Lost and found: Roman surveying of municipal territories on the northern Adriatic islands, Croatia

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The introduction of airborne laser scanning (ALS) technology in the Mediterranean region over the past decade has significantly increased opportunities for archaeological research. Archaeological remote sensing has proven to be a versatile tool with numerous applications beyond simple site mapping. One approach is the large-scale interpretation of ALS data, which allows for the analysis of the stratigraphic information contained within the data. This is particularly useful for analysing the rich remains of past land use in the karst landscapes of coastal Croatia.
The Roman dry stone walls of the Kvarner islands of Krk and Cres serve as an example. These structures outline the framework backbone of Roman surveying; however, due to their poor state of preservation, many remains can only be identified through ALS data rather than aerial photography. An absolute chronology for these features was established using the OSL profiling and dating method (OSL-PD), providing a date range of AD 200 ± 100. These results can be considered the first clear evidence of surveying municipal lands on the Croatian islands.

KEY WORDS: Airborne laser scanning, LiDAR, OSL dating, Roman survey, *scamnatio*, Kvarner Islands, Roman land use

Uvođenje tehnologije zračnog laserskog skeniranja (ALS) tijekom proteklog desetljeća znatno je povećalo mogućnosti arheoloških istraživanja u mediteranskom području. Arheološka daljinska detekcija pokazala se kao svestran alat, koji pored jednostavnih kartiranja nalazišta omogućuje i brojne druge primjene. Jedan od pristupa je opsežna interpretacija ALS podataka, koja omogućuje analizu stratigrafskih informacija sadržanih u podatcima. Takav pristup je posebno koristan kod analize brojnih ostataka nekadašnje uporabe zemljišta u krškim krajolicima priobalne Hrvatske.
Jedan takav primjer su rimski suhozidi na kvarnerskim otocima Krku i Cresu, koji ocrtavaju okosnicu rimske izmjere zemljišta. No, zbog loše očuvanosti, mnogi ostatci suhozida mogu se prepoznati samo putem ALS podataka, a ne na zračnim fotografijama. Apsolutna kronologija ovih objekata uspostavljena je korištenjem metode OSL profiliranja i datiranja (OSL-PD), koja daje raspon datiranja od 200 ± 100 g. po. Kr. Dobiveni rezultati nude prve jasne dokaze mjerenja municipalnih zemljišta na hrvatskim otocima.

KLJUČNE RIJEČI: zračno lasersko skeniranje (ALS), LiDAR, OSL datiranje, rimska parcelacija, *scamnatio*, kvarnerski otoci, rimsko korištenje zemljišta

Introduction

The process of extending Roman power, involving the assimilation of newly incorporated territories into the structures of Roman rule, included spatial aspects such as urbanisation, land surveying, and infrastructure development – what Clifford Ando has called the "organisation of the landscape" (2006: 183). The imprint of land surveying, particularly the use of a Roman cadastral grid system, can still be observed in the contemporary landscape of many former Roman provinces. Such grid systems (mainly *centuriae*) reflect historical changes brought about by the implementation of Roman practices. Brian Campbell (2000: lxi) concisely captures the essence of Roman surveying: "In conclusion, throughout Roman history the drawing of lines on the ground (and subsequently on maps) was important in order to demarcate territorial boundaries, city boundaries, public land, imperial estates, and private property." A substantial number of books and articles have been published on the subject of Roman land surveying (e.g., Dilke 1971; Settis 1983; Lewis 2001), which even has a dedicated specialist journal, *Agri Centuriati – International Journal of Landscape Archaeology*. Over the past two decades, the subject of Roman land surveying has been approached in the journal through various disciplines, including archaeology, ancient history, epigraphy, geography, and Roman law.

The phenomenon of Roman surveying is significant to the archaeology of the Croatian coast. Spanning over 500 km, the region encompasses most of the so-called eastern Adriatic, which also includes the coastlines of Montenegro and Albania. Evidence of Roman interest in the area dates back to the 3rd century BC; following a series of conflicts with local tribes (e.g., Šašel Kos 1986), this led to the establishment of the provinces of Histria and Illyricum/Dalmatia (Matijašić 2009). The urbanisation of the Croatian coast is reflected in the history of the *coloniae Parentium* (Poreč), *Pola* (Pula), *Iader* (Zadar), *Salona* (Solin), *Narona* (Vid/Metković), and *Epidaurum* (Cavtat) (Suić 1976). According to Robert Matijašić (2018, with older literature), their origins can be traced back to the late period of Caesar's reign. Roman land surveying has been confirmed for most of them (Suić 1955). The region of Istria, with *centuriatio* around Pola and Parentium, represents the most extensively researched area (e.g., Matijašić 1988; Marchiori 2010; Bulić 2012; Popović et

Uvod

Proces širenja rimske vlasti, koji je uključivao asimilaciju pripojenih teritorija u strukture rimske vladavine, obuhvaćao je i prostorne aspekte kao što su urbanizacija, izmjera zemljišta (parcelacija) i razvoj infrastrukture – ono što je Clifford Ando nazvao „organizacijom krajolika" (2006: 183). Trag izmjere zemljišta, a pogotovo uporaba rimskog katastarskog mrežnog sustava, može se uočiti i u današnjem krajoliku mnogih bivših rimskih provincija. Takvi mrežni sustavi (uglavnom centurije) odražavaju povijesne promjene koje je donijelo uvođenje rimske prakse. Brian Campbell (2000: lxi) sažeto opisuje bit rimske izmjere zemljišta: „Zaključno, kroz cijelu rimsku povijest, povlačenje crta na zemlji (a potom i na kartama) bilo je važno kako bi se obilježile teritorijalne granice, gradske granice, javna zemljišta, carski posjedi i privatno vlasništvo." O rimskoj izmjeri zemljišta objavljen je znatan broj knjiga i članaka (npr. Dilke 1971; Settis 1983; Lewis 2001), a stručni časopis *Agri Centuriati – International Journal of Landscape Archaeology* posvećen je isključivo toj temi. U protekla dva desetljeća, temi rimske izmjere zemljišta pristupano je u časopisu kroz različite discipline, uključujući arheologiju, antičku povijest, epigrafiju, geografiju i rimsko pravo.

Fenomen rimske izmjere zemljišta značajan je za arheologiju hrvatske obale. Protežući se na više od 500 km, to područje obuhvaća većinu istočnog Jadrana, u koji spadaju i obale Crne Gore i Albanije. Tragovi rimskog interesa za ovo područje sežu u 3. st. pr. Kr., a nakon niza sukoba s lokalnim plemenima (npr. Šašel Kos 1986), uspostavljene su provincije Histrija i Ilirik/Dalmacija (Matijašić 2009). Urbanizacija hrvatske obale ogleda se u povijesti kolonija kao što su *Parentium* (Poreč), *Pola* (Pula), *Iader* (Zadar), *Salona* (Solin), *Narona* (Vid/Metković) i *Epidaurum* (Cavtat) (Suić 1976). Prema Robertu Matijašiću (2018, sa starijom literaturom), njihovi početci sežu u kasno razdoblje Cezarove vladavine. Za većinu kolonija potvrđena je rimska izmjera zemljišta (Suić 1955). Istra, s centurijacijama oko Pole i Parentiuma, predstavlja najopsežnije istraživano područje (npr. Matijašić 1988; Marchiori 2010; Bulić 2012; Popović et al. 2021). U Dalmaciji su istraživanja rimske centurijacije započela nakon Drugog svjetskog rata, sa značaj-

al. 2021). In Dalmatia, research into Roman surveying began after the Second World War, with notable contributions from Mate Suić (1955) and John Bradford (1957: 178–193). The discussion about the size and exact location of these colonial territories has continued since then (Suić 1976; Maršić 1993; Kadi 2020).

Potential evidence for Roman surveying on the Croatian islands has so far always been seen in the context of the *coloniae* established on the mainland, as only *municipia* have been identified on the islands. The mapping of the *centuriae* on the island of Ugljan, located opposite Zadar, was first outlined by John Bradford (1957: 183; see also Kadi 2019). Mate Suić (1955: 16–17) suggested that this evidence implies that the territory of *colonia Iader*, due to its limited size, was subsequently extended from the mainland to the island of Ugljan. Further attempts have been made to provide evidence of *centuriatio* on the islands of Šolta (Bradford 1957: 190) and Pag (Ilakovac 1998), while Marin Zaninović (1970; 2001) argues that they have also been preserved on the island of Korčula and the Pelješac Peninsula. A system of Roman land division is also assumed for the island of Hvar (e.g., Gamulin 2011), although a more recent study on the Greek and Roman distribution of agricultural land on Hvar could not provide definitive evidence of *centuriatio* (Popović 2020: 81–83).

The discovery of reliable evidence of Roman land surveys is a challenging undertaking. The long history of use of field parcels and dry stone walls, as exemplified by the island of Hvar, complicates the task of proving a Roman origin. Moreover, until recently, reconstructing surveying systems could only be accomplished with the aid of aerial photographs and cartographic materials. However, the application of these techniques across the islands has frequently been ineffective due to the extensive coverage of dense Mediterranean vegetation. With the advent of airborne laser scanning (ALS or LiDAR), however, a more suitable methodology is now available, allowing for a more rigorous approach to the chronology of dry stone wall systems.

In a recent publication, a part of the hinterland of the Roman city of Osor on the island of Cres has been interpreted in detail based on an ALS-derived terrain model and historical maps (Doneus et al. 2022a). This allowed for the identification of a relatively chronological sequence of agricultural features (dry stone walls, terraces). The oldest elements, identified stratigraphically,

nim doprinosima Mate Suića (1955) i Johna Bradforda (1957: 178–193). Rasprave o veličini i točnoj lokaciji tih kolonijalnih teritorija su još uvijek u tijeku (Suić 1976; Maršić 1993; Kadi 2020).

Mogući tragovi rimske izmjere zemljišta na hrvatskim otocima obično se promatraju u kontekstu kolonija osnovanih na kopnu jer su na otocima identificirani samo municipiji. Kartiranje centurija na Ugljanu, smještenom nasuprot Zadru, prvi je opisao John Bradford (1957: 183; vidi i Kadi 2019). Mate Suić (1955: 16–17) smatrao je da ti tragovi znače da je teritorij kolonije *Iader*, zbog svoje ograničene veličine, naknadno proširen s kopna na otok Ugljan. Daljnja istraživanja uključivala su traženje dokaza o centurijaciji na Šolti (Bradford 1957: 190) i Pagu (Ilakovac 1998), dok Marin Zaninović (1970; 2001) tvrdi da su također sačuvane na otoku Korčuli i Pelješkom poluotoku. Sustav rimske parcelacije pretpostavlja se i za otok Hvar (npr. Gamulin 2011), iako novija studija o grčkoj i rimskoj raspodjeli poljoprivrednog zemljišta na Hvaru nije pružila konačan dokaz o centurijaciji (Popović 2020: 81–83).

Otkrivanje pouzdanih tragova rimske izmjere zemljišta težak je pothvat. Duga povijest korištenja poljoprivrednih parcela i suhozida, primjerice na Hvaru, otežava dokazivanje njihovog rimskog podrijetla. Nadalje, donedavno je rekonstrukcija rimske izmjere zemljišta bila moguća samo uz pomoć zračnih fotografija i kartografske građe. Međutim, primjena tih tehnika često je nedjelotvorna na otocima zbog guste sredozemne vegetacije. S pojavom zračnog laserskog skeniranja (ALS ili LiDAR) dostupna je prikladnija metodologija, koja omogućava detaljniji uvid u kronologiju sustava suhozida.

U nedavnom radu, dio zaleđa rimskog grada Osora na Cresu detaljno je interpretiran na temelju modela terena dobivenog laserskim skeniranjem (ALS) i povijesnih karata (Doneus et al. 2022a), čime je omogućena identifikacija relativno-kronološkog niza poljoprivrednih objekata (suhozidi, terase). Stratigrafski najstariji elementi sastoje se od niza pravocrtnih oronulih i usporedno položenih suhozida na udaljenosti od oko 710 m. Ovo iznenađujuće otkriće potaknulo je sljedeće istraživačko pitanje: jesu li teritoriji malih gradova (municipija) na hrvatskim otocima bili izmjereni u rimsko vrijeme, i ako jesu, u kojem obliku?

consist of a series of straight, decayed dry stone walls that run parallel to each other at a distance of approximately 710 m. This surprising discovery prompted the following research question: Were the territories of the small towns (*municipia*) on Croatian islands mapped by Roman surveyors, and if so, in what form? Given that Roman *limites* on the Croatian coast typically lack datable material and appear only as stone deposits (Popović et al. 2021), the study also investigated whether the newly discovered relics could be dated using optically stimulated luminescence (OSL) methods. Following an introduction to the study area, this paper details our methods and results.

Case study: Kvarner Islands

Croatia's northernmost archipelago in the Kvarner Bay comprises the islands of Krk, Cres, Lošinj, and Rab, along with several smaller, only partially inhabited islands (Fig. 1). While Krk and Cres are approximately the same size (405 km^2), the areas of Rab (86 km^2) and Lošinj (74 km^2) are significantly smaller (Duplančić et al. 2004: 11–12). This karst region is characterised by a variety of geomorphological elements that contribute to a distinctive cultural landscape, including open pasture areas, hillside terraces, and sinkholes enclosed by dry stone walls (Andlar et al. 2018). The use of dry stone walls to demarcate boundaries likely dates back to prehistoric times (Faber 2018), as evidenced by Bronze and Iron Age hilltop settlements that employed this construction technique (e.g., Mirosavljević 1974; Faber 2000).

As stated by Alka Starac (2000: 78–83), epigraphic sources indicate that town privileges were granted during the 1st century AD. A total of five *municipia* across three Kvarner islands have been documented in written sources (e.g., Wilkes 1969: 196–199; Margetić 1979): *Fulfinum* (Omišalj) and *Curicum* (Krk) on the island of Krk; *Apsorus* (Osor) and *Crexi* (Cres) on the island of Cres; and *Arba* (Rab) on the island of Rab (ancient toponyms after Margetić 1979: 330–332 and Starac 2000: 78–83). The practice of using the same name for the most important town and the entire island is common along the Croatian coast.

Of these five Roman cities, only *Curicum* (Filjak 1982) and *Arba* (Nedved 1989) have maintained their urban functions. *Apsorus* (Faber 1982) lost its regional importance over time, and *Crexi* and *Fulfinum* were completely abandoned in favour of other sites. The location of the Roman Cres,

Budući da rimski granični zidovi (*limites*) na hrvatskoj obali obično ne sadrže nalaze koji se mogu datirati i pojavljuju se samo kao slojevi kamena (Popović et al. 2021), u studiji je također istraženo mogu li se novootkriveni ostatci datirati pomoću metode optički stimulirane luminescencije (OSL). Nakon uvoda o području istraživanja, ovaj rad podrobno opisuje naše metode i rezultate.

Studija slučaja: kvarnerski otoci

Najsjeverniji hrvatski arhipelag u Kvarnerskom zaljevu čine otoci Krk, Cres, Lošinj i Rab, zajedno s mnogo manjih i tek djelomično naseljenih otoka (sl. 1). Dok su Krk i Cres približno iste veličine (405 km^2), Rab (86 km^2) i Lošinj (74 km^2) imaju znatno manju površinu (Duplančić et al. 2004: 11–12). Ovo krško područje obilježavaju raznoliki geomorfološki elementi koji doprinose jedinstvenom kulturnom krajoliku otvorenih pašnjaka, terasastih padina i ponikva ograđenih suhozidima (Andlar et al. 2018). Korištenje suhozida za označavanje granica vjerojatno seže u prapovijesno doba (Faber 2018), što potvrđuju brončanodobne i željeznodobne gradine koje su koristile tu tehniku gradnje (npr. Mirosavljević 1974; Faber 2000).

Kako navodi Alka Starac (2000: 78–83), epigrafski izvori ukazuju na to da su gradske povlastice dodijeljene tijekom 1. st. po. Kr. U pisanim je izvorima dokumentirano ukupno pet municipija na tri Kvarnerska otoka (npr. Wilkes 1969: 196–199; Margetić 1979): *Fulfinum* (Omišalj) i *Curicum* (Krk) na Krku; *Apsorus* (Osor) i *Crexi* (Cres) na Cresu; te *Arba* (Rab) na Rabu (antički toponimi prema Margetić 1979: 330–332 i Starac 2000: 78–83). Duž cijele hrvatske obale uvriježena je praksa korištenja istog imena za najvažniji grad i cijeli otok.

Od tih pet rimskih gradova, samo su *Curicum* (Filjak 1982) i *Arba* (Nedved 1989) zadržali svoje urbane funkcije do danas. *Apsorus* (Faber 1982) je s vremenom izgubio svoj regionalni značaj, a *Crexi* i *Fulfinum* su potpuno napušteni radi drugih lokacija. Dok je položaj rimskog Cresa, poznatog kao *Crexi*, još uvijek predmet znanstvene rasprave (Ćus-Rukonić 2014), lokacija Fulfinuma je potvrđena oko 1 km jugozapadno od današnjeg naselja (Čaušević-Bully, Valent 2015). Također je nepoznato može li se današnje naselje Beli, smješteno na sjevernoj strani otoka Cresa, smatrati teritorijalno neovisnim naseljem ili gradom (Imamović 1975:

Fig. 1 – The Kvarner Islands and the locations of the cities mentioned in the text (base: SRTM; made by: N. Doneus, 2024)
Sl. 1 – Kvarnerski otoci i položaji gradova spomenutih u tekstu (osnova: SRTM; izradila: N. Doneus 2024.)

known as *Crexi*, remains a subject of scholarly debate (Ćus-Rukonić 2014), whereas *Fulfinum* is confirmed to be situated approximately 1 km southwest of the present-day village (Čaušević-Bully, Valent 2015). It is unclear whether the modern village of Beli, located on the northern side of the island of Cres, can be considered a territorially independent settlement or town (Imamović 1975: 223–224), as the only reference to date is the reported discovery (Fortis 1771: 137) of an inscription referencing the construction of a *curia* during the reign of Tiberius (CIL III 3148 (10131)).

Of the five Roman cities on the Kvarner Islands, *Apsorus* (Osor) on the island of Cres has the most extensive research history. According to legend, the ancient name *Apsyrtides*, often equated with the Cres/Lošinj archipelago, is derived from the Argonaut myth (Blečić Kavur 2015: 15–18). The town of Osor appears to have assumed the role of a regional centre from the Iron Age onwards (Mohorovičić 1953). The rise of the city is primarily attributed to its favourable geographical setting on a circular land bridge between the islands of Cres and Lošinj. These islands are separated by

223–224) jer se jedini dokaz oslanja na navodno otkriće (Fortis 1771: 137) natpisa koji se odnosi na gradnju kurije za vrijeme Tiberijeve vladavine (CIL III 3148 (10131)).

Od pet rimskih gradova na kvarnerskim otocima, *Apsorus* (Osor) na Cresu ima najopsežniju povijest istraživanja. Prema legendi, antičko ime *Apsyrtides*, često korišteno za cresko-lošinjski arhipelag, potječe iz mita o Argonautima (Blečić Kavur 2015: 15–18). Čini se da je grad Osor preuzeo ulogu regionalnog centra od željeznog doba nadalje (Mohorovičić 1953). Uzlet grada prvenstveno se pripisuje njegovom povoljnom geografskom položaju na kružnom kopnenom mostu između otoka Cresa i Lošinja. Oba otoka su odvojena uskim plovnim kanalom, za koji se pretpostavlja da je uključio Osor u duge pomorske rute (Faber 1982).

Trenutni projekt „Osor onkraj mita" proučava ulogu Osora u trgovačkim rutama i istražuje krajolik i iskorištavanje zemljišta oko grada pod rimskom vlašću. Projekt se temelji na višegodišnjem istraživanju provedenom na cresko-lošinjskom arhipelagu (Doneus et

a narrow navigable channel, which presumably provided Osor with opportunities to engage in long-distance maritime routes (Faber 1982).

The current project, "Osor Beyond the Myth", examines the role of Osor in trade routes and evaluates the landscape and land use surrounding the city under the Roman regime. The project is founded on several years of research conducted on the Cres/Lošinj archipelago (Doneus et al. 2013; 2015; 2017), which includes a systematic and large-scale analysis of the ALS data mentioned in the introduction.

Methods

Airborne laser scanning

Research into Roman land surveying has traditionally been closely associated with cartography and aerial photography (e.g., Settis 1983; Chouquer et al. 1987; Franceschelli 2016; Fusco et al. 2022). In areas of dense vegetation, however, the use of ALS methodology is preferred (e.g., Vinci et al. 2024), as this method also captures the terrain covered by dense maquis (e.g., Bernardini, Vinci 2020; Popović et al. 2021; Štular et al. 2021a; Doneus et al. 2022a; Bernandini 2023). This active remote sensing technique (e.g., Grussenmeyer et al. 2016) enables surveys of entire landscapes, visualising the terrain, its vegetation, and all objects located on it in detailed point clouds. After classification (Štular, Lozić 2020; Doneus et al. 2022a; 2022b), these point clouds are filtered according to specific criteria, leading to the derivation of corresponding elevation models, with Digital Terrain Models (DTM – only ground points) and Digital Feature Models (DFM – points classified as ground and buildings) being relevant for archaeology (Pingel et al. 2015; Štular et al. 2021b).

A small portion of the data used in this paper, primarily from the southern part of the island of Cres, comes from archaeological projects that have been described in detail (Doneus et al. 2022a). The majority of the data originates from a comprehensive ALS survey of Croatia, which has recently become publicly accessible upon request as a DTM with a resolution of 1 m grid width through the project "Multisenzorsko zračno snimanje Republike Hrvatske" (Multisensor Aerial Survey of the Republic of Croatia). The data were visualised using the Relief Visualisation Toolbox (Zakšek et al. 2011; Kokalj, Somrak 2019), with the Visualisation for Archaeological Topography (VAT) technique primarily employed for interpretation.

Metode

Zračno lasersko skeniranje

Istraživanje rimske izmjere zemljišta oduvijek je usko vezano uz kartografiju i zračne fotografije (npr. Settis 1983; Chouquer et al. 1987; Franceschelli 2016; Fusco et al. 2022). Međutim, u područjima s gustim raslinjem preferira se uporaba ALS metodologije (npr. Vinci et al. 2024) jer ta metoda dokumentira teren prekriven gustom makijom (npr. Bernardini, Vinci 2020; Popović et al. 2021; Štular et al. 2021a; Doneus et al. 2022a; Bernandini 2023). Tehnika aktivnog daljinskog snimanja (npr. Grussenmeyer et al. 2016) omogućava snimanje cijelih krajolika i vizualizaciju reljefa, vegetacije i svih struktura pomoću detaljnih oblaka točaka. Nakon klasifikacije (Štular, Lozić 2020; Doneus et al. 2022a; 2022b), ovi oblaci točaka filtriraju se prema određenim kriterijima i omogućavaju izradu visinskih modela, pri čemu su arheologiji zanimljivi digitalni modeli terena (DTM – samo točke tla) i digitalni modeli objekata (DFM – točke se klasificiraju kao tlo i zgrade) (Pingel et al. 2015; Štular et al. 2021b).

Manji dio podataka korištenih u ovom radu, prvenstveno s južnog dijela otoka Cresa, potječe iz arheoloških projekata koji su već detaljno opisani (Doneus et al. 2022a). Većina podataka potječe iz sveobuhvatnog ALS snimanja Hrvatske koje je nedavno postalo javno dostupno na zahtjev, kao DTM s razlučivošću mrežne širine od 1 m, kroz projekt „Multisenzorsko zračno snimanje Republike Hrvatske". Podaci su vizualizirani pomoću alata Relief Visualisation Toolbox (Zakšek et al. 2011; Kokalj, Somrak 2019), pri čemu je za interpretaciju prvenstveno korištena tehnika Visualisation for Archaeological Topography (VAT).

S obzirom na veliki opseg sustava suhozida, na terenu je istraženo samo ograničeno područje, s glavnim naglaskom na području Punta Križa južno od Osora tijekom nekoliko kampanja između 2021. i 2024. godine (sl. 2). Pri tome se pokazalo, da je identifikacija suhozida bez prethodne analize ALS podataka dijelom vrlo teška, ako ne i nemoguća. Smanjivanje poljoprivrednih aktivnosti na Cresu dovelo je do propadanja sustava suhozida i širenja sekundarne vegetacije,

Fig. 2 – The condition of the walls varies depending on the history of the area after the Roman period. Area (a) has been used for forestry for an extended period. Here, the former wall is entirely covered by earth, giving the appearance of a bank. In area (b), the walls are preserved to a height of approximately half a metre. Area (c) features a wall that has undergone extensive collapse, similar to the region of Istria (Popović et al., 2021, Figure 8b). (d) Map indicating the locations of images a–c (base: OpenStreetMap, CC by-SA 2.0 and project-owned DFM visualization; photographed and made by: M. Doneus, 2024)
Sl. 2 – Stanje zidova varira ovisno o povijesti područja nakon rimskog razdoblja. Područje (a) dulje se vrijeme koristi za šumarstvo. Ovdje je nekadašnji zid u potpunosti prekriven zemljom, pa izgleda kao nasip. Na području (b) zidovi su sačuvani do visine od približno pola metra. Područje (c) prikazuje zid koji se znatno urušio, slično kao u regiji Istre (Popović et al., 2021, sl. 8b). (d) Karta koja prikazuje lokacije slika a–c (osnova: OpenStreetMap, CC by-SA 2.0 i projektna vizualizacija DFM-a; izradio: M. Doneus, 2024.)

Given the extent of the dry stone walls, only a limited region could be investigated in the field, focusing primarily on the Punta Križa area south of Osor during several campaigns between 2021 and 2024 (Fig. 2). In the field, it is challenging – if not impossible – to identify these walls without prior analysis of the ALS data. The ongoing decline in agricultural activity on Cres has led to the deterioration of dry stone wall systems and the encroachment of secondary vegetation, rendering aerial photographs an ineffective source of data. Furthermore, the Croatian Base Map does not include any mapping of the heavily eroded dry stone walls.

čime su zračne fotografije postale nedjelotvoran izvor podataka. Nadalje, Hrvatska osnovna karta ne uključuje kartiranje potpuno erodiranih suhozida.

Optički stimulirana luminescencija

Profiliranje i datiranje optički stimulirane luminescencije (OSL-PD) koristi tri faze za procjenu stratigrafija sedimenata, iznošenje hipoteza o povijesti sedimentiranja i datiranje ciljanih konteksta i sedimentnih horizonata (Turner et al. 2021; Srivastava et al. 2023). Prvo, prije-

Optically stimulated luminescence

Optically stimulated luminescence profiling and dating (OSL-PD) utilises a three-stage approach to evaluate sediment stratigraphies, propose hypotheses on depositional histories, and date targeted contexts and sedimentary horizons (Turner et al. 2021; Srivastava et al. 2023). First, portable OSL equipment is employed to evaluate the luminescence properties of bulk sediment samples in the field and to construct luminescence stratigraphies which can inform the interpretation of depositional and constructional sequences (Stage 1). Next, a subset of these samples is subjected to calibrated luminescence screening and characterisation in the laboratory, providing the first approximation of the magnitude and range in apparent doses that may correlate with age (Stage 2). Finally, those samples with archaeological significance for defining a chronology, along with promising attributes identified in Stages 1 and 2, are advanced to OSL dating (Stage 3).

OSL-PD was used at Punta Križa to date three of the above mentioned dry stone walls, now largely collapsed. Small slot trenches were excavated across these features, allowing access to the underlying soil(s) and substrate. PTK24-1 and PTK24-2 were positioned along the main northeast-southwest alignment, on opposite banks, while PTK24-3 was placed on a perpendicular alignment that was slightly better preserved (Figs. 3–4).

In Fig. 5, the sample positions are coloured to reflect the OSL intensities observed during screening: cooler colours (blues) indicate lower intensities, while warmer colours (reds) indicate higher intensities. In well-bleached sediment, OSL intensities can serve as a proxy for age, with blues representing younger sediment that has been bleached more recently, and reds representing older sediment. Samples from PK24-1 and PK24-2 were characterised by very similar profiles: samples taken immediately beneath the collapsed wall in contexts (101) and (201) returned lower intensities, in the range of 4.4 to 4.8 x10^4 counts, compared to those at greater depth, from contexts (102) and (202), which exhibited intensities greater than 7.8 x10^4 counts (Tab. 1). This finding is promising for dating, as it suggests that the luminescence signal in the sediment immediately beneath the wall was reset following disturbance at the time of construction.

PK24-3 was characterised by a different profile: OSL intensities progress from 1.6–1.7 x10^4 to 1.9–2.1 x10^4 counts in context (301), and 2.8 x10^4

nosna OSL oprema koristi se za procjenu luminescencijskih svojstava uzoraka sedimenta na terenu i za izradu luminescencijskih stratigrafija koje mogu pomoći u tumačenju depozicijskih i konstrukcijskih sekvenca (1. faza). Zatim se podskup tih uzoraka podvrgava kalibriranom luminescencijskom probiranju i karakterizaciji u laboratoriju, čime se dobiva prva procjena veličine i raspona prividnih doza koje mogu korelirati s dobi (2. faza). U zadnjem koraku se uzorci koji su arheološki značajni za definiranje kronologije, zajedno s obećavajućim osobinama identificiranim u 1. i 2. fazi, datiraju OSL metodom (3. faza).

OSL-PD je korišten na Punta Križi za datiranje tri linearne kamene strukture, koje su danas uglavnom urušene. Male i uske sonde iskopane su preko tih objekata kako bi se omogućio pristup donjem tlu/tlima i podlozi. PTK24-1 i PTK24-2 su bile smještene duž glavne osi sjeveroistok – jugozapad, na suprotnim stranama, dok je PTK24-3 bila postavljena na okomitu os, koja je bila nešto bolje očuvana (sl. 3–4).

Na sl. 5, položaji uzoraka obojeni su kako bi odražavali intenzitete OSL-a zabilježene tijekom probiranja: hladnije boje (plave) označavaju niže intenzitete, a toplije (crvene) označavaju više intenzitete. U dobro izbijeljenom sedimentu, intenziteti OSL-a mogu poslužiti kao indikator starosti, pri čemu plave boje predstavljaju mlađi sediment koji je izbijeljen nedavno, a crvene predstavljaju stariji sediment. Uzorke PK24-1 i PK24-2 obilježavali su vrlo slični profili: uzorci uzeti neposredno ispod urušenog zida u kontekstima (101) i (201) dali su niže intenzitete, u rasponu od 4,4 do 4,8 x10^4, za razliku od onih na većoj dubini, iz konteksta (102) i (202), koji su imali intenzitete veće od 7,8 x10^4 (tab. 1). To otkriće obećava mogućnost datiranja jer upućuje na to da je luminescentni signal u sedimentu neposredno ispod zida bio ponovno aktivan nakon poremećaja u vrijeme gradnje.

PK24-3 je obilježio drukčiji profil: intenziteti OSL-a kreću se od 1,6–1,7 x10^4 do 1,9–2,1 x10^4 u kontekstu (301) i od 2,8 x10^4 do > 4,1 x10^4 u kontekstu (302). Tumačenje na terenu ukazalo je da su elementi PK24-1 i PK24-2 slične starosti, dok je okomiti element PTK24-3 izgrađen kasnije. Uzorci su radi datiranja postavljeni ispod zidova kako bi se testirala ova hipoteza, pružajući *terminus post quem* za izgradnju.

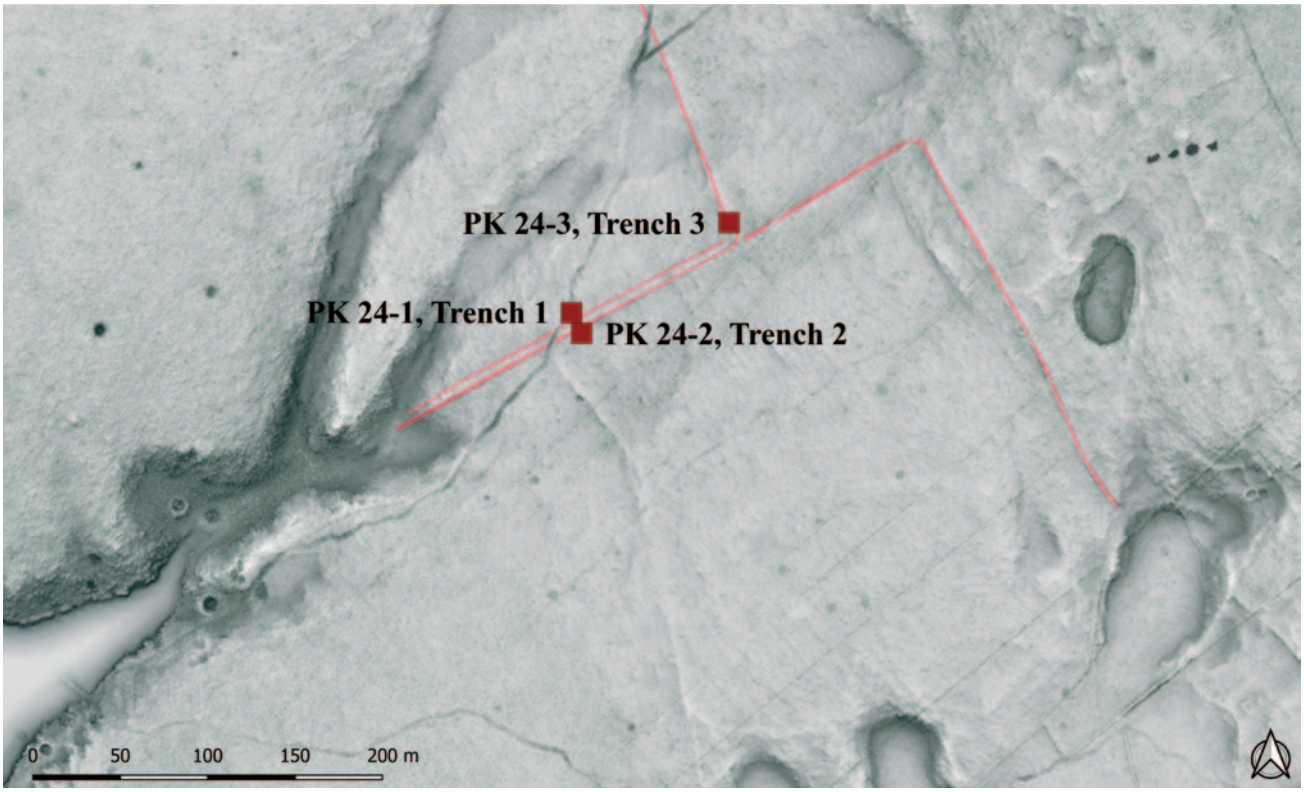

Fig 3 – Location of the sampled dry stone walls; see also Fig. 2: area c (base: project-owned DFM visualization; made by: M. Fera, 2024)
Sl. 3– Lokacija uzorkovanih suhozida; vidi također sl. 2: područje c (osnova: projektna vizualizacija DFM; izradio: M. Fera, 2024.)

Fig. 4 – Fieldwork: (a) the remains of the Roman wall are visible as stone deposits in the woods of Punta Križa; (b) sampling of sediments in trench 1, PK 24-1 (photos and made by: M. Fera, M. Doneus, 2024)
Sl. 4 –Terenski rad: (a) ostaci rimskog zida vidljivi su kao naslage kamenja u šumi na Punta Križi; (b) uzorkovanje sedimenata u sondi 1, PK 24-1 (snimili i izradili: M. Fera, M. Doneus, 2024.)

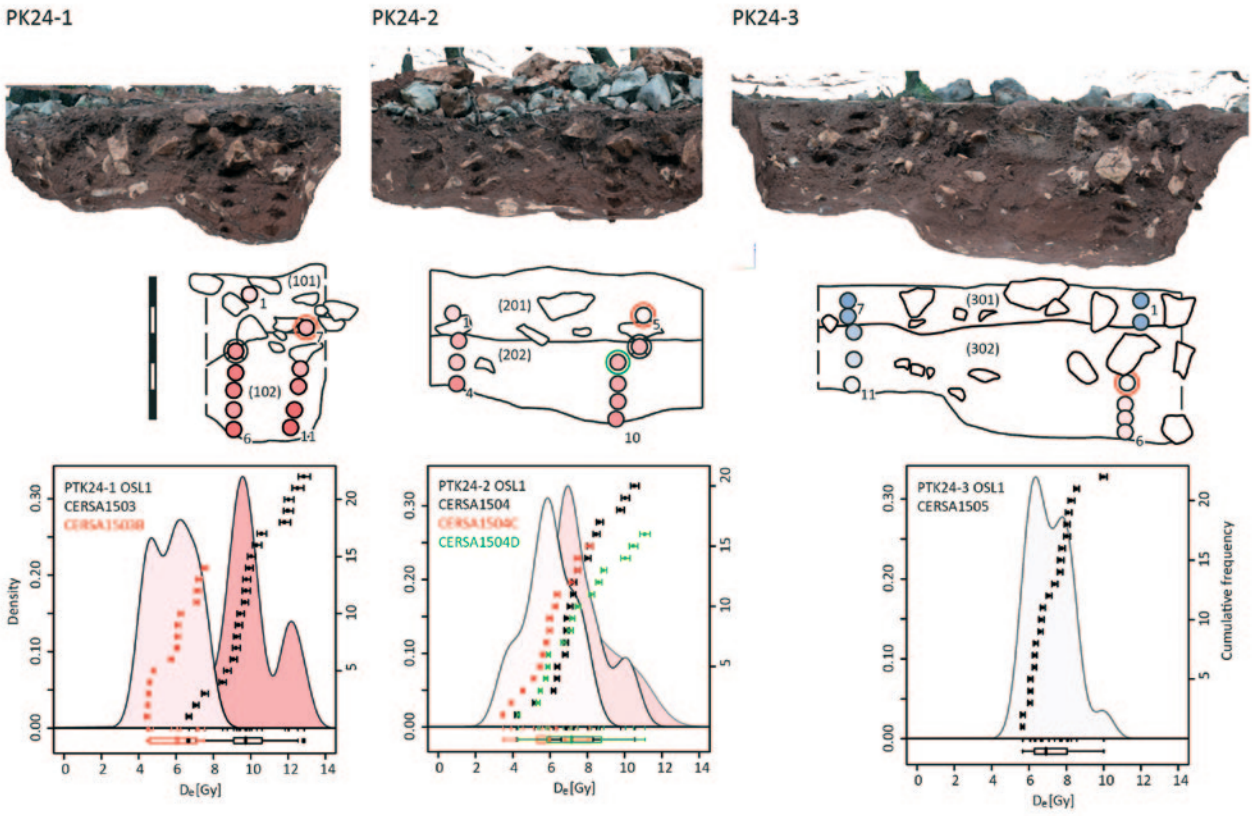

Fig. 5 – Images (top) based on photogrammetric models for trenches PTK24-1, PTK24-2, and PTK24-3, which were excavated through the Punta Križa walls; the section drawings for each trench (centre) show the positions of OSL profiling samples (indicated by single circles) throughout each sequence, coloured by intensity (see Appendix 1, Tab. 2; the profiling samples were taken in a series of vertical columns; in the section drawings, the top and bottom samples in each column are numbered). Below these, the graphs represent kernel density estimates showing equivalent dose distributions from each of the OSL dating samples collected in the field using steel tubes (indicated by double circles in the section drawings) (photos and made by: T. Kinnaird, C. Sevara, 2024)
Sl. 5 – Slike (gore) temeljene na fotogrametričkim modelima za sonde PTK24-1, PTK24-2 i PTK24-3, koje su iskopane kroz zidove Punta Križe; crteži profila za svaku sondu (sredina) prikazuju položaje uzoraka za OSL profiliranje (označeni jednostrukim krugovima) kroz svaki niz, obojene prema intenzitetu (vidi Dodatak 1, tab. 2; uzorci za profiliranje uzeti su u nizu okomitih stupaca; u crtežima profila numerirani su gornji i donji uzorci u svakom stupcu). Grafovi ispod njih predstavljaju procjene funkcije gustoće koje prikazuju distribucije ekvivalentnih doza za svaki od OSL uzoraka za datiranje sakupljenih na terenu pomoću čeličnih cijevi (označenih dvostrukim krugovima na crtežima profila) (snimili i izradili: T. Kinnaird, C. Sevara, 2024.)

to >4.1 x10^4 counts in context (302). The interpretation in the field suggested that features PK24-1 and PK24-2 were similar in age, while the perpendicular feature PTK24-3 was constructed later. Samples were positioned for dating purposes beneath the walls to test this hypothesis, providing a *terminus post quem* for construction.

Results

A systematic analysis of ALS data strengthened the initial hypothesis regarding Roman municipal land surveying on two of the four Kvarner islands, namely Cres and Krk (Figs. 6–7; 9).

Rezultati

Sustavna analiza ALS podataka poduprla je početnu hipotezu o rimskoj municipalnoj izmjeri zemljišta na dva od četiri kvarnerska otoka – naime, na Cresu i Krku (sl. 6–7, 9). Na Lošinju i Rabu nisu pronađeni dokazi o mogućoj rimskoj parcelaciji.

Na Cresu, niz paralelnih suhozida proteže se od južnog kraja otoka do otprilike 2 km južno od Creskog zaljeva, na ukupnoj dužini od oko 35 km (sl. 6). Ti su suhozidi raspoređeni u mrežu s orijentacijom sjeveroistok – jugozapad pod kutom od 65° naspram sjevera

Fig. 6 – The island of Cres, with the *municipium* of *Apsorus* and the survey grid (base: Google Maps, Map data ©2015 Google; made by: N. Doneus, 2024)
Sl. 6 – Otok Cres, municipij *Apsorus* i mreža izmjere zemljišta (osnova: Google Maps, Map data ©2015 Google; izradila: N. Doneus, 2024.)

No evidence of possible Roman surveying was found on the islands of Lošinj and Rab.

On the island of Cres, a series of parallel dry-stone walls extends from the southern tip of the island to approximately 2 km south of Cres Bay, covering a total length of about 35 km (Fig. 6). These walls are arranged in a grid with a northeast-southwest orientation of 65° from the north (base grid north in the ETRS89 UTM 33N, EPSG 25833 system). The distance between the individual walls is not entirely uniform, ranging from 630 to 720 m. Some walls appear to extend across the entire width of the island, while others can only be traced over shorter distances. Occasionally, remnants of walls can be observed extending at right angles to the alignment described above, indicating the former division of land plots.

The impact of topography is particularly evident. The survey appears to have commenced at the flat southern end of the island. As the distance to the north increases, the number of walls decreases, concluding near the present-day city of Cres. Here, the island narrows, and the terrain rises steadily to over 300 m above sea level. The survey relics yielded no insights into the potential location of Crexi, a presumed *municipium* near the modern town of Cres, and were not identified in the vicinity of the possible Roman settlement of Beli.

A spatial connection has been identified between the survey and the *municipium* of *Apsorus*, situated at the northwestern extremity of the Punta Križa Peninsula (Fig. 6). Following large-scale geophysical measurements conducted in 2014–2015 (Doneus et al. 2017), Osor became the focus of a second geophysical survey in autumn 2023 and spring 2024. The results, which are currently being prepared for publication, provide insights into the NE-SW oriented street grid of a small town with a diameter of approximately 300 m (Fig. 8). The *forum* was situated in the southwestern part of the city, and its location was confirmed during archaeological rescue excavations in the main square from 2022 to 2024 (Baričević 2023). A comparison of the town plan with the land survey reveals several similarities (Fig. 7): (1) The town is located precisely between two boundary lines, similar to the *colonia* of *Pola* (Bulić 2012: Fig. 6). These two lines are situated 633 m apart, likely because they were laid out to center the city between them. (2) An imaginary line drawn between and parallel to the two boundary lines would lead directly to the northern side of the *forum*, where it can be assumed that the *umbilicus* (the intersection of the survey axes) was located. The city plan aligns with Hyginus's re-

(osnovni računski sjever u sustavu ETRS89 UTM 33N, EPSG 25833). Udaljenost između pojedinih zidova nije posve ujednačena, a kreće se između 630 i 720 m. Čini se da se neki zidovi protežu cijelom širinom otoka, dok se drugi mogu pratiti samo na kraćim udaljenostima. Povremeno se mogu uočiti ostatci zidova koji se protežu pod pravim kutom u odnosu na spomenuti pravac, što upućuje na nekadašnju podjelu zemljišnih parcela.

Utjecaj topografije posebno je očigledan. Čini se da je izmjera zemljišta započela na ravnom južnom kraju otoka. Kako se povećava udaljenost prema sjeveru, tako se smanjuje broj zidova, završavajući u blizini današnjeg grada Cresa. Ovdje se otok sužava, a teren postupno uzdiže na više od 300 m nadmorske visine. Ostatci izmjere zemljišta nisu pružili uvid u moguću lokaciju naselja *Crexi*, pretpostavljenog municipija u blizini suvremenog grada Cresa, a također nisu identificirani u blizini mogućeg rimskog naselja Beli.

Prostorna povezanost utvrđena je između izmjere zemljišta i municipija *Apsorus*, smještenog na sjeverozapadnom kraju poluotoka Punta Križe (sl. 6). Nakon opsežnih geofizičkih mjerenja provedenih 2014. – 2015. (Doneus et al. 2017), Osor se našao u središtu drugog geofizičkog istraživanja u jesen 2023. i proljeće 2024. godine. Rezultati, koji su trenutno u pripremi za objavu, pružaju uvid u mrežu ulica s orijentacijom sjeveroistok – jugozapad u malom gradu promjera oko 300 m (sl. 8). Forum se nalazio u jugozapadnom dijelu grada, a njegova je lokacija potvrđena tijekom zaštitnih arheoloških iskopavanja na glavnom trgu od 2022. do 2024. godine (Baričević 2023). Usporedba tlocrta grada s katastarskim planom otkriva nekoliko sličnosti (sl. 7): (1) Grad se nalazi točno između dvije granične linije, slično koloniji *Pola* (Bulić 2012: sl. 6). Te su dvije linije udaljene 633 m jedna od druge, vjerojatno stoga da grad leži centralno između njih. (2) Zamišljena linija, povučena između dviju graničnih linija i paralelna s njima, vodila bi izravno do sjeverne strane foruma, gdje se može pretpostaviti da se nalazio *umbilicus* (sjecište osi katastarskog plana). Tlocrt grada odgovara Higinovim preporukama o osnivanju obalnog grada (usp. Lindermann et al. 2018: sl. 30).

Rezultati OSL datiranja suhozida južno od Osora prikazani su u tab. 1. Tehnički detalji nalaze se u Dodatku 1. Uzorci istaknuti podebljano, CERSA1305B i 1504C, daju vrijeme gradnje

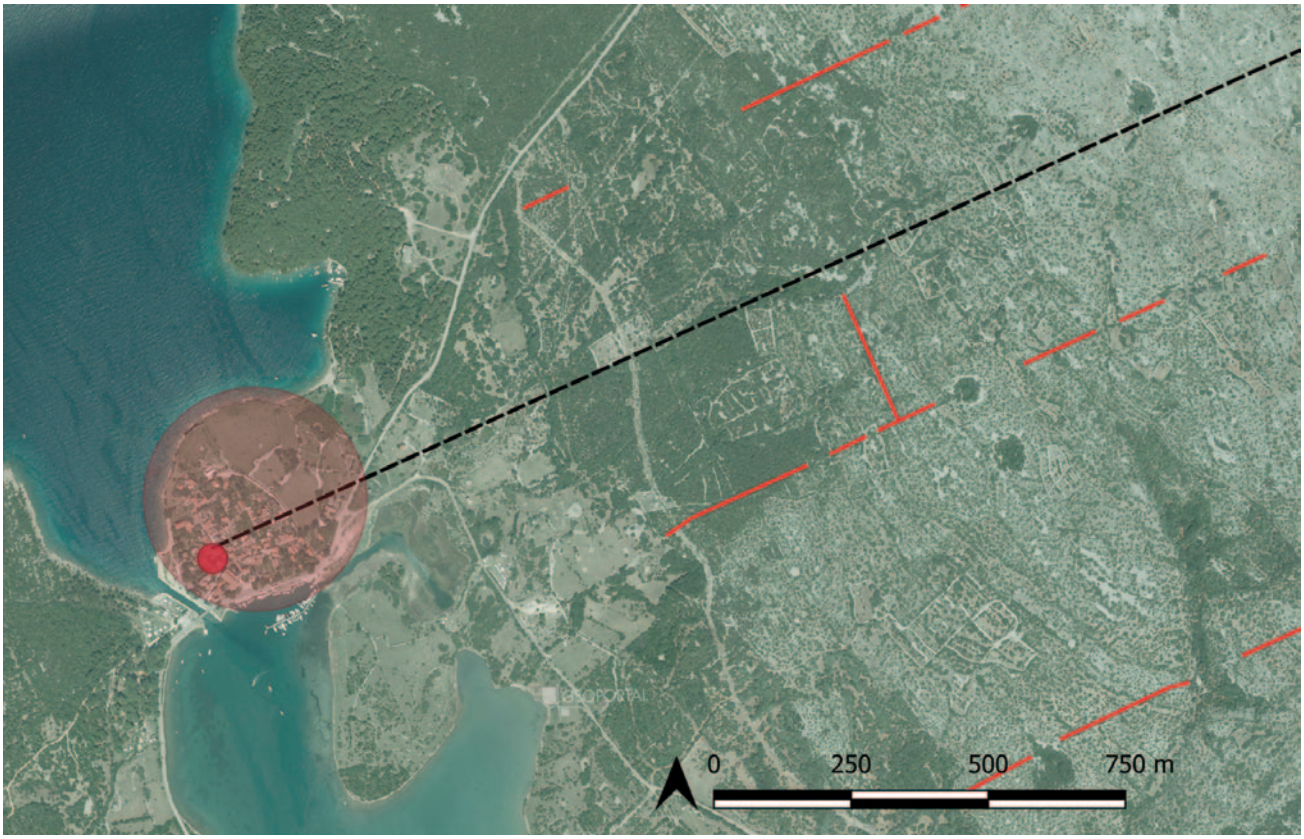

Fig. 7 – The city of *Apsorus* with the *forum* (red dot) and the Roman survey lines (red) showing a spatial connection: an imaginary line (black), drawn between and parallel to the survey lines, leads directly to the Roman city centre (base: digital orthophoto DOF 1:5000, Geoportal SGA; made by: N. Doneus, 2024)
Sl. 7 – Grad *Apsorus* s forumom (crvena točka) i rimskim katastarskim linijama (crveno) koje pokazuju prostornu povezanost: zamišljena linija (crno), povučena između katastarskih linija i paralelno s njima, vodi izravno do središta rimskog grada (osnova: digitalna ortofoto karta DOF 1 : 5000, Geoportal DGU; izradila: N. Doneus, 2024.)

commendations regarding the founding of a coastal city (cf. Lindermann et al. 2018: Fig 30).

The results of the OSL dating of dry stone walls located south of Osor are presented in Tab. 1. Technical details are provided in Appendix 1. The samples highlighted in bold, CERSA1305B and 1504C, provide *terminus post quem* dates for the timing of construction: AD 180 ± 130 and AD 220 ± 160, respectively. Trenches 1 and 2 sampled parallel stone alignments (Fig. 3; Appendix 1), and given their close temporal and spatial association, the weighted combination of the two ages – AD 200 ± 100 – best constrains the period of construction. The perpendicular feature PTK24-3 was constructed later than PTK24-1 and PTK24-2.

On the island of Krk, two distinct survey grids were identified. The first grid encompasses the central region of the island, extending approximately 17 km from the village of Punat to the northern vicinity of the village of Malinska (Fig. 8: a). Parallel

kao *terminus post quem* datume: 180. ± 130, odnosno 220. ± 160 g. po. Kr. Sondama 1 i 2 uzorkovani su paralelni suhozidi (sl. 3; Dodatak 1), a s obzirom na njihovu blisku vremensku i prostornu povezanost, ponderirana kombinacija dva vremena – 200 ± 100 g. po. Kr. – najbolje ograničava razdoblje gradnje. Okomiti element PTK24-3 izgrađen je nakon PTK24-1 i PTK24-2.

Na otoku Krku utvrđene su dvije različite parcelacijske mreže. Prva mreža obuhvaća središnji dio otoka i proteže se približno 17 km od naselja Punat do sjeverne okolice naselja Malinska (sl. 8: a). Paralelni suhozidi s orijentacijom sjeveroistok – jugozapad, pod kutom od 53° naspram sjevera (osnovni računski sjever u sustavu ETRS89 UTM 33N, EPSG 25833), dio su pravilne mreže, s prosječnim razmakom između njih od približno 706 m. Nadalje, uočljive su brojne poprečne, sjeve-

CERSA #	Trench Sonda	Context Kontekst	Palaeodose / Gy Paleodoza / Gy	Aliquots, n Alikvoti, n	Dose rate / mGy a^{-1} Omjer doze / mGy a^{-1}	Age / ka Dob / ka	Calendar years Kalendarske godine
1503	1	102	9.22 ± 0.37	22 (22)	2.89 ± 0.12	3.19 ± 0.18	1170 ± 180 BC
1503B	1	101	5.34 ± 0.32	14 (16)	2.89 ± 0.11	1.85 ± 0.13	**AD 180 ± 130**
1504	2	202	6.78 ± 0.36	20 (20)	2.88 ± 0.12	2.35 ± 0.16	330 ± 160 BC
1504C	2	201	5.21 ± 0.39	15 (16)	2.89 ± 0.12	1.8 ± 0.16	**AD 220 ± 160**
1504D	2	201	6.22 ± 0.53	16 (16)	2.89 ± 0.12	2.15 ± 0.21	130 ± 210 BC
1505	3	302	6.73 ± 0.21	22 (22)	2.74 ± 0.12	2.46 ± 0.13	430 ± 130 BC

Tab. 1 – OSL results (made by: T. Kinnaird)
Tab. 1 – Rezultati OSL-a (izradio: T. Kinnaird)

dry stone walls oriented northeast-southwest, with a bearing of 53° from the north (base grid north in the ETRS89 UTM 33N, EPSG 25833 system), align with a regular grid, featuring an average distance of approximately 706 m between them. Furthermore, a multitude of cross-connections oriented northwest to southeast and internal divisions within the measuring strips are discernible. The measuring system is spatially related to the *municipium* of *Curicum* (Krk). This is supported by the comparable orientation of the Roman street grid, which is reflected in the contemporary street layout of the town, and the layout of the survey.

In the northern part of the island of Krk, a second system of parallel dry stone walls was identified in the ALS visualisations (Fig. 8: b), oriented approximately east-west (bearing 83°, base grid north in the ETRS89 UTM 33N, EPSG 25833 system) and spaced at regular intervals of approximately 710 m. The system extends from the village of Čižići to the village of Omišalj, the former *municipium* of *Fulfinum*. Only the *forum* and the remains of a few buildings from *Fulfinum* are known (Čaušević-Bully, Valent 2015). Nevertheless, it can be observed that the northwest-southeast orientation of the *forum* is similar to that of the *municipium* of *Apsorus* but does not correspond to the course of the Roman survey outside the city.

Discussion

Two out of the three dry stone walls sampled using OSL dating on Punta Križa provided evidence of construction during the Roman era (AD 200 ± 100). Given that these walls are part of a vast network spanning significant portions of the islands of Cres and Krk, and that they are stratigraphically situated at the base of the local network of linear features, we can postulate surveying

rozapad – jugoistok orijentirane linije, kao i unutarnje podjele katastarskih jedinica. Mjerni je sustav prostorno povezan s municipijem *Curicum* (Krk). To podupire usporediva orijentacija rimske ulične mreže, koja se odražava u suvremenom rasporedu ulica grada, kao i u katastarskom rasporedu.

U sjevernom dijelu otoka Krka, u ALS vizualizacijama utvrđen je drugi sustav paralelnih suhozida (sl. 8: b), orijentiran približno u smjeru istok – zapad (kut 83°, osnovni računski sjever u sustavu ETRS89 UTM 33N, EPSG 25833), s pravilnim razmacima od približno 710 m. Sustav se proteže od naselja Čižići do naselja Omišalj, nekadašnjeg municipija *Fulfinum*. Poznati su samo forum i ostaci nekoliko zgrada Fulfinuma (Čaušević-Bully, Valent 2015). Ipak, može se primijetiti da je orijentacija foruma u smjeru sjeverozapad – jugoistok slična onoj municipija *Apsorus*, te da ne odgovara pravcu rimske parcelacije izvan grada.

Rasprava

Dva od tri suhozida uzorkovana metodom OSL datiranja na Punta Križi pružila su dokaze o gradnji tijekom rimskog doba (200 ± 100 g. po. Kr.). S obzirom da su ovi zidovi dio opsežne mreže koja obuhvaća znatne dijelove otoka Cresa i Krka, te da se stratigrafski nalaze na dnu lokalne mreže linearnih obilježja, možemo postaviti hipotezu o sustavima zemljišne izmjere rimskog podrijetla. Međutim, rasprava o njihovoj povijesnoj pozadini je složena.

Pitanje treba li suhozide na Cresu i Krku klasificirati kao *rigores* (linije izmjere) ili *limites* (granice koje su također služile kao ceste ili putovi) pokazuje kakve su teškoće svojstvene pre-

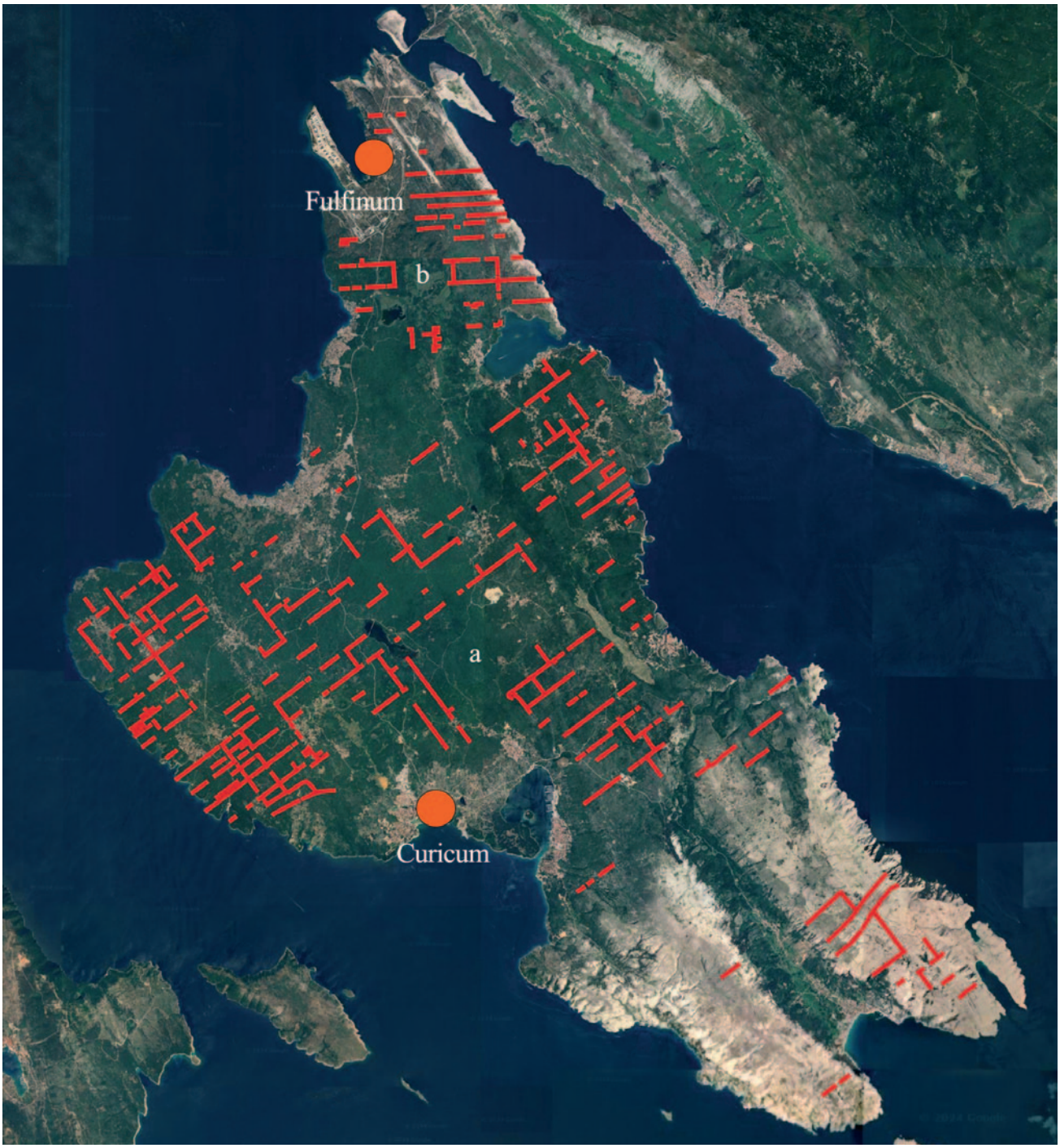

Fig. 8 – The island of Krk with two *municipia* and two survey grids (base: Google Maps, Map data ©2015 Google; made by: N. Doneus, 2024)
Sl. 8 – Otok Krk s dva municipija i dvije parcelacijske mreže (osnova: Google Maps, Map data ©2015 Google; izradila: N. Doneus, 2024.)

systems of Roman origin. However, the debate regarding their historical background is complex.

The question of whether the dry stone walls on Cres and Krk should be classified as *rigores* (survey lines) or *limites* (boundary lines that

ciznom imenovanju ostataka izmjere. Paralelni suhozidi mogu se uočiti na više lokacija na Krku i Cresu, a razmak između njih samo je 5 do 6 m (sl. 3, 9), što bi moglo ukazivati na elemente cestovne mreže.

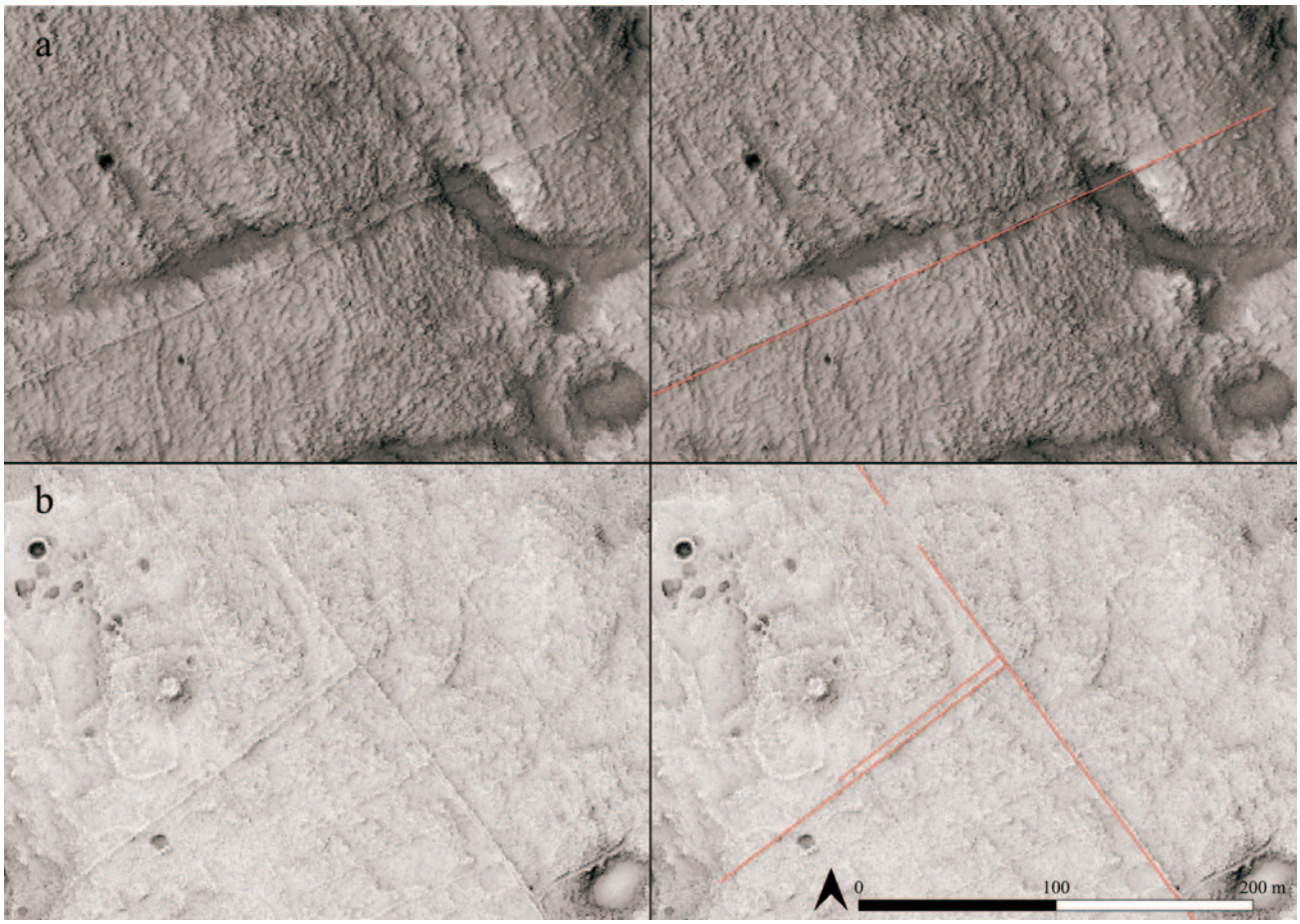

Fig. 9 – Roman surveying lines: a) the island of Cres with a single survey line; b) the island of Krk with a double survey line (base: State Geodetic Administration (SGA); made by: N. Doneus, M. Fera, 2024)
Sl. 9 – Rimske zemljomjerne linije : a) otok Cres s jednostrukom parcelacijskom linijom; b) otok Krk s dvostrukom parcelacijskom linijom (osnova: Državna geodetska uprava (DGU); izradili: N. Doneus, M. Fera, 2024.)

also served as roads or paths) illustrates the challenges inherent in accurately naming surveying relics. Parallel dry stone walls can be observed in several locations on Krk and Cres, with only approximately 5 to 6 m between them (Figs. 3, 9), which could indicate potential elements of a road network.

A comparative analysis of the cities of *Fulfinum*, *Curicum*, *Apsorus*, and *Arba* (on the island of Rab) reveals a certain uniformity in their orientation, size, and city plan (to be published separately). This may be attributed to the fact that these settlements attained town status in the 1st century AD, despite slight chronological divergences observed in the development of their municipal organisation (Margetić 1979: 330–332). It is assumed that *Arba* became a *municipium* as early as the reign of Augustus (Margetić 1979: 330), while *Fulfinum* only achieved this status during the Flavian period (Rendić-Miočević 1974). The question of whether the *municipium* of *Apsorus* and/or the *municipium* of *Crexi*

Komparativna analiza gradova *Fulfinum*, *Curicum*, *Apsorus* i *Arba* (na otoku Rabu) otkriva izvjesnu jednoobraznost orijentacije, veličine i urbanističkog plana (što će biti zasebno objavljeno). To se može pripisati činjenici da su ta naselja stekla status grada u 1. st. po. Kr., unatoč malim kronološkim odstupanjima u razvoju njihovog municipalnog ustroja (Margetić 1979: 330–332). Pretpostavlja se da je *Arba* postala municipij već za vrijeme Augustove vladavine (Margetić 1979: 330), dok je *Fulfinum* ovaj status stekao tek pod Flavijevcima (Rendić-Miočević 1974). Pitanje jesu li municipij *Apsorus* i/ili municipij *Crexi* osnovani pod Tiberijem, kako pretpostavlja Géza Alföldy (1965: 74), ostaje zasad nerazriješeno. S obzirom na te podatke, vjerojatno je da su predstavljeni ostatci povezani s municipalnim statusom tih kvarnerskih gradova i da se mogu smatrati alternativom *agri centuriati* na kopnu (Campbell 2000: lxi).

were founded under Tiberius, as assumed by Géza Alföldy (1965: 74), remains unresolved at this time. Considering this evidence, it is probable that the relicts presented here are related to the municipal status of these Kvarner cities and may be viewed as an alternative to the *agri centuriati* on the mainland (Campbell 2000: lxi).

Despite this common historical background and all the general similarities in size, there are notable differences between the three survey systems. The Roman survey on Cres is characterised by variability in line spacing and lengths (no uniform grid), which may be related to the mountainous terrain. In this context, the term *scamnatio* is applicable. The measuring system in the northern part of the island of Krk is similar but combines the *scamna* with a uniform grid (Fig. 8: b).

The parcelling of land using *scamna* (the longitudinal direction extending east-west) or *strigae* (the longitudinal direction extending north-south) is attested in the *Corpus Agrimensorum Romanorum* (e.g., Campbell 2000, with older literature). In the context of archaeological research, the terms *scamna* and *strigae* refer to relics from different periods. They are associated with the oldest irregular strip surveys in Italy, which lack a uniform grid (Hinrichs 1974; Flach 1990: 15–18), as well as with younger regular strip surveys associated with colonies founded from the 4th century BC onwards (Chouquer et al. 1987). Some of these strip surveys have undergone further analysis, and their dating has been confirmed (e.g., Sacchi 2004; Kim 2021), while others have yet to be examined. This is a significant point, as Brian Campbell (1996: 86) observed: "But the evidence for a consistently early date for *scamna* and *strigae* remains unproved, and it is possible to believe that land division into strips was not necessarily a primitive system but a variation dictated by circumstances, for example in cases where the land was too rough or awkwardly located to make division into *centuriae* feasible, or where, if only a small amount of land was required for settlement, full-scale division into *centuriae* was deemed unnecessary."

An alternative approach to the *scamnatio* on the Kvarner islands could seek its origins in the changes of the Flavian period. The progressive urbanisation of the Croatian coast and its hinterland is attributed to the Flavian period (Alföldy 1965: 201; see also Mrozewicz 2014). This is perhaps also reflected in the Flavian *municipium* of Fulfinum. Additionally, a supra-regional land reform aimed at reclaiming public lands is associated with the same period. As Lauretta Mangazani (2010) notes, the reform con-

Unatoč toj zajedničkoj povijesnoj podlozi i svim općim sličnostima u pogledu veličine, postoje i značajne razlike između tri katastarske mreže. Rimsku zemljišnu izmjeru na Cresu obilježava varijabilnost u razmaku i duljinama linija (nema ujednačene mreže), što bi moglo biti povezano s planinskim terenom. U tom kontekstu primjenjiv je pojam *scamnatio*. Mjerni sustav u sjevernom dijelu otoka Krka sličan je, ali kombinira *scamna* s ujednačenom mrežom (sl. 8: b).

Parceliranje zemljišta korištenjem *scamna* (uzdužni smjer od istoka prema zapadu) ili *strigae* (uzdužni smjer od sjevera prema jugu) dokumentirano je u *Corpus Agrimensorum Romanorum* (npr. Campbell 2000, sa starijom literaturom). U kontekstu arheoloških istraživanja, pojmovi *scamna* i *strigae* odnose se na ostatke iz različitih razdoblja. Povezani su s najstarijom izmjerom zemljišta u obliku dugačkih, uskih i nepravilnih parcela u Italiji, bez ujednačene mreže (Hinrichs 1974; Flach 1990: 15–18), kao i s mlađim mjerenjima ujednačene mreže, koja se vežu uz kolonije osnovane od 4. st. pr. Kr. nadalje (Chouquer et al. 1987). Neke od tih izmjera zemljišta prošla su daljnje analize i potvrđeno je njihovo datiranje (npr. Sacchi 2004; Kim 2021), dok druga tek trebaju biti istražena. To je važan detalj, kao što zapaža Brian Campbell (1996: 86): „No dosljedno rano datiranje *scamna* i *strigae* ostaje nedokazano, pa je moguće da (ta) podjela zemljišta nije nužno bila primitivan sustav, već varijacija uvjetovana okolnostima – na primjer, u slučajevima kad je zemljište bilo previše neravno ili nezgodno smješteno da bi podjela na centurije bila moguća, ili tamo gdje je za naselje bilo potrebno tako malo zemljišta da se sveobuhvatna podjela u centurije smatrala nepotrebnom."

Alternativni pristup za *scamnatio* na kvarnerskim otocima mogao bi potražiti njegovo podrijetlo u promjenama pod Flavijevcima. Flavijevskom se razdoblju pripisuje rastuća urbanizacija hrvatske obale i zaleđa (Alföldy 1965: 201; vidi također Mrozewicz 2014). Taj proces se možda odražava i u flavijevskom municipiju *Fulfinum*. Osim toga, s istim se razdobljem povezuje nadregionalna zemljišna reforma usmjerena na povrat javnih zemljišta. Kako primjećuje Lauretta Mangazani (2010), reforma koja se odnosi na *ager vectigalis* (javno zemljište koje se iznajmljuje pojedincima u zamjenu za zakupninu) ne samo da je dovela do jasnog definiranja takvih zemljišta, već je također, kako pre-

cerning *ager vectigalis* (public land leased to private individuals in return for land rent) not only led to a clear definition of such lands but also, as recommended by Hyginus, involved marking them distinctly using the *scamna et strigae* system to permanently differentiate them from *ager immunis* (land free of obligations). Therefore, it is possible that the Flavian land reform was implemented on the Kvarner islands during the course of the 2nd century.

The third survey system covers the central region of the island of Krk and is spatially linked to the *municipium* of *Curicum* (Fig. 8: a). The survey bears a striking resemblance to a *centuriatio* grid, although the survey lines extending in the northeast-southwest direction (*scamnatio*) predominate, and the characteristic chessboard pattern has not been consistently realised. Only further research can clarify whether this form of land surveying is connected to the time of the granting of municipal rights, which is assumed to have occurred in the first half of the 1st century (summary in Starac 2000: 81), or with other legal or political objectives. It also illustrates that Roman surveying should be regarded as a research subject in its own right, rather than merely an indication of the extent of the city's territory.

The question of whether the agriculturally valuable land of a single island was administered solely by the island communities or whether the (coastal) communities also claimed the land of neighbouring islands (Suić 1956: 15; Čaušević-Bully, Valent 2015: 111–112) cannot be answered on the basis of the available survey relics. The current results provide only a glimpse into the "skeleton" of a landscape organisation that has long since ceased to exist. What can be recognised is that we are dealing with a surveying system that resembles other known examples but is not necessarily identical to those found in other regions. After all, every land survey merely reflects the prevailing legal, political, and agricultural requirements.

The main aim of the discussion presented here is to introduce new results. The analysis of individual *scamna*, including their subdivision into actual agricultural plots and their spatial relationship to *villae rusticae*, has yet to be undertaken. Similarly, other aspects will need to be addressed in the future. In addition to the political and legal issues already mentioned, other elements of Roman surveying are also important. These include, on one hand, astronomical aspects (cf. Rodríguez-Antón et al. 2023), which may have played a role in the surveying process. On the other hand, it seems important to understand how regional processes have affected the present appearance of Roman survey relics. The poručuje Higin, uključivala njihovo jasno obilježavanje sustavom *scamna et strigae* kako bi se trajno razlikovala od *ager immunis* (zemljište oslobođeno obveza). Stoga je moguće da je flavijevska zemljišna reforma bila provedena na kvarnerskim otocima tijekom 2. stoljeća.

Treća katastarska mreža pokriva središnji dio otoka Krka i prostorno je povezana s municipijem *Curicum* (sl. 8: a). Ta mreža je izrazito slična centurijacijskoj mreži, premda prevladavaju linije izmjere koje se protežu u smjeru sjeveroistok – jugozapad (*scamnatio*) te karakteristični uzorak šahovske ploče nije dosljedno realiziran. Samo daljnja istraživanja mogu razjasniti je li taj oblik izmjere zemljišta povezan s vremenom dodjele municipalnih prava, za koju se pretpostavlja da se dogodila u prvoj polovici 1. stoljeća (sažetak u Starac 2000: 81), ili s nekim drugim pravnim ili političkim razlozima. Ovo također pokazuje da se rimska izmjera zemljišta treba smatrati zasebnim predmetom istraživanja, a ne samo pokazateljem opsega teritorija grada.

Na pitanje jesu li poljoprivredno vrijednim zemljištem pojedinog otoka upravljale isključivo otočke zajednice ili su (obalne) zajednice također polagale pravo na zemljište susjednih otoka (Suić 1956: 15; Čaušević-Bully, Valent 2015: 111–112), ne može se trenutno odgovoriti na osnovi dostupnih podataka. Novi rezultati pružaju samo uvid u „kostur" organizacije krajolika koja odavno više ne postoji. Ono što se može prepoznati jest da se radi o sustavu izmjere koji podsjeća na druge poznate primjere, ali nije nužno identičan onima iz drugih regija. U konačnici, svaka izmjera zemljišta samo odražava vladajuće pravne, političke i poljoprivredne uvjete.

Glavni cilj ove rasprave predstavljanje je novih rezultata. Analiza pojedinačnih *scamna*, kao i njihove podjele na stvarne poljoprivredne parcele te prostorni odnos s *villae rusticae* tek treba provesti. Također, u budućnosti treba obraditi i druge aspekte. Uz politička i pravna pitanja koja su već spomenuta, važni su i drugi elementi rimske izmjere zemljišta. S jedne strane, to uključuje astronomske aspekte (usp. Rodríguez-Antón et al. 2023), koji su možda igrali ulogu u procesu izmjere. S druge strane, čini se važnim razumjeti kako su regionalni procesi utjecali na današnji izgled ostataka rimske izmjere zemljišta. Na trenutnu interpretaciju utječe činjenica da je samo 10–15 % rimskih suhozida sastavni dio današnjih sustava parce-

current interpretation is influenced by the fact that only 10–15% of the Roman dry-stone walls remain as part of the modern parcelling systems on Krk and Cres. This raises questions about how subsequent historical processes have interacted with Roman heritage (e.g., Suić 1956; Baraka Perica 2022). Equally important is the question of the spatial relationship between Iron Age hilltop settlements and land use and later Roman land takeover, as well as how they interacted. Last but not least, we must consider whether some of the remains discovered in southern Krk and Cres, which do not conform to the rectangular system, are related to pastoralism (cf. Camerieri, Mattioli 2011).

Conclusion

The Kvarner islands are relatively small, but archaeological findings indicate that their karst landscape is characterised by more than just small-scale, regional processes. Given that over 20 other islands along the Croatian coast were settled and cultivated during the Roman era, it is likely that similar survey relics of municipal territories will be identified using ALS methodology. This will facilitate further research on fundamental questions regarding the historical processes reflected in the North Adriatic land survey.

While Luigi Capogrossi Colognesi (2020: 168) proposes the "stratigraphic reading"' of the texts of the *agrimensores*, the same approach is necessary for analysing archaeological features detected through remote sensing surveys. The integration of geographical, hydrographic, and other relevant data into the research (e.g., Dall'Aglio 2010; Willi 2014; de Haas 2017) highlights the importance of a landscape archaeology perspective (see also Orengo, Palet Martinez 2010). It is evident that their current appearance is not a direct reflection of the Roman landscape but has also been shaped by the respective regional histories preceding and succeeding the Roman period. This fact does not call their historical value into question (see also Franceschelli 2016: 205–206).

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lizacije na Krku i Cresu. To potiče pitanja o djelovanju kasnijih povijesnih procesa na rimsku baštinu (npr. Suić 1956, Baraka Perica 2022). Jednako je važno pitanje prostornog odnosa željeznodobnih gradina i korištenja zemljišta te kasnijeg rimskog preuzimanja teritorija, kao i njihove međusobne interakcije. Napokon, potrebno je razmotriti jesu li neki od ostataka zidova otkrivenih na jugu Krka i Cresa, koji ne odgovaraju pravokutnom sustavu, povezani sa stočarstvom (usp. Camerieri, Mattioli 2011).

Zaključak

Kvarnerski su otoci relativno mali, ali arheološki nalazi ukazuju na to da njihov krški krajolik ne obilježavaju samo regionalni procesi malih razmjera. S obzirom na činjenicu da je tijekom rimskog razdoblja više od 20 drugih otoka duž hrvatske obale bilo naseljeno i obrađivano, može se opravdano pretpostaviti da će slični ostatci izmjere municipalnih teritorija biti identificirani korištenjem ALS metodologije. To će omogućiti daljnja istraživanja temeljnih pitanja o povijesnim procesima koji se odražavaju u izmjeri zemljišta na sjevernom Jadranu.

Dok Luigi Capogrossi Colognesi (2020: 168) predlaže „stratigrafsko čitanje" tekstova *agrimensores*, isti je pristup neophodan za analizu arheoloških struktura otkrivenih daljinskim snimanjem. Integracija geografskih, hidrografskih i drugih relevantnih podataka u istraživanja (npr. Dall'Aglio 2010; Willi 2014; de Haas 2017) naglašava koliko je važna perspektiva krajobrazne arheologije (vidi također Orengo, Palet Martinez 2010). Očito je da njihov sadašnji izgled nije izravan odraz rimskog krajobraza, već je također oblikovan odgovarajućom regionalnom poviješću prije i poslije rimskog razdoblja. Ova činjenica ne dovodi u pitanje njihovu povijesnu vrijednost (vidi također Franceschelli 2016: 205–206).

Zahvale

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Prijevod Translation **MARKO MARAS**
Lektura Proofreading **MARKO MARAS**

ABBREVIATION KRATICA

CIL – *Corpus Incriptionum Latinarum*, IL vols. with Suppl. by E. Lommatzsch (1894–1930), Berlin, https://cil.bbaw.de/

INTENET SOURCES INTERNETSKI IZVORI

Agri Centuriati – International Journal of Landscape Archaeology, http://digital.casalini.it/18251277

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Geoportal DGU – Geoportal, Državna geodetska uprava / State Geodetic Adiminstration (SGA), https://geoportal.dgu.hr/

Google Maps – https://www.google.com/maps

Multisenzorsko zračno snimanje Republike Hrvatske / Multisensor Aerial Survey of the Republic of Croatia – https://dgu.gov.hr/multisenzorsko-zracno-snimanje-republike-hrvatske/5700

OpenStreetMap – Open StreetMap Foundation (OSMF), www.openstreetmap.org/copyright

SRTM – Shuttle Radar Topography Mission (STRM), NASA EarthData, https://www.earthdata.nasa.gov/data/instruments/srtm

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Appendix 1 Dodatak 1
Osor Beyond the Myth: OSL investigations
Osor onkraj mita: OSL istraživanja

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Introduction

This Appendix describes the background of the luminescence investigations, sampling and initial luminescence profiling using portable OSL equipment, the preliminary interpretations, and the subsequent laboratory analyses, culminating in quantitative quartz single aliquot regenerative dose (SAR) OSL dating.

Relevant publications can be found in the reference list, which includes Burbidge et al. 2007; Guérin et al. 2017; Jarvis, Jarvis 1992; Kinnaird et al. 2017; Kinnaird et al. 2019; Lichtenberger et al. 2019; Munyikwa et al. 2020; Muñoz-Salinas et al. 2014; Tudyka et al. 2018; Turner et al. 2021, and Vervust 2020.

Methodology

Sample collection and OSL profiling

Sampling for OSL-PD took place between the 10th and 12th of March 2024.

***Punta Križa*. The objective of this study was to date the construction of the *Punta Križa* stone walls, which are now largely collapsed but recognised as a series of loose stone alignments. Small slot trenches were excavated across these features, allowing access to the underlying soil(s) and substrate. Trenches PTK24-1 and PTK24-2 were positioned along the main NW-SE alignment on opposite banks, while PTK24-3 was located on a perpendicular alignment that is slightly better preserved. The proxies of IRSL and OSL net signal intensities, IRSL and OSL depletion indices, and IRSL:OSL ratios are presented in Tab. 2. OSL signal intensities can serve as a proxy for age in well-bleached sediment; older sediment should be characterised by higher signal intensities, whereas younger sediment, bleached more recently, exhibits lower intensities. In this study and the main manuscript, the magnitude and range of OSL signal intensities**

Uvod

Ovaj Dodatak opisuje podlogu istraživanja luminescencije, uzorkovanje i početno profiliranje luminescencije pomoću prijenosne OSL opreme, preliminarne interpretacije i naknadne laboratorijske analize, a završava kvantitativnim određivanjem starosti kvarca pomoću OSL metode regenerativne doze s jednim alikvotom (SAR).

Relevantne publikacije nalaze se u popisu literature, a uključuju radove: Burbidge et al. 2007; Guérin et al. 2017; Jarvis, Jarvis 1992; Kinnaird et al. 2017; Kinnaird et al. 2019; Lichtenberger et al. 2019; Munyikwa et al. 2020; Muñoz-Salinas et al. 2014; Tudyka et al. 2018; Turner et al. 2021 i Vervust 2020.

Metodologija

Prikupljanje uzoraka i OSL profiliranje

Uzorkovanje za OSL-PD provedeno je između 10. i 12. ožujka 2024.

Punta Križa. Cilj ovog istraživanja bilo je datiranje izgradnje suhozida na položaju *Punta Križa*, koji su danas uglavnom urušeni, ali su prepoznati kao niz poredanog rasutog kamenja. Male sonde iskopane su preko tih objekata i omogućile pristup temeljnom tlu i podlozi. Sonde PTK24-1 i PTK24-2 postavljene su duž glavne orijentacije sjeverozapad – jugoistok na suprotnim stranama, dok je PTK24-3 bio smješten na okomitoj osi koja je nešto bolje očuvana. Pokazatelji neto intenziteta signala IRSL i OSL, indeksi iscrpljenosti IRSL i OSL te omjeri IRSL:OSL prikazani su u tablici 2. Intenziteti OSL signala mogu poslužiti kao pokazatelj starosti u dobro izbijeljenom sedimentu; stariji sediment trebaju obilježavati viši intenziteti signala, dok mlađi sediment, izbijeljen u novije vrijeme, pokazuje niže intenzitete. U ovom istraživanju i glavnom radu naglašavaju

are emphasised through colour: warmer colours (reds) indicate sample positions characterised by higher intensities, while cooler colours (blues) represent lower intensities. The same colour scale is applied across figures and tables. Additionally, the probability density functions in the kernel density estimate (KDE) plots are coloured to reflect the intensities observed at equivalent sampling positions.

The luminescence stratigraphies were reviewed in light of archaeology and sedimentology, and were used to position samples for dating purposes in each trench. PK24-1 and PK24-2 were characterised by very similar profiles: samples taken immediately beneath the 'wall' in contexts (101) and (201) returned lower intensities, ranging from 4.4 to 4.8 x10^4 counts, compared to those at depth in contexts (102) and (202), which exceeded 7.8 x10^4 counts (Tab. 2). This is promising for dating, as it suggests that the sediment immediately beneath the wall was disturbed during construction, resulting in a luminescence reset. PK24-3 was characterised by a different profile: OSL intensities progressed from 1.6-1.7 x10^4 to 1.9-2.1 x10^4 counts in context (301), and from 2.8 x10^4 to over 4.1 x10^4 counts in context (302). The interpretation in the field was that the banks PK24-1 and PK24-2 were similar in age, while the perpendicular bank, PTK24-3, was constructed later. Dating samples were positioned beneath the walls to test this hypothesis and to provide a *terminus post quem* (TPQ) for construction. To accomplish this, steel tubes with a diameter of 3.5 cm were inserted into the cleaned face of the section in contexts (102), (202), and (302), then extracted and sealed. Due to the packing density of stones in the upper contexts (101), (201), and (301), these could not be sampled using tubes; instead, 'bulk' samples of sediment were extracted under dark cover from the cleaned face of the section into plastic containers, which were sealed and made light-safe.

In-situ field gamma spectrometry measurements were conducted at PK24-1-OSL1, PK24-2-OSL1, and PK24-3-OSL1 using a Gamma Surveyor Vario paired with a 19 cm^3 Bismuth Germanate Oxide detector. Additionally, 'bulk' sediment samples were collected for laboratory measurements of water content and dosimetry from sample locations.

se magnituda i raspon intenziteta OSL signala pomoću boja: toplije boje (crvene) označavaju položaje uzoraka s višim intenzitetima, dok hladnije boje (plave) predstavljaju niže intenzitete. Ista skala boja primjenjuje se u svim slikama i tablicama. Osim toga, funkcije gustoće vjerojatnosti u dijagramima procjene gustoće jezgre (KDE) obojene su kako bi odražavale intenzitete utvrđene na ekvivalentnim položajima uzorkovanja.

Stratigrafije luminescencije pregledane su u svjetlu arheologije i sedimentologije te su korištene za pozicioniranje uzoraka radi datiranja u svakoj sondi. PK24-1 i PK24-2 obilježili su vrlo slični profili: uzorci uzeti neposredno ispod "zida" u kontekstima (101) i (201) dali su niže intenzitete, u rasponu od 4,4 do 4,8 x10^4, u usporedbi s onima na većim dubinama u kontekstima (102) i (202), koji su prelazili 7,8 x10^4 (tab. 2). Ovo je obećavajuće za datiranje, jer ukazuje da je sediment neposredno ispod zida bio poremećen tijekom izgradnje, što je dovelo do resetiranja luminescencije. PK24-3 obilježio je drukčiji profil: OSL intenziteti napredovali su od 1,6–1,7 x10^4 do 1,9–2,1 x10^4 u kontekstu (301) te od 2,8 x10^4 do preko 4,1 x10^4 u kontekstu (302). Interpretacija na terenu bila je da su nasipi PK24-1 i PK24-2 slične starosti, dok je okomiti nasip, PTK24-3, izgrađen poslije. Uzorci za datiranje postavljeni su ispod zidova kako bi se testirala ova hipoteza i osigurao *terminus post quem* (TPQ) za izgradnju. U tu svrhu, čelične cijevi promjera 3,5 cm umetnute su u očišćenu stranu profila u kontekstima (102), (202) i (302), a zatim izvučene i zapečaćene. Zbog gustoće kamenja u gornjim kontekstima (101), (201) i (301), nije bilo moguće uzorkovati pomoću cijevi, nego su uzorci „rasutog" sedimenta izvađeni pod tamnim pokrovom iz očišćene strane profila u plastične posude, koje su zatim zapečaćene i zaštićene od svjetlosti.

Na lokacijama PK24-1-OSL1, PK24-2-OSL1 i PK24-3-OSL1 provedena su mjerenja gama spektrometrije *in situ* pomoću uređaja Gamma Surveyor Vario uparenog s detektorom Bismuth Germanate Oxide zapremine 19 cm^3. Osim toga, prikupljeni su uzorci „rasutog" sedimenta za laboratorijska mjerenja količine vode i dozimetrije s lokacija uzorkovanja.

Field ID ID polja	Depth Dubina	IRSL signal intensities Intenziteti signala IRSL	IRSL depletion Iscrpljenost IRSL	OSL signal intensities Intenziteti signala OSL	OSL depletion Iscrpljenost OSL	IRSL : OSL ratio Omjer IRSL : OSL
PK24-1/1	8	5450 ± 80	1.3 ± 0.04	48780 ± 220	1.66 ± 0.02	0.1116 ± 0.0017
PK24-1/2	26	11620 ± 110	1.33 ± 0.03	77790 ± 280	1.68 ± 0.01	0.1494 ± 0.0015
PK24-1/3	33	14430 ± 120	1.35 ± 0.02	88680 ± 300	1.67 ± 0.01	0.1627 ± 0.0015
PK24-1/4	40	12020 ± 110	2.09 ± 0.04	85500 ± 290	1.64 ± 0.01	0.1405 ± 0.0014
PK24-1/5	47	15360 ± 130	1.37 ± 0.02	73380 ± 270	3.17 ± 0.03	0.2093 ± 0.0019
PK24-1/6	54	16340 ± 130	1.3 ± 0.02	93150 ± 310	1.68 ± 0.01	0.1754 ± 0.0015
PK24-1/7	19	9010 ± 100	1.3 ± 0.03	64080 ± 260	1.68 ± 0.01	0.1406 ± 0.0017
PK24-1/8	33	9010 ± 100	1.3 ± 0.03	64000 ± 260	1.68 ± 0.01	0.1408 ± 0.0017
PK24-1/9	40	12680 ± 120	1.33 ± 0.02	81670 ± 290	1.68 ± 0.01	0.1553 ± 0.0015
PK24-1/10	47	18450 ± 140	1.33 ± 0.02	95650 ± 310	1.6 ± 0.01	0.1929 ± 0.0016
PK24-1/11	56	17510 ± 140	1.33 ± 0.02	95560 ± 310	1.59 ± 0.01	0.1833 ± 0.0015
PK24-2/1	18	6530 ± 90	1.31 ± 0.03	52520 ± 230	1.73 ± 0.02	0.1243 ± 0.0017
PK24-2/2	30	9500 ± 100	1.32 ± 0.03	66400 ± 260	1.7 ± 0.01	0.143 ± 0.0017
PK24-2/3	38	9960 ± 110	1.31 ± 0.03	59260 ± 250	1.65 ± 0.01	0.1681 ± 0.0019
PK24-2/4	45	11970 ± 110	1.31 ± 0.02	81600 ± 290	1.67 ± 0.01	0.1466 ± 0.0015
PK24-2/5	9	4800 ± 80	1.31 ± 0.04	43880 ± 210	1.71 ± 0.02	0.1093 ± 0.0018
PK24-2/6	25	8290 ± 100	1.25 ± 0.03	63270 ± 250	1.68 ± 0.01	0.1311 ± 0.0016
PK24-2/7	29	9250 ± 100	1.33 ± 0.03	65840 ± 260	1.7 ± 0.01	0.1404 ± 0.0016
PK24-2/8	37	10720 ± 110	1.38 ± 0.03	70290 ± 270	1.68 ± 0.01	0.1525 ± 0.0017
PK24-2/9	44	11790 ± 110	1.34 ± 0.03	71960 ± 270	1.67 ± 0.01	0.1638 ± 0.0017
PK24-2/10	50	13320 ± 120	1.35 ± 0.02	78850 ± 280	1.61 ± 0.01	0.1689 ± 0.0016
PK24-3/1	6	2030 ± 60	1.39 ± 0.07	17760 ± 140	1.59 ± 0.02	0.1144 ± 0.0034
PK24-3/2	11	2540 ± 60	1.26 ± 0.05	18990 ± 140	1.43 ± 0.02	0.1338 ± 0.0032
PK24-3/3	35	6480 ± 90	1.32 ± 0.03	41370 ± 210	1.65 ± 0.02	0.1565 ± 0.0023
PK24-3/4	42	8460 ± 100	1.32 ± 0.03	48350 ± 220	1.62 ± 0.02	0.175 ± 0.0022
PK24-3/5	47	8620 ± 100	1.35 ± 0.03	50800 ± 230	1.61 ± 0.01	0.1697 ± 0.0021
PK24-3/6	52	10270 ± 110	1.31 ± 0.03	50000 ± 230	1.61 ± 0.01	0.2054 ± 0.0023
PK24-3/7	6	1940 ± 60	1.37 ± 0.07	15960 ± 130	1.58 ± 0.03	0.1216 ± 0.0036
PK24-3/8	12	2930 ± 60	1.36 ± 0.05	20590 ± 150	1.53 ± 0.02	0.1424 ± 0.0032
PK24-3/9	21	4200 ± 70	1.39 ± 0.05	28450 ± 170	1.6 ± 0.02	0.1478 ± 0.0027
PK24-3/10	28	5630 ± 80	1.39 ± 0.04	35070 ± 190	1.58 ± 0.02	0.1607 ± 0.0025
PK24-3/11	35	6210 ± 90	1.31 ± 0.03	40640 ± 200	1.65 ± 0.02	0.1529 ± 0.0023

Tab. 2 – IRSL and OSL net signal intensities, IRSL and OSL depletion indices and the IRSL: OSL ratios for the bulk sediment samples taken from trenches PK24-1, 2 and 3 (the Punta Križa stone walls) (made by: T. Kinnaird)
Tab. 2 – Neto intenziteti signala IRSL i OSL, indeksi iscrpljenosti IRSL i OSL te omjeri IRSL : OSL za uzorke rasutog sedimenta prikupljene iz sonda PK24-1, 2 i 3 (suhozidi na području Punta Križa) (izradio: T. Kinnaird)

Field ID ID polja	CERSA ID ID CERSA	Sample location (see Fig. 5) Lokacija uzorka (vidi sl. 5)	Depth (cm) (see Tab. 2) Dubina (cm) (vidi tab. 2)	Feature Objekt	Significance Značaj
PK24-1-OSL1	1503	PK24-1/2	24	main linear – bank 1 glavna linija – strana 1	TPQ for construction TPQ za izgradnju
	1503B	PK24-1/7	19		
PK24-2-OSL1	1504	PK24-2/6	25	main linear – bank 2 glavna linija – strana 2	
	1504C	PK24-2/5	9		
	1504D	PTK24-2/7	29		
PK24-3-OSL1	1505	PTK24-3/3	35	wall perpendicular to main linear zid okomit na glavnu liniju	

Tab. 3 – Sample details (made by: T. Kinnaird)
Tab. 3 – Pojedinosti uzoraka (izradio: T. Kinnaird)

Quartz SAR OSL dating

A luminescence age is calculated as the quotient of the burial dose (in Gy) divided by the effective environmental dose rate (in mGy a^{-1}). It requires that the sediment was fully bleached prior to burial. Equivalent dose (De) determinations were made on sets of 16-26 aliquots using the single aliquot regenerative dose (SAR) OSL protocol. Different permutations of the assimilation of equivalent doses to obtain the burial dose were considered, including weighted combinations and statistical dose models (see Guérin et al. 2017). Dose rates for these sediments were assessed using a combination of in situ gamma spectrometry, low-level environmental radioactivity measurements in the laboratory, and determinations of radionuclide concentrations by mass spectrometry.

Radionuclide concentrations and environmental dose rates

Radionuclide concentrations of ^{232}Th, ^{238}U and ^{40}K were determined using inductively coupled plasma mass spectrometry (ICP-MS; U, Th) and inductively coupled plasma optical emission spectrometry (ICP-OES; K) at X-Ray Mineral Services in Welshpool (Tab. 4). Infinite matrix dose rates were calculated from these using the conversion factors provided by Guérin et al. (2011) and adjusted for attenuation based on grain size and chemical etching, using the datasets of Guérin et al. (2012) and Bell (1979), respectively (Tab. 5). Field and saturated water contents were determined for all samples in the laboratory (~15-28% and ~23–33%, respectively), with working values of 18–27% adopted to calculate effective environmental dose rates (Ḋ). The contribution from the cosmic dose ($\dot{D}_{cosmic}$) was determined following Prescott and Hutton (1994), with adjustments made for longitude, latitude, altitude, and sample depth within the section. The dose rate measurements were combined with the assumed burial water contents to determine the total effective dose rates for age estimation (Tab. 6).

SAR OSL datiranje kvarca

Luminescentna dob izračunava se kao kvocijent doze zakapanja (Gy) podijeljene s efektivnim omjerom okolišne doze (mGy a^{-1}). Za to je potrebno da je sediment bio potpuno izbijeljen prije zakapanja. Određivanje ekvivalentne doze (De) provedeno je na skupovima od 16-26 alikvota koristeći OSL protokol regenerativne doze jednog alikvota (SAR). Razmatrane su različite permutacije asimilacije ekvivalentnih doza za dobivanje doze zakapanja, uključujući ponderirane kombinacije i statističke modele doza (vidi Guérin et al. 2017). Omjeri doza za te sedimente procijenjeni su kombinacijom gama spektrometrije ***in situ***, mjerenja niske okolišne radioaktivnosti u laboratoriju i određivanja koncentracije radionuklida masenom spektrometrijom.

Koncentracije radionuklida i omjeri okolišnih doza

Koncentracije radionuklida ^{232}Th, ^{238}U i ^{40}K određene su pomoću masene spektrometrije s induktivno spregnutom plazmom (ICP-MS; U, Th) i optičke emisijske spektrometrije s induktivno spregnutom plazmom (ICP-OES; K) u laboratoriju X-Ray Mineral Services u Welshpoolu (tab. 4). Na temelju njih izračunati su beskonačni matrični omjeri doza pomoću konverzijskih faktora prema Guérin et al. (2011), a prilagođeni su za atenuaciju na temelju veličine zrna i kemijskog nagrizanja, koristeći skupove podataka iz Guérin et al. (2012) odnosno Bell (1979) (tab. 5). Količina vode u terenskim i zasićenim uvjetima određivana je za sve uzorke u laboratoriju (~15-28% odnosno ~23-33%), dok su za izračun efektivnih omjera okolišnih doza (Ḋ) korištene radne vrijednosti od 18–27%. Doprinos kozmičke doze ($\dot{D}_{cosmic}$) određen je prema Prescott i Hutton (1994), s prilagodbama za geografsku dužinu, širinu, nadmorsku visinu i dubinu uzorka unutar profila. Mjerenja omjera doza kombinirana su s pretpostavljenim sadržajem vode tijekom zakapanja kako bi se odredile ukupne efektivne omjere doza za procjenu starosti (Tab. 6).

Lab code / CERSA# *Lab. šifra / CERSA#*	*Field ID* *ID polja*	K / %	U / ppm	Th / ppm
1503	PK24-1 OSL1	1.47 ± 0.09	3.13 ± 0.19	18.17 ± 1.09
1504	PK24-2 OSL2	1.45 ± 0.09	3.22 ± 0.19	18.17 ± 1.09
1505	PK24-3 OSL1	1.42 ± 0.09	3.52 ± 0.21	17.47 ± 1.05

Tab. 4 – ICP-MS and ICP-OES determinations of K (%), U and Th (ppm) concentrations (made by: T. Kinnaird)
Tab. 4 – Određivanje koncentracija K (%), U i Th (ppm) metodama ICP-MS i ICP-OES (izradio: T. Kinnaird)

Lab code/ CERSA# *Lab. šifra/ CERSA#*	FGS	ICP-MS and ICP-OES ICP-MS i ICP-OES		
	Gamma, dry / mGy a^{-1} Gama, suho / mGy a^{-1}	Alpha, dry / mGy a^{-1} Alfa, suho / mGy a^{-}	Beta, dry / mGy a^{-1} Beta, suho / mGy a^{-1}	Gamma, dry / mGy a^{-1} Gama, suho / mGy a^{-1}
1503	1.12 ± 0.09	22.16 ± 0.96	1.88 ± 0.08	1.59 ± 0.06
1504	1.20 ± 0.10	22.40 ± 0.97	1.88 ± 0.08	1.59 ± 0.06
1505	1.00 ± 0.08	22.73 ± 0.97	1.88 ± 0.08	1.58 ± 0.06

Tab. 5 – Infinite matrix dose rates determined from FGS, and ICP-MS and ICP-OES (made by: T. Kinnaird)
Tab. 5 – Beskonačni matrični omjeri doza zračenja određeni pomoću FGS, ICP-MS i ICP-OES (izradio: T. Kinnaird)

Lab code / CERSA#	*Field ID*	Water content / %	Cosmic dose, mGy a^{-1}	Effective dose rates, wet / mGy a^{-1}		
				Beta [a]	Gamma [b]	Total [d]
1503	PK24-1 OSL1	22 ± 5	0.17 ± 0.02	1.51 ± 0.1	1.21 ± 0.06	2.89 ± 0.12
1503B		22 ± 5	0.18 ± 0.02	1.51 ± 0.1	1.21 ± 0.06	2.89 ± 0.11
1504	PK24-2 OSL2	24 ± 6	0.17 ± 0.02	1.48 ± 0.1	1.23 ± 0.06	2.88 ± 0.12
1504C		24 ± 6	0.18 ± 0.02	1.48 ± 0.1	1.23 ± 0.06	2.89 ± 0.12
1504D		24 ± 6	0.18 ± 0.02	1.48 ± 0.1	1.23 ± 0.06	2.89 ± 0.12
1505	PK24-3 OSL1	26 ± 6	0.17 ± 0.02	1.46 ± 0.11	1.11 ± 0.06	2.74 ± 0.12

Tab. 6 – Effective beta and gamma dose rates following water correction. [a]Effective beta dose rate combining water content corrections with inverse grain size attenuation factors obtained Mejdahl (1979) for K, U, and Th [b]includes a reconcilation of gamma dose rates from adjacent samples, using a distance weighting function (made by: T. Kinnaird)
Tab. 6 – Efektivni omjeri doza beta i gama zračenja nakon korekcije za sadržaj vode. aefektivni omjer doze beta zračenja koji kombinira korekcije za sadržaj vode s faktorima inverzne atenuacije veličine zrna, prema Mejdahl (1979), za K, U i Th buklјučuje usklađivanje omjera doza gama zračenja iz susjednih uzoraka pomoću funkcije ponderiranja udaljenosti (izradio: T. Kinnaird)

De determinations and distributions

Mineral separation procedures similar to those used by Kinnaird et al. (2017) were used to extract HF-etched 'quartz' from all samples. The samples were wet-sieved to obtain the 90 to 250 µm fractions. These fractions were then treated with 1M HCl for 10 minutes, followed by 40% HF for 40 minutes, and a further treatment with 1M HCl for another 10 minutes. The 90 to 250 µm HF-etched fractions were density-separated in LST fastfloat solutions with densities of 2.64 and 2.74 g/cm^{-3}. The 90–250 µm HF-etched fractions at densities of 2.64–2.74 g/cm^{-3} were re-sieved at 150 µm, and the 150–250 µm fractions were dispensed into 10 mm stainless steel discs for measurement.

Equivalent dose (De) determinations were initially made on sets of 16 or more aliquots using a single aliquot regenerative dose (SAR) OSL protocol (cf. Murray Wintle, 2000; Kinnaird et al. 2017). OSL measurements were conducted using a Risø TL/OSL DA-20 automated dating system. Data reduction and De determinations were performed in Luminescence Analyst v.4.31.9 and the *Luminescence* package in R. Individual decay curves were scrutinised for shape and consistency. Dose response curves were fitted with an exponential function, with the growth curve passing through zero and the repeat recycling points. Error analysis was conducted using Monte Carlo simulation. Aliquots satisfying the following criteria were accepted for the assimilation of De values: 1) recuperation of less than 5%; 2) recycling ratio within 10% of unity, including uncertainties (Murray, Wintle 2003); 3) OSL IR depletion ratio within 10% of unity (Duller 2003); and 4) test dose signals 3σ greater than background levels.

Fig. 5 shows the equivalent dose distributions for CERSA1503, 1504, and 1505 as kernel density estimate (KDE) plots, alongside the corresponding stratigraphy.

***Age assimilations*. Tab. 7 lists the burial doses, environmental dose rates, and corresponding depositional ages for CERSA1503–1505.**

Određivanje i distribucija De

Za ekstrakciju HF-jetkanog „kvarca" iz svih uzoraka korišteni su postupci separacije minerala slični onima koje su koristili Kinnaird et al. (2017). Uzorci su mokro prosijani kako bi se dobile frakcije veličine 90 do 250 µm. Te su frakcije zatim tretirane s 1M HCl tijekom 10 minuta, nakon čega je uslijedio tretman s 40 % HF tijekom 40 minuta, te tretman s 1M HCl još 10 minuta. HF-jetkane frakcije veličine 90–250 µm razdvojene su prema gustoći u LST fastfloat otopinama s gustoćama od 2,64 i 2,74 g/cm^3. HF-jetkane frakcije od 90 do 250 µm, pri gustoćama od 2,64 do 2,74 g/cm^3 ponovno su prosijane na 150 µm, a frakcije od 150 do 250 µm stavljene su u diskove od nehrđajućeg čelika od 10 mm radi mjerenja.

Određivanje ekvivalentne doze (De) inicijalno je provedeno na skupovima od 16 ili više alikvota korištenjem protokola za optički stimuliranu luminiscenciju (OSL) s regenerativnom dozom pojedinačnih alikvota (SAR) (usp. Murray, Wintle (2000); Kinnaird et al. 2017). Za mjerenja OSL-a koristio se automatizirani sustav za datiranje Risø TL/OSL DA-20. Redukcija podataka i određivanje De vrijednosti provedeni su u softveru Luminescence Analyst v.4.31.9 i paketu *Luminescence* u R-u. Za pojedinačne krivulje raspada provjereni su oblik i konzistentnost. Krivulje reakcije na dozu prilagođene su eksponencijalnom funkcijom, pri čemu krivulja rasta prolazi kroz nulu i točke ponovnog recikliranja. Analiza pogreške provedena je pomoću simulacije Monte Carlo. Za asimilaciju vrijednosti De prihvaćeni su alikvoti koji zadovoljavaju sljedeće kriterije: 1) rekuperacija manja od 5 %; 2) omjer recikliranja unutar 10 % jedinice, uključujući neizvjesnosti (Murray, Wintle 2003); 3) omjer iscrpljenosti OSL IR unutar 10 % jedinice (Duller 2003); i 4) signali testne doze 3σ veći od razina pozadinske vrijednosti.

Sl. 5 prikazuje distribucije ekvivalentne doze za CERSA1503, 1504 i 1505 kao procjene gustoće jezgre (KDE) uz odgovarajuću stratigrafiju.

Asimilacije dobi. Tab. 7 navodi doze zakapanja, omjere okolišnih doza i odgovarajuće dobi taloženja za CERSA1503–1505.

	CERSA #	Palaeodose / Gy Paleodoza / Gy	Aliquots, n Alikvoti, n	Dose rate / mGy a^{-1} Omjer doze / mGy a^{-1}	Age / ka Dob / ka	Calendar years Kalendarske godine
PTK	1503	9.22 ± 0.37	22 (22)	2.89 ± 0.12	3.19 ± 0.18	1170 ± 180 BC
	1503B	5.34 ± 0.32	14 (16)	2.89 ± 0.11	1.85 ± 0.13	AD 180 ± 130
	1504	6.78 ± 0.36	20 (20)	2.88 ± 0.12	2.35 ± 0.16	330 ± 160 BC
	1504A	5.21 ± 0.39	15 (16)	2.89 ± 0.12	1.8 ± 0.16	AD 220 ± 160
	1504B	6.22 ± 0.53	16 (16)	2.89 ± 0.12	2.15 ± 0.21	130 ± 210 BC
	1505	6.73 ± 0.21	22 (22)	2.74 ± 0.12	2.46 ± 0.13	430 ± 130 BC

Tab. 7 – Burial doses, total effective environmental dose rates and corresponding depositional ages for CERSA1503 to 1505 (made by: T. Kinnaird)
Tab. 7 – Doze zakapanja, ukupni efektivni omjeri okolišnih doza i odgovarajuće dobi taloženja za CERSA1503 do 1505 (izradio: T. Kinnaird)