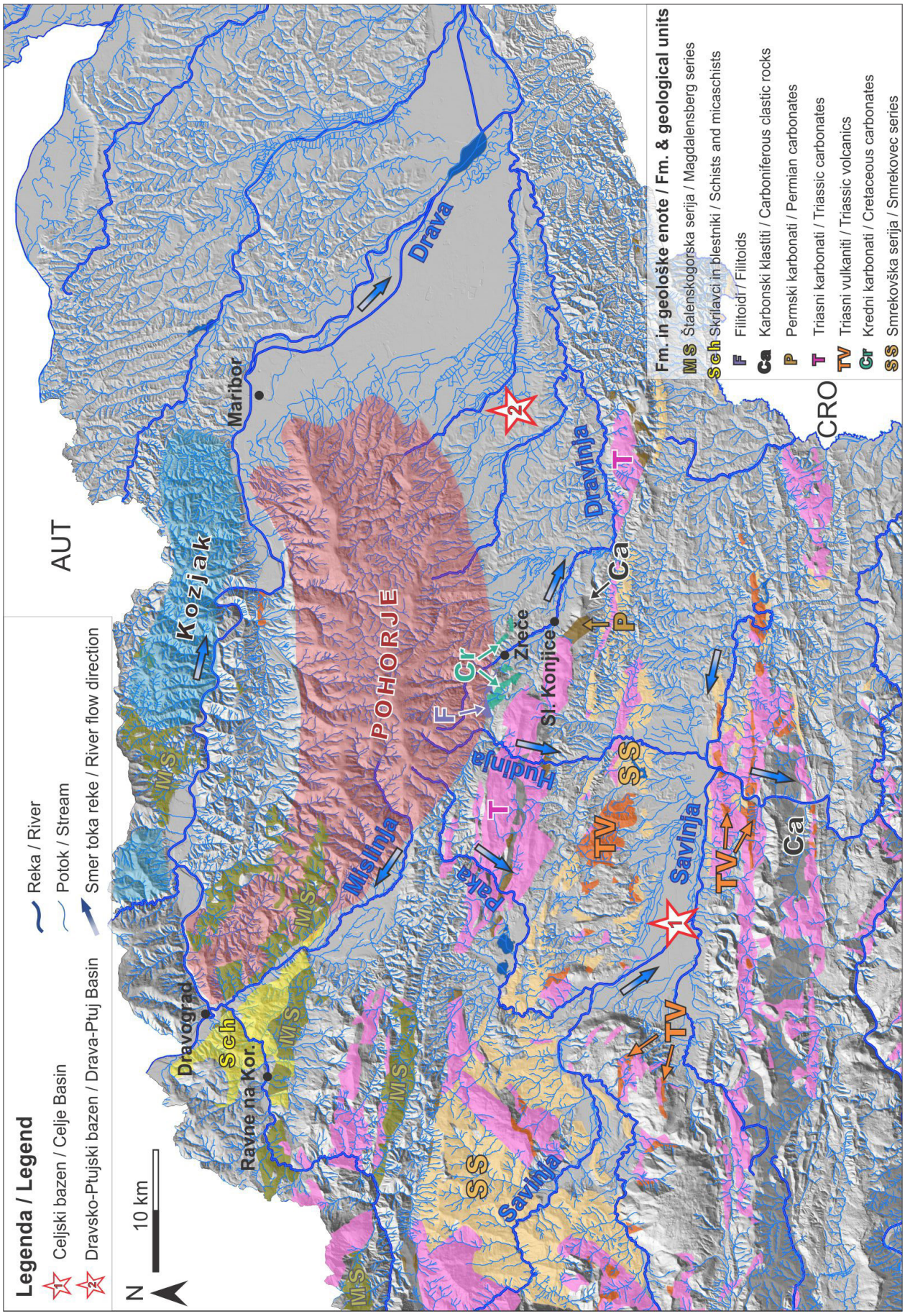

Fig. 10. Interpretation of the source areas of Plio-Early Pleistocene gravel deposits in the Celje (1) and Drava-Ptuj Basins (2).

Sl. 10. Interpretacija izvornih območij plio-zgodnjepleistocenskih prodnatih sedimentov v Celjskem (1) in Dravsko-Ptujskem bazenu (2).

CB and up to 14 m above the floodplain in DPB. Terrace treads and risers are very well preserved, terrace treads are typically wide and (almost) flat surfaces. Lidar data show that the terrace treads have preserved abandoned river meanders, which are common and moderate to well preserved in DPB, whereas rare and poorly preserved in CB. Terrace treads gently slope in direction consistent with the flow of present streams. Sediments of these terraces are composed of carbonate gravel exhibiting only low degree of weathering. Terrace riser's heights (e.g. between T0 and T1; between T1 and T2) are relatively low (2–5 m). Since the terraces T0, T1 and T2 have well preserved geomorphic traces of former river system, which is typical for youngest Quaternary periods (e.g. Blum & Törnqvist, 2000; Lewin & Macklin, 2003), and are older than the Holocene floodplain, we interpret the age of the low-level terrace group of Late Pleistocene.

Middle-level terrace group comprises terraces and fans T3 occurring at up to 14 m above the floodplain in CB and up to 23 m above the floodplain in the DPB. Similarly, as in low-level terrace group, their gravel is composed of carbonate clasts and exhibits low degree of weathering. Their terrace treads slope in direction consistent with the flow of present streams. In contrast with the low-level terrace group, the degree of terrace preservation is lower, and terrace treads occur in considerably less extensive surfaces in middle-level terrace group. Therefore, we interpret the terraces and fans T3 are of Middle Pleistocene age.

High-level terrace group encompasses terraces and fans T4 and T5. Compared to middle-level terrace group, T4 and T5 have several levels occurring at different relative height from approximately 40 to 124 m above the floodplains. Terrace, and fan surfaces are strongly degraded. Surfaces are not flat anymore but have developed a rough relief because of degradation processes. Often the surfaces are only remnants of former morphology of sedimentary bodies, preserved in narrow, flat-crest tops. Risers are clearly visible as scarps between two terrace levels but are often strongly eroded by ephemeral and perennial streams. Risers are considerably higher than risers in low- and middle-level terrace group. The degree of weathering of sediments (clasts) in CB is significantly higher than in low- and middle-level terrace group, the prominent difference is also in lithologic composition of gravel, which is here exclusively non-carbonate. In DPB, sediments of this group are as well much more

do približno 8 m nad poplavno ravnico v CB in do 14 m nad poplavno ravnico v DPB. Terase in ježe teras so zelo dobro ohranjene, pri čemer terasne ravnine zavzemajo značilno široke in ravne površine. Lidarski posnetki kažejo na površinah teras opuščene rečne meandre, ki so ponekod pogostejši in srednje dobro do dobro ohranjeni (DPB), ponekod pa redki in slabše ohranjeni (CB). Terasne površine vpadajo v smeri današnjih vodotokov. V sestavi sedimentov nastopa zgolj malo preperel karbonatni prod. Višina ježe teras med sosednje ležečimi terasami (npr. med T0 in T1; med T1 in T2) je relativno majhna (od 2 do 5 m). Glede na to, da imajo terase T0, T1 in T2 dobro ohranjene geomorfne sledove nekdanjega rečnega sistema, kar je značilno za najmlajša obdobja kvartarja (npr. Blum & Törnqvist, 2000; Lewin & Macklin, 2003), in da so starejše od holocenske PR, je interpretirana starost spodnjega terasnega nivoja pozni pleistocen.

Srednji terasni nivo obsega terase in vršaje T3, ki se nahajajo do 14 m nad poplavno ravnico v CB in do 23 metrov nad poplavno ravnico v DPB. Čeprav je prod, tako kot v spodnjem terasnem nivoju, nepreperel in karbonatne sestave, površine pa prav tako vpadajo v smeri današnjih vodotokov, so slednje za stopnjo slabše ohranjene in obsegajo znatno manjše površine kot terase spodnjega terasnega nivoja. Zato so terase in vršaji T3 interpretirani kot srednjepleistocenski.

Zgornji terasni nivo obsega terase in vršaje T4 in T5. Za razliko od srednjega terasnega nivoja je v T4 in T5 grupiranih več nivojev površin, ki se pojavljajo na različnih relativnih višinah od približno 40 do 124 m nad poplavnimi ravnicami. Površina teras in vršajev je močno degradirana. Ni več ravna, temveč je hrapava zaradi delovanja degradacijskih procesov in pogosto omejena le na ostanke nekdanjih površinskih oblik, ohranjenih v ozkih grebenih. Ježe teras so jasno razvidne kot stopnje med dvema nivojema teras, vendar so pogosto močno prečno erodirane z občasnimi ali stalnimi potoki, višine ježa pa so znatno višje kot v nižjem in srednjem terasnem nivoju. Stopnja preperelosti sedimentov (prodnikov) v CB je znatno višja kot v spodnjem in srednjem terasnem nivoju, izrazita pa je tudi razlika v litološki sestavi proda, ki je tu izključno nekarbonaten. V DPB so sedimenti prav tako znatno bolj prepereli, a razlike v litološki sestavi z nižjima sistemoma teras ni, kar je bilo ugotovljeno že v preteklih raziskavah (Mioč & Žnidarčič, 1989). Terase in vršaji zgornjega terasnega nivoja so bile tako v skladu s podatki Osnovne geološke karte (Buser, 1979;

weathered, but there is no difference in lithologic composition compared to lower terrace groups, as already pointed out by previous investigations (Mioč & Žnidarčič, 1989). Terraces and fans of high-level terrace group were thus interpreted as Plio-Early Pleistocene, which agrees with Basic geologic map (Buser, 1979; Mioč & Žnidarčič, 1989). It is important to note, however, that sediment deposition in terraces, related to strong climate changes, typical for Quaternary, as well as numerical age dating from other comparable intramountain basins in the region (Cline et al., 2016) and previous observations (e.g. Kuščer, 1993) indicate mostly Early Pleistocene and not Pliocene age.

Provenance of the Plio-Early Pleistocene sediments

The interpretation of the provenance of the Plio-Early Pleistocene sediments in the CB and the DPB is based on clast lithological analysis. We focused on the indicative lithologies; these are lithologies that can be attributed to certain formation with high reliability and that are outcropping on a relatively small area (Büchi, 2016). Interpretation of the possible source areas of Plio-Early Pleistocene gravel deposits in the CB and DPB is depicted in the figure 10.

Celje Basin

The provenance of the Plio-Early Pleistocene sediments in the CB is constrained with metamorphic, volcanic and volcaniclastic and clastic rocks (Table 4). In the group of metamorphic rocks filitoid mica schist is the main indicative lithology, which was sampled from the sediments on the southern margin of the CB. The occurrence of this type of metamorphic rocks is limited to the area of the Eastern Alps, outcropping only north of the CB (in the area of the Hudinja spring). However, the dip of the sampled terraces is indicating the sediment supply from the south. Regarding these two contradictory arguments, we propose that ether i) these metamorphic clasts are resedimented from older (possibly Miocene; Ivančič et al., 2017) deposits from the south of the CB, which were originally deposited from the north or that ii) the present day dip of the terrace surfaces is a result of post-sedimentary tectonics and does not correspond to the direction of the drainage system in the Plio-Early Pleistocene.

In the group of the volcanic and volcaniclastic rocks Triassic and Oligocene clasts were identified. The outcrops of Triassic volcanic rocks are located on the northern, western and southern

Mioč & Žnidarčič, 1989) uvrščene v plio-zgodnji pleistocen. Pri tem je potrebno poudariti, da način odlaganja sedimentov v terasah, ki je pogojen z močnejšimi podnebnimi nihanji, značilnimi za obdobje kvartarja, podatki numeričnih datacij v drugih primerljivih medgorskih bazenih v regiji (Cline et al., 2016) ter predhodna opazovanja (npr. Kuščer, 1993) nakazujejo v večji meri zgodnjepleistocensko in ne pliocensko starost.

Provenienca plio-zgodnjepleistocenskih sedimentov

Provenienca plio-zgodnjepleistocenskih sedimentov je interpretirana na osnovi litološke analize klastov. Med vsemi določenimi litotipi so za interpretacijo provenience prodnatih sedimentov CB in DPB pomembne tako imenovane indikativne litologije, t.j. litologije, ki se lahko z veliko stopnjo zanesljivosti pripišejo določeni formaciji in izdanjajo na relativno majhnem območju (Büchi, 2016). Današnja prostorska razširjenost formacij, ki bi lahko bile izvor indikativnih litologij, prepoznanih v plio-pleistocenskih prodnih sedimentih CB in DPB, je prikazana na sliki 10.

Celjski bazen

Provenienco plio-zgodnjepleistocenskih sedimentov v CB nakazujejo skupine metamorfnih, vulkanskih in vulkanoklastičnih ter klastičnih kamnin (Tabela 4).

V prvi skupini je indikativna litologija filitoidni sljudnati skrilavec, najden v sedimentih na južnem robu CB. Danes izdanja v bližini izvira potoka Hudinja, severno od CB, ne pa tudi na južnih obronkih CB. Nagib vzorčenih teras sicer nakazuje pritok iz juga CB, vendar pa se izvorne metamorfne kamnine, omejene na območje Vzhodnih Alp, pojavljajo le severno od CB. Glede na nasprotujoča si argumenta se porajajo dodatne interpretacije, in sicer i) da so prodniki omenjene litologije resedimentirani iz nanosov starejših paleopritokov, ki so prihajali s severa (miocenski sedimenti?; Ivančič et al., 2017) ali pa ii), da je današnji nagib teras rezultat post-sedimentacijske tektonike in ne ustreza smeri drenaže v plio-zgodnjempleistocenu.

V skupini vulkanskih in vulkanoklastičnih kamnin so bili ugotovljeni prodniki triasnega in oligocenskega vulkanizma. Prvi se pojavlja v manjših erozijskih ostankih na severnih, zahodnih in južnih pobočjih CB, drugi pa na širšem območju severno in zahodno od CB, kar ustreza provenienci paleo-Savinje (Buser, 2010).

hillslopes of the CB and occur as smaller erosional remnants (Buser, 2010). The outcrops of the Oligocene volcanic rocks can be found in a wider area north and west of the CB. This corresponds to the provenance of paleo-Savinja and its tributaries.

The outcrops of clastic Carboniferous rocks are located on the southern, northern and northwestern hillslopes of the CB (Buser, 2010) which corresponds to the provenance of the paleo-Paka, paleo-Savinja and their tributaries.

Source areas of Plio-Early Pleistocene sediments are therefore located in the vicinity of the deposits. Hence, we interpreted that the drainage system of the paleo-Savinja and its tributaries in Pliocene-Quaternary corresponds to the present one.

Drava-Ptuj Basin

In the DPB two indicative lithogroups were identified; metamorphic rocks are prevailing in the NV and HO samples and carbonate rocks present solely in RA and SKA samples (Table 5).

Varieties of amphibolite and epidote amphibole schists originate from Pohorje Massif and Kozjak mountain range (Buser, 2010). Mica schists and schists corresponds to the lithologies that are typical for the wider area of the Eastern Alps. The clasts likely originate from the Pohorje Massif and Kozjak mountain range, however the provenance from the area between Ravne na Koroškem and Dravograd and further away from Eastern Alps in Austria cannot be excluded. Slate varieties were interpreted to originate from Magdalensberg series located on the western part of the Pohorje Massif and in Kozjak mountain range (Buser, 2010). The group of metamorphic rocks in the NV and HO samples was therefore attributed to the provenance of paleo-Drava and its tributaries.

Carbonate rocks were identified solely in the RA and SKA samples which corresponds to the provenance of paleo-Dravinja and its tributaries. Permian carbonate rocks were attributed to Lower Permian Dovžanova soteska and Trogkofel Formations that can be found in the area around Slovenske Konjice (Buser, 2010). Varieties of Triassic carbonate rocks are located in the area west and north of the Slovenjske Konjice and Zreče. Upper Cretaceous carbonate rocks were attributed to rudist limestone from Gossau group (Pleničar, 1993; Moro et al., 2016) and occupy area east and west of Zreče (Buser, 2010).

Igneous rocks were, despite the immediate vicinity of the Pohorje Massif, not found in any of studied localities. Based on structural, radi-

Klastične kamnine karbonske starosti se danes v primarni legi pojavljajo na južnih, severnih in severozahodnih obronkih CB (Buser, 2010), kar ustreza provenienci paleo-Pake, paleo-Savinje ter njunih pritokov. Izvorna območja plio-zgodnjepleistocenskih sedimentov se torej nahajajo v relativni bližini obravnavanih rečnih nanosov, rečna mreža v pliocenu-kvartarju pa je potekala v skladu z današnjo drenažo, torej s smerjo toka Savinje in manjših potokov z obronkov CB.

Dravsko-Ptujski bazen

V DPB sta bili ugotovljeni dve indikativni skupini kamnin, in sicer metamorfne kamnine, ki močno prevladujejo v vzorcih NV in HO in karbonatne kamnine, ki se pojavljajo izključno v vzorcih RA in SKA (Tabela 5).

Različki amfibolita in epidotno amfibolskega skrilavca so bili pripisani območju Pohorja in Kozjaka (Buser, 2010). Značilnosti skupine blestnikov in skrilavcev ustrezajo različkom, ki se pojavljajo na širšem območju Vzhodnih Alp. Predvidevamo donos s Pohorja in Kozjaka, manj verjetno pa iz bolj oddaljenega območja med Ravnami na Koroškem in Dravogradom in seveda naprej iz avstrijskega dela Vzhodnih Alp. Skupino glinastih skrilavcev (ang. slate) smo povezali s Štalenskogorsko serijo, ki se nahaja na zahodnem Pohorju in na Kozjaku (Buser, 2010) ter jo danes erodirajo pritoki Drave. Skupini metamorfnih kamnin v vzorcih NV in HO je bila tako pripisana drenaža paleo-Drave in njenih pritokov.

Karbonatne kamnine so bile ugotovljene le v vzorcih RA in SKA, kar generalno ustreza drenaži paleo-Dravinje in njenih pritokov. Permske karbonatne kamnine so bile pripisane spodnjepermski Dovžanosoteški in Trogkofelski formaciji, ki izdanjata v okolici Slovenskih Konjic (Buser, 2010). Pojavnost različkov triasnih karbonatnih kamnin je omejena na območje zahodno in severno od Slovenskih Konjic in Zreč. Zgornjekredne kamnine so opredeljene kot rudistni apnenci Gossauske grupe (Pleničar, 1993; Moro et al., 2016), ki izdanjajo vzhodno in zahodno od Zreč (Buser, 2010).

Kljub pričakovanjem, magmatskih kamnin s Pohorja na vzorčenih lokacijah nismo našli. Glede na dosedanje strukturne, radiometrične in paleomagnetne raziskave (Márton et al. 2006; Trajanova et al. 2008; Fodor et al. 2008; Trajanova, 2013) se osnovna morfologija Pohorja, kljub levi (ccw) rotaciji bloka, v času kvartarja ni bistveno spremenila. Zato sklepamo, da je bil tudi drenažni sistem podoben današnjemu. Kot je razvidno s slik 1 in 3, nobeden od današnjih vodotokov,

ometric and paleomagnetic analyses (Márton et al., 2006; Trajanova et al., 2008; Fodor et al., 2008; Trajanova, 2013) the morphology of the Pohorje Massif in the Quaternary, despite its counterclockwise rotation, did not changed significantly. Therefore, the drainage system was presumably similar as today. None of the present-day streams reach up to the granodioritic pluton. (Figs. 1, 3). Besides, the relief of its eastern part in the late Miocene is modeled to be significantly higher and gravitationally disintegrated in the latest Miocene-Pliocene (Trajanova, 2013), which would yield that erosion and transport of the granodiorite to the DPB in the Quaternary was even less likely.

The results of the provenance analysis indicate two different source areas of the Plio-Early Pleistocene sediments; paleo-Drava and paleo-Dravinja. Moreover, the river system in the Plio-Early Pleistocene is similar to the present one, which corresponds to the previous studies in the area of the Eastern Alps (e.g. Keil and Neubauer, 2009).

Enigmatic carbonate clasts in the "Plio-Quaternary" sediments?

In the wider Alpine foreland area, there are several examples from Switzerland (Graf, 1993; Preusser et al., 2011), Germany (Doppler et al., 2011; Ellwanger et al., 2011) and Austria (van Husen & Reitner, 2011), where the criteria for distinguishing different terraces is the presence/absence of carbonate clasts. A similar model is currently applied in the Krško Basin, where Plio-Early Pleistocene gravel (Globoko Alloformation, Verbič, 2008) is characterized as non-carbonate gravel (e.g. Poljak, 2017). However, several authors (Verbič, 2008; Mencin Gale, unpublished data) report an exception in the Libna locality. The absence of carbonate clasts was in the previous studies explained with i) in-situ dissolution of the carbonates (Kuščer, 1993) or with ii) dissolution of the carbonate gravel during the transport and resedimentation (Verbič, 2008). Both explanations are therefore climate-related. On the contrary, carbonate clasts were reported in several "Plio-Quaternary" basins in the region; the Velenje Basin (Mioč, 1978; Kralj et al., 2018) and DPB (Mioč & Žnidarčič, 1989; this study). Therefore, we propose an alternative explanation that the presence of the carbonate clasts in these basins is not climate-related but rather dependent from the vicinity of the carbonate source rocks and the evolution of the drainage network.

ki prečijo obravnavano območje, ne sega do granodioritnega plutona. Glede na model nastanka Pohorskega tektonskega bloka (Trajanova, 2013) je bil relief njegovega vzhodnega dela v času poznega miocena celo znatno višji in je gravitacijsko razpadal koncem miocena in v pliocenu. Zaradi tega je erozija in transport granodiorita na obravnavano območje še manj verjetna.

Rezultati analize provenience nakazujejo dve glavni izvorni območji plio-zgodnjepleistocenskih sedimentov DPB, in sicer provenienci paleo-Drave in paleo-Dravinje. Nadalje, rečna mreža je v plio-zgodnjempleistocenu potekala v skladu z današnjo, kar je v skladu z drugimi opazovanji na širšem območju Vzhodnih Alp (npr. Keil and Neubauer, 2009).

Enigmatični karbonatni prodniki v »pliokvartarnih « sedimentih?

V širšem prostoru alpskega predgorja, kot na primer v Švici (Graf, 1993; Preusser et al., 2011), Nemčiji (Doppler et al., 2011; Ellwanger et al., 2011) in v Avstriji (van Husen & Reitner, 2011), terase pogosto ločujejo na podlagi vsebnosti karbonatnih prodnikov. Podoben kriterij za ločevanje različnih prodnatih zasipov je trenutno uveljavljen tudi v Krškem bazenu. Eden od kriterijev za ločevanje Plio-zgodnjepleistocenskih sedimentov Krškega bazena (Globoška aloformacija; Verbič, 2004) od mlajših sedimentov je prisotnost izključno nekarbonatnega proda (npr. Poljak, 2017), čeprav Verbič (2008) navaja izjemo prisotnosti karbonatnega proda na območju Libne (potrjeno tudi z osebnimi podatki Mencin Gale). Odsotnost karbonatnih prodnikov v plio-zgodnjepleistocenskih sedimentih Krškega bazena je možno pojasniti na dva načina: i) in-situ raztapljanje že odloženega karbonatnega proda (Kuščer, 1993), ali ii) raztapljanje karbonatnega proda med večkratno resedimentacijo rečnih nanosov (Verbič, 2008). Obe razlagi torej širše gledano pogojujeta podnebno-odvisen proces. Nasprotno so bili »pliokvartarni« karbonatni prodniki dokumentirani v nekaterih drugih medgorskih bazenih v regiji, na primer v Velenjskem bazenu (Mioč, 1978; Kralj et al., 2018) in v DPB (Mioč & Žnidarčič, 1989; pričujoča študija). Ob navedenih dejstvih se tako pojavi dodatna interpretacija, da v omenjenih bazenih ne gre pogojevati vsebnosti karbonatnih prodnikov s podnebnimi procesi, temveč z bližino izvornega območja karbonatnih kamnin in razvojem rečne mreže.

Conclusions

Investigation of Plio-Early Pleistocene sediments in the Celje and Drava-Ptuj basins bring new insights on the genesis, composition, morphostratigraphy and provenance of these sediments. Due to higher resolution obtained with detailed morphostratigraphy in this paper, we propose that the former chronostratigraphic name of the studied unit "Plio-Quaternary" is replaced with "Plio-Early Pleistocene". Plio-Early Pleistocene, Middle Pleistocene and Late Pleistocene sediments were deposited in alluvial environments and are preserved in several terrace and fan levels. Interpreted terrace and fan ages are based on several morphological and sedimentological criteria. The low-level terrace group encompasses terraces T0, T1 and T2 with an interpreted Late Pleistocene age. The middle-level terrace group represented by terraces and fans T3 is attributed to the Middle Pleistocene. The high-level terrace group comprised of terraces and fans T4 and T5 is interpreted to the Plio-Early Pleistocene.

The provenance of Plio-Early Pleistocene sediments is attributed to local source areas, which is supported by facies analysis of sediments, suggesting short transport, and provenance analysis of clasts. Metamorphic clasts in Plio-Early Pleistocene sediments of the Celje Basin originate from the southern Pohorje Massif, while clasts of volcanic, volcaniclastic and clastic rocks originate from northern, western and southern hillslopes of the Celje Basin. This is consistent with drainage of the paleo-Savinja and its tributaries. Clasts of metamorphic rocks in Plio-Early Pleistocene deposits of the Drava-Ptuj Basin probably originate mostly from Pohorje Massif and Kozjak area, and carbonate clasts are presumably from surroundings of Slovenske Konjice and Zreče. The provenance of clasts from Drava-Ptuj Basin is therefore related to the drainages of paleo-Drava, paleo-Dravinja and their tributaries. Our results thus indicate that the drainage in Plio-Early Pleistocene corresponded to present one, in agreement with other observations from the Eastern Alps.

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Zaključki

Raziskave plio-zgodnjepleistocenskih sedimentov v Celjskem in Dravsko-Ptujskem bazenu so pokazale nova spoznanja na področju geneze, sestave, morfostratigrafije in provenience sedimentov. Zaradi višje ločljivosti, ki temelji na detajlni morfostratigrafiji v tem članku opuščamo do sedaj ustaljeno kronostratigrafsko ime enote »pliokvartar« ter predlagamo ime plio-zgodnjepleistocenski sedimenti. Plio-zgodnjepleistocenski, srednjepleistocenski in poznopleistocenski sedimenti so se odlagali v rečnem okolju ter so ohranjeni v več terasnih in vršajnih nivojih. Interpretirane starosti teras in vršajev temeljijo na več morfoloških in sedimentoloških kriterijih. Spodnji terasni nivo obsega terase T0, T1 in T2 z interpretirano poznopleistocensko starostjo. Srednji terasni nivo obsega terase in vršaje T3, ki jim je bila pripisana srednjepleistocenska starost. Zgornji terasni nivo obsega terase in vršaje T4 in T5 z interpretirano plio-zgodnjepleistocensko starostjo.

Provenienca plio-zgodnjepleistocenskih sedimentov je bila pripisana lokalnim izvornim območjem, kar potrjuje facielna analiza sedimentov, ki kaže na krajši transport, kot tudi analiza provenience klastov. Metamorfni klasti v plio-zgodnjepleistocenskih sedimentih v Celjskem bazenu izvirajo iz območja južnega Pohorja, klasti vulkanskih, vulkanoklastičnih in klastičnih kamnin pa s severnih, in zahodnih in južnih obronkov Celjskega bazena. Pri tem je potrebno upoštevati možnost, da so lahko nekateri klasti resedimentirani in ne odražajo smeri transporta v plio-zgodnjempleistocenu. Generalno pojavnost izvornih kamnin ustreza drenaži paleo-Savinje in njenih pritokov. Prodniki metamorfnih kamnin v plio-zgodnjepleistocenskih nanosih Dravsko-Ptujskega bazena verjetno izvirajo predvsem z območja Pohorja in Kozjaka, karbonatni prodniki pa domnevno izvirajo iz okolice Slovenskih Konjic in Zreč. Izvorno območje klastov iz Dravsko-Ptujskega bazena je torej pogojeno z drenažo paleo-Drave in paleo--Dravinje ter njunih pritokov. Rezultati tako iz Celjskega kot iz Dravsko-Ptujskega bazena potrjujejo, da je bila drenaža v plio-zgodnjempleistocenu podobna kot danes, kar je v skladu z drugimi opazovanji na širšem območju Vzhodnih Alp.

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