IZMEĐU ISTRAŽIVANJA I OČUVANJA — INTEGRACIJA ANALITIČKIH METODA U ZAŠTITNIM ISKOPAVANJIMA ŠPILJE VINDIJE

BETWEEN RESEARCH AND CONSERVATION — INTEGRATING ANALYTICAL METHODS IN THE RESCUE EXCAVATIONS OF THE VINDIJA CAVE

Marko Banda
Odsjek za arheologiju
Filozofski fakultet Sveučilišta u Zagrebu
Ivana Lučića 3
HR – 10000 Zagreb
mabanda@ffzg.unizg.hr

Filomena Sirovica
Arheološki muzej u Zagrebu
Trg Nikole Šubića Zrinskog 19
HR – 10000 Zagreb
fsirovica@amz.hr

Ivor Janković
Centar za primijenjenu bioantropologiju
Institut za antropologiju
Ljudevita Gaja 32
HR – 10000 Zagreb
ivor@inantro.hr

Lia Vidas
Centar za primijenjenu bioantropologiju
Institut za antropologiju
Ljudevita Gaja 32
HR – 10000 Zagreb
lia.vidas@inantro.hr

Nikola Vukosavljević
Odsjek za arheologiju
Filozofski fakultet Sveučilišta u Zagrebu
Ivana Lučića 3
HR – 10000 Zagreb
nvukosav@ffzg.unizg.hr

Giovanni Boschian
Dipartimento di Biologia
Università di Pisa
via Derna 1
I – 56125 Pisa, Italy

Palaeo-Research Institute, University of Johannesburg
P.O. Box 524, Auckland Park, 2006
South Africa
giovanni.boschian@unipi.it

Katarina Gerometta
Centar za interdisciplinarna arheološka istraživanja krajolika
Filozofski fakultet Sveučilišta Jurja Dobrile u Puli
Negrijeva 6
HR – 52100 Pula
katarina.gerometta@unipu.hr

Marko Banda
Department of Archaeology, Faculty of Humanities and Social Sciences, University of Zagreb
Ivana Lučića 3
HR – 10000 Zagreb
mabanda@ffzg.unizg.hr

Filomena Sirovica
Archaeological Museum in Zagreb
Trg Nikole Šubića Zrinskog 19
HR – 10000 Zagreb
fsirovica@amz.hr

Ivor Janković
Centre for Applied Bioanthropology
Institute for Anthropological Research
Ljudevita Gaja 32
HR – 10000 Zagreb
ivor@inantro.hr

Lia Vidas
Centre for Applied Bioanthropology
Institute for Anthropological Research
Ljudevita Gaja 32
HR – 10000 Zagreb
lia.vidas@inantro.hr

Nikola Vukosavljević
Department of Archaeology
Faculty of Humanities and Social Sciences, University of Zagreb,
Ivana Lučića 3
HR – 10000 Zagreb
nvukosav@ffzg.unizg.hr

Giovanni Boschian
Department of Biology
University of Pisa
via Derna 1
I – 56125 Pisa, Italy.

Palaeo-Research Institute, University of Johannesburg
P.O. Box 524, Auckland Park, 2006
South Africa
giovanni.boschian@unipi.it

Katarina Gerometta
Centre for Interdisciplinary Research in Landscape Archaeology
Faculty of Humanities, Juraj Dobrila University of Pula
Negrijeva 6
HR – 52100 Pula
katarina.gerometta@unipu.hr

Victoria Oberreiter
University of Veterinary Medicine
Konrad Lorenz Institute of Ethology
Savoyenstraße 1
A –1160 Vienna, Austria
victoria.oberreiter@gmail.com

James C. M. Ahern
Northern Illinois University
1425 West Lincoln Hwy, DeKalb
IL 60115, USA
jahern@niu.edu

Sanjin Mihelić
Muzej za umjetnost i obrt
Trg Republike Hrvatske 10
HR – 10000 Zagreb
sanjin.mihelic@muo.hr

Ivor Karavanić
Odsjek za arheologiju
Filozofski fakultet Sveučilišta u Zagrebu
Ivana Lučića 3
HR – 10000 Zagreb
ikaravanic@ffzg.unizg.hr

Victoria Oberreiter
University of Veterinary Medicine
Konrad Lorenz Institute of Ethology
Savoyenstraße 1
A –1160 Vienna, Austria
victoria.oberreiter@gmail.com

James C. M. Ahern
Northern Illinois University
1425 West Lincoln Hwy
DeKalb IL 60115, USA
jahern@niu.edu

Sanjin Mihelić
Museum of Arts and Crafts
Trg Republike Hrvatske 10
HR – 10000 Zagreb
sanjin.mihelic@muo.hr

Ivor Karavanić
Department of Archaeology
Faculty of Humanities and Social Sciences, University of Zagreb
Ivana Lučića 3
HR – 10000 Zagreb
ikaravanic@ffzg.unizg.hr

UDK / UDC: 902.3:551.442(497.523-37Varaždin)"632"
10.52064/vamz.58.2.1
Prethodno priopćenje / Preliminary report

U ovome radu donose se podatci o zaštitnim iskopavanjima i uzorkovanjima južne strane unutarnjega profila špilje Vindije (profil 3) provedenima 2023. Cilj radova bila je zaštita južne strane profila i prikupljanje uzoraka za nove, dosad neprovedene analize. Špilja Vindija dugo zauzima važno mjesto u arheološkoj struci, ne samo zbog izvanrednih nalaza koštanih ostataka neandertalaca i paleolitičkih kamenih te koštanih izrađevina, nego i zbog rane primjene raznih analitičkih metoda čiji su rezultati doprinijeli rješavanju ključnih pitanja o životu i razvoju paleolitičkih populacija. U radu su opisane metodologija, tijek iskopavanja, postupci uzorkovanja, a pruženi su i osnovni kvantitativni podatci o prikupljenim nalazima. Nadalje, donose se podatci o stratigrafiji te korelacije sa stratigrafskom shemom prijašnjih istraživanja. Tim iskopavanjem prikupljeni su uzorci za radiokarbonsko datiranje, mikromorfološku analizu, sedaDNA analizu te tefrokronološku determinaciju, kojima je cilj pružiti dodatne uvide u procese nastanka nalazišta, kronologiju nastanka naslaga te okolišne uvjete tijekom gornjega pleistocena. Shodno navedenomu, naglašeno je kako uzorkovanja za provedbu suvremenih analitičkih metoda u okviru arheološke znanosti mogu biti integrirana sa zahtjevima zaštitnih iskopavanja, čak i u okviru iznimno ograničenoga opsega istraživanja.

This article presents data about rescue excavations and sampling of the south face of the interior profile (profile 3), conducted in the Vindija cave in 2023. The goal of the fieldwork was the protection of the south profile face and the collection of samples for new and hitherto unconducted analyses. Vindija has been a relevant site in the field of archaeology for many years, not only because of the extraordinary finds of Neandertal skeletal remains and Palaeolithic stone and bone artefacts, but also due to the early implementation of various analytical methods, whose results have contributed to answering key questions about the life and development of Palaeolithic populations. This paper describes the methodology, the course of the excavation, and the sampling procedure, while also providing basic quantitative data on the finds recovered. In addition, data on stratigraphy is provided, as well as correlation with the stratigraphic framework established by earlier research. During this excavation, samples were collected for radiocarbon dating, micromorphological analysis, sedimentary ancient-DNA (sedaDNA) analysis, and tephrochronological determination, all aimed at offering deeper insights into site-formation processes, the chronology of sediment deposition, and environmental conditions during the Upper Pleistocene. In accordance with this, the study emphasizes that sampling for the application of modern analytical methods within archaeological science can successfully be integrated with the requirements of rescue excavations, even within the constraints of highly limited research.

Ključne riječi:
paleolitik, Vindija, zaštitna iskopavanja, uzorkovanje, radiokarbonsko datiranje, mikromorfološka analiza

Key words:
Palaeolithic, Vindija, rescue excavations, sampling, radiocarbon dating, micromorphological analysis

Uvod i pozadina istraživanja

Špilja Vindija značajno je arheološko i paleontološko nalazište, smješteno u okolici Rijeke Voćanske, na zapadnoj padini brda Vidov breg (E 467636 N 5129201), Općina Donja Voća, Varaždinska županija (Karta 1). Smještena je iznad doline potoka Šokot, na nadmorskoj visini od oko 275 metara. Sastoji se od jedne nepravilne dvorane kupolastoga svoda koja se postupno sužava prema unutrašnjosti, ukupne dubine oko 50 metara.[1] Današnji ulaz u špilju širok je 28 metara, a visok više od 10 metara. Prva iskopavanja na lokalitetu započeo je Stjepan Vuković dvadesetih godina prošloga stoljeća,[2] pri čemu je pronašao arheološke ostatke iz paleolitika, mlađe prapovijesti i antike. Akademik Mirko Malez nastavio je s istraživanjima od 1974. do 1986.,[3] kada su pronađeni brojni ostatci pleistocenske faune, arheološki nalazi iz različitih razdoblja paleolitika te fosilni ostatci neandertalaca i modernih ljudi.[4] Tijekom toga vremena uklonjen je veći dio kvartarnih naslaga iz špilje, ali ostavljena su tri kontrolna profila. Prvi i najveći očuvani profil (profil 1) nalazi se na samome ulazu u špilju, na njegovu sjevernomu kraju, a drugi, najmanji profil (profil 2), smješten je blizu južnoga kraja ulaza u špilju. Treći profil (profil 3), na kojemu su 2023. provedena zaštitna arheološka iskopavanja ograničenoga opsega, smješten je u unutrašnjemu dijelu špilje, uz njezin sjeverni zid, te sadrži dobro očuvane slojeve iz gornjega dijela stratigrafskog slijeda (Sl. 1).

Tijekom svojih iskopavanja, Malez je zabilježio stratigrafski slijed kvartarnih naslaga od 12 metara, koji su činile 13 osnovnih stratigrafskih jedinica (A – M), od kojih su neke podijeljene i na podslojeve.[5] Slojevi A – D/gore nastali su u vrijeme holocena, u posljednjih 12 tisuća godina, a stariji slojevi formirani su u vrijeme gornjega i srednjega pleistocena.[6] U raznim slojevima pronađeni su i ljudski kosturni ostatci. U sloju D pronađeni su ostatci anatomski modernih ljudi, a u slojevima G1, G3 i H pronađeni su kosturni ostatci neandertalaca.[7] Osim toga, naslage su bile bogate i paleontološkim materijalom[8] i arheološkim nalazima.

U slojevima D – Fd/d pronađene su izrađevine iz razdoblja gornjega paleolitika, a u slojevima ispod njih (G1 – M) izrađevine koje se vežu za srednji paleolitik i materijalne ostatke neandertalaca. Ipak, specifično obilježje toga nalazišta nalazi su iz sloja G1, gdje su, uz nalaze koji tipološki pripadaju srednjemu paleolitiku, pronađene i kamene i koštane izrađevine koje se najčešće vežu za gornji paleolitik.[9] Štoviše, u sloju G1 fosilni ostatci neandertalaca pronađeni su zajedno s orinjasijenskim koštanim šiljcima i kamenim oruđem, čime je to nalazište postalo ključno mjesto u raspravama o interakciji modernih ljudi

1 Malez, Rukavina 1979.

2 Vuković 1935; 1949; 1950.

3 Malez 1975; Malez, Šimunić, Šimunić 1984.

4 Za detaljniji uvid u povijest istraživanja vidjeti Smith *et al.* 2024.

5 Malez, Rukavina 1979; Rukavina 1983; Malez, Šimunić, Šimunić 1984.

6 Malez, Šimunić, Šimunić 1984; Malez 1988.

7 Wolpoff *et al.* 1981; Smith, Boyd, Malez 1985; Ahern *et al.* 2004; Devièse *et al.* 2017.

8 Miracle, Mauch Lenardić, Brajković 2010; Patou-Mathis, Karavanić, Smith 2018.

9 Karavanić, Smith 1998.

Introduction and research background

The Vindija cave is a significant archaeological and palaeontological site, located in the vicinity of Rijeka Voćanska, on the western slope of the hill of Vidov Breg (E 467636 N 5129201), Donja Voća municipality in Varaždin County (Map 1). The site is located above the Šokot stream valley, 275 metres above sea level. It consists of a single irregular chamber with a domed ceiling, which gradually narrows towards the interior, with a total depth of around 50 metres.[1] Nowadays the entrance is 28 metres wide and over 10 metres tall. Initial excavations were started by Stjepan Vuković in the 1920s, during which finds from the Palaeolithic, later periods of Prehistory and the Roman period were recovered.[2] Mirko Malez continued the research from 1974 to 1986,[3] when numerous finds of Pleistocene fauna, archaeological finds from various periods of the Palaeolithic and fossil remains of Neandertals were found.[4] During that period most of the Quaternary deposits were removed from the cave, but three control profiles were left in place. The first and largest preserved profile (profile 1) is located at the very entrance to the cave, at its northern end, while the second and smallest profile (profile 2) is positioned near the southern end of the cave entrance. The third profile (profile 3), where limited rescue excavations were carried out in 2023, is located in the inner part of the cave, along its northern wall, and contains well-preserved layers from the upper part of the stratigraphic sequence (Fig. 1).

During his excavations, Malez recorded a 12-metre stratigraphic sequence of Quaternary deposits, consisting of 13 general stratigraphic units (A–M), some of which are additionally subdivided into subunits.[5] Layers A–D/*gore* (Eng. ‘upper’) were formed during the Holocene, within the last 12 ka, while older layers were formed during the Upper and Middle Pleistocene.[6] Human skeletal remains were found in various layers. In layer D, remains of anatomically modern humans were discovered, while Neandertal skeletal remains were found in layers G1, G3 and H.[7] In addition, the deposits were rich in palaeontological material[8] and archaeological finds.

Artefacts from the Upper Palaeolithic were found in layers D–F*d/d* (‘lower/lower’), while the layers beneath them (G1–M) yielded artefacts associated with the Middle Palaeolithic and material remains of Neandertals. However, a distinctive feature of this site is represented by finds from layer G1, where, alongside typologically Middle Palaeolithic artefacts, both stone and bone artefacts typically linked to the Upper Palaeolithic were also discovered.[9] Moreover, in layer G1, Neandertal fossil re-

1 Malez, Rukavina 1979.

2 Vuković 1935; 1949; 1950.

3 Malez 1975; Malez, Šimunić, Šimunić 1984.

4 For a more detailed insight into the history of the research see Smith *et al.* 2024.

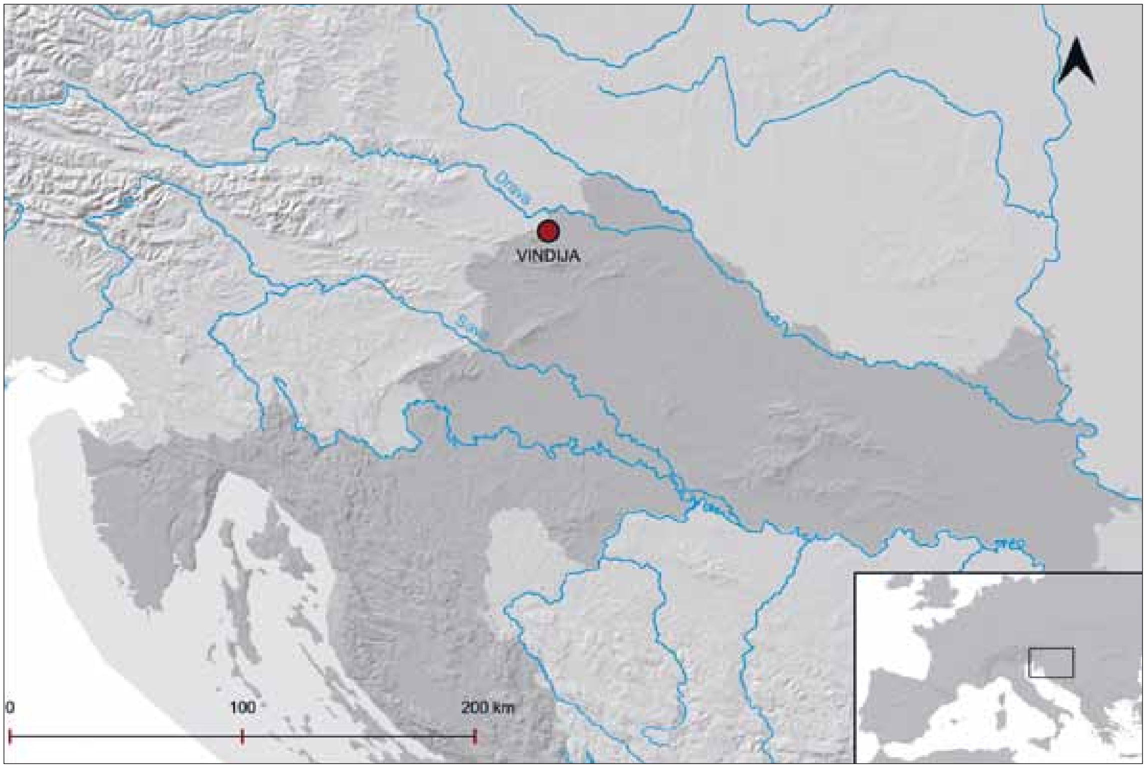
5 Malez, Rukavina 1979; Rukavina 1983; Malez, Šimunić, Šimunić 1984.

6 Malez, Šimunić, Šimunić 1984; Malez 1988.

7 Wolpoff *et al.* 1981; Smith, Boyd, Malez 1985; Ahern *et al.* 2004; Devièse *et al.* 2017.

8 Miracle, Mauch Lenardić, Brajković 2010; Patou-Mathis, Karavanić, Smith 2018.

9 Karavanić, Smith 1998.



KARTA 1. Položaj nalazišta (izradio D. Tresić Pavičić; podloga: EU-DEM – realization of the Copernicus programme funded by the European Union).

MAP 1. Site location (made by D. Tresić Pavičić; basemap: EU-DEM – realization of the Copernicus programme funded by the European Union).

i neandertalaca u vrijeme prijelaza iz srednjega u gornji paleolitik.[10] Također, fosilni ostatci iz Vindije bili su prvi iz kojih je uspješno sekvenciran stanični genom neandertalaca,[11] što je omogućilo detaljne uvide u evolucijske promjene i filogeniju na molekularnoj razini te potaknulo ubrzani razvoj paleogenomike kao nove znanstvene discipline.

Zbog svoje važnosti Vindija je, rješenjem Ministarstva kulture, 2003. zaštićena kao nepokretno kulturno dobro te upisana u Registar kulturnih dobara Republike Hrvatske (reg. br. Z-1078). Istodobno je, zbog paleontoloških ostataka, zaštićena i kao spomenik prirode te upisana u Registar zaštićenih objekata prirode pri Državnome zavodu za zaštitu prirode.

Nažalost, u razdoblju nakon iskopavanja M. Maleza preostale naslage u špilji doživjele su znatnu devastaciju. U špilji su vidljivi tragovi nedopuštenoga kopanja, tragovi penjanja po profilu 1, tragovi paljenja vatre na površini preostalih sedimenata te različite rupe nastale zbog nedopuštenoga uzorkovanja. Među drastičnije devastacije ubraja se i potkopani dio južne strane profila 3, pogotovo u visini slojeva G1 – H, koji je očigledni dokaz ilegalnoga kopanja u potrazi za fosilima i drugim nalazima. Krajnji učinak tih devastacija na profilu 3 jest izbočenost naslaga koje se nalaze u gornjoj polovini južne strane profila 3, odnosno naslaga smještenih iznad sloja G1, koja neprekidno i nepovratno ugrožava stabilnost cijeloga profila.

Upravo iz toga razloga, cilj istraživanja provedenoga 2023. bio je uklanjanje izbočenih naslaga koje će omogućiti dugoročnu

10 Karavanić, Smith 1998; 2013; Smith, Janković, Karavanić 2005; Zilhão 2009.

11 Green *et al.* 2010.

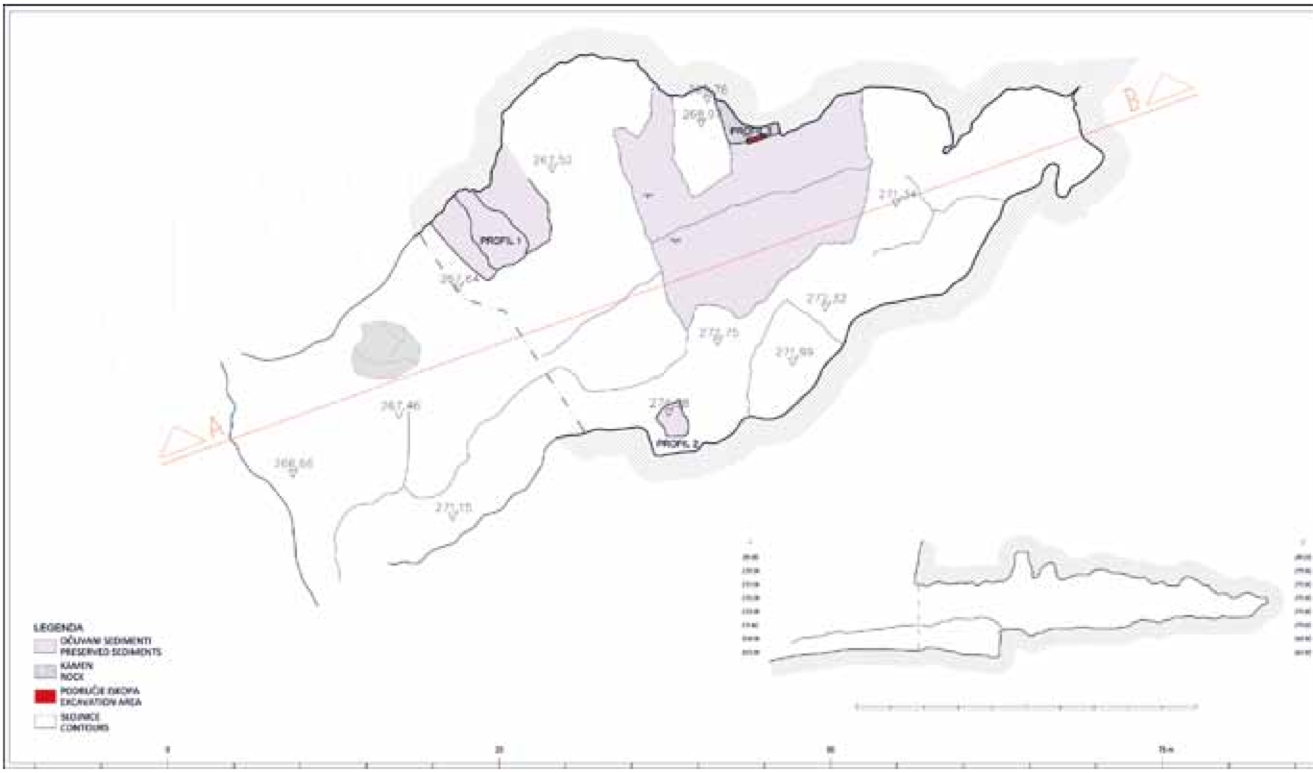
mains were found in association with Aurignacian bone points and stone tools, making this site a key location in discussions about interactions between modern humans and Neandertals during the Middle-to-Upper Palaeolithic transition.[10] Furthermore, the fossil remains from Vindija were the first from which the Neandertal nuclear genome was successfully sequenced,[11] providing detailed insights into evolutionary changes and phylogeny at the molecular level and significantly contributing to the rapid development of palaeogenomics as a new scientific discipline.

Due to its significance, Vindija was protected as a cultural heritage site in 2003 by decision of the Ministry of Culture, and was added to the Register of Cultural Property of the Republic of Croatia (reg. num. Z-1078). At the same time, due to its palaeontological remains, it was also protected as a natural monument and included in the Register of Protected Natural Values with the State Institute for Nature Protection.

Unfortunately, in the period since the excavations by Malez the remaining cave deposits have suffered significant devastation. Traces of unsanctioned excavations are visible in the cave, as well as traces from climbing onto profile 1, traces of fires on the surfaces of the remaining sediments, and various holes from unsanctioned sampling. Among the most drastic devastations is the undermined section of the southern side of profile 3, especially at the level of layers G1–H, which clearly indicates illegal excavations in search of fossils and other finds. The ultimate effect of this damage to profile 3 is the protrusion of de-

10 Karavanić, Smith 1998; 2013; Smith, Janković, Karavanić 2005; Zilhão 2009.

11 Green *et al.* 2010.



SLIKA 1. Tlocrt i presjek špilje Vindije (izradio J. Jagetić, SU Kraševski zviri; obradila F. Sirovica).

FIGURE 1. Cave plan and cross-section (made by J. Jagetić, SU Kraševski zviri; modified by F. Sirovica).

stabilizaciju cijeloga profila.[12] Izvorno planirani radovi trebali su obuhvatiti uklanjanje izbočenih naslaga u cijeloj širini južne strane profila 3. Riječ je o zahvatu koji bi južnu stranu profila zahvatio u dužini od oko 4 m i uklonio sediment u dubinu od maksimalno 45 cm. Međutim, iskopavanja su u konačnici znatno ograničena,[13] pa je odlučeno da se izbočina ukloni u maksimalnoj dubini od 20 cm te da se netaknutim ostavi oko 1 m od

posits located in the upper half of its southern side, specifically those lying above layer G1, which continuously and irreversibly threatens the stability of the entire profile.

For this reason, the goal of the excavation conducted in 2023 was to remove the protruding deposits in order to ensure the long-term stabilization of the entire profile.[12] The work origi-

12 Na temelju odluke Ministarstva kulture i medija, Uprave za zaštitu kulturne baštine, Konzervatorskoga odjela u Varaždinu i rješenjem Upravnoga odjela za poljoprivredu i zaštitu okoliša Varaždinske županije od 23. 8. 2023., izdanima Arheološkomu muzeju u Zagrebu, od 28. kolovoza do 22. rujna 2023. provedena su zaštitna arheološka iskopavanja u špilji Vindiji. Financijska sredstva za istraživanje osiguralo je Ministarstvo kulture i medija, na temelju ugovora br. 49-0068-23 od 2. ožujka 2023. Iskopavanja su provedena pod stručnim vodstvom Ivora Karavanića (Odsjek za arheologiju, Filozofski fakultet Sveučilišta u Zagrebu), a uloge zamjenika voditelja obnašali su Ivor Janković (Institut za antropologiju) i Marko Banda (Odsjek za arheologiju, Filozofski fakultet Sveučilišta u Zagrebu). Ostali dio stručne ekipe sačinjavali su Nikola Vukosavljević (Odsjek za arheologiju, Filozofski fakultet Sveučilišta u Zagrebu), Filomena Sirovica (Arheološki muzej u Zagrebu), Lia Vidas (Institut za antropologiju), James C. M. Ahern (Department of Anthropology, University of Wyoming), Robert Vazdar (Arheološki muzej u Zagrebu) te studenti arheologije Luka Bariša, Ana Jagić, Katarina Lukač i Claudia Pittner. U istraživanju su u svrhu prikupljanja uzoraka za različite analize sudjelovali i Victoria Oberreiter (Department of Evolutionary Anthropology, University of Vienna), Katarina Gerometta (Centar za interdisciplinarna arheološka istraživanja krajolika, Filozofski fakultet Sveučilišta Jurja Dobrile u Puli) te Giovanni Boschian (Department of Biology, University of Pisa). Laserska i fotogrametrijska snimanja proveo je stručni tim Hrvatskoga geološkog instituta.

13 Odluka o ograničavanju opsega iskopavanja donesena je u skladu s odredbama odluke Upravnoga odjela za poljoprivredu i zaštitu okoliša Varaždinske županije (KLASA: 352-02/23-01/123, URBROJ: 517-19-2-1-23-2) te zaključcima donesenima na sastanku koji je na nalazištu održan 29. kolovoza 2023., uz sudjelovanje predstavnika Konzervatorskoga odjela Ministarstva kulture i medija u Varaždinu, Gradskoga muzeja Varaždin, JU Priroda Varaždinske županije, Općine Donja Voća te voditelja istraživanja.

12 On the basis of the decision of the Ministry of Culture and Media, Directorate for the Protection of Cultural Heritage, Conservation Department in Varaždin and the decision of the Directorate for Agriculture and Environmental Protection of Varaždin County of 23 August 2023, issued to the Archaeological Museum in Zagreb, rescue excavations were conducted in Vindija in the period from 28 August to 22 September 2023. Financial support for the research was provided by the Ministry of Culture and Media, under contract num. 49-0068-23, dated 2 March 2023. The excavations were carried out under the supervision of Ivor Karavanić (Department of Archaeology, Faculty of Humanities and Social Sciences of the University of Zagreb), with Ivor Janković (Institute for Anthropological Research) and Marko Banda (Department of Archaeology, Faculty of Humanities and Social Sciences of the University of Zagreb) acting as co-supervisors. The rest of the team included Nikola Vukosavljević (Department of Archaeology, Faculty of Humanities and Social Sciences of the University of Zagreb), Filomena Sirovica (Archaeological Museum in Zagreb), Lia Vidas (Institute for Anthropological Research), James C. M. Ahern (Department of Anthropology, University of Wyoming), Robert Vazdar (Archaeological Museum in Zagreb) and students Luka Bariša, Ana Jagić, Katarina Lukač and Claudia Pittner. In addition, Victoria Oberreiter (Department of Evolutionary Anthropology, University of Vienna), Katarina Gerometta (Centre for Interdisciplinary Research in Landscape Archaeology, Faculty of Humanities of the Juraj Dobrila University in Pula) and Giovanni Boschian (Department of Biology, University of Pisa) participated in the research with the aim of collecting samples for various analyses. Laser and photogrammetric recordings were carried out by a professional team from the Croatian Geological Survey.

zapadnoga i istočnoga ruba južne strane profila, odnosno da se iskopa središnji dio južne strane profila u širini od 1,5 m.

U konačnici su i ta iskopavanja dodatno ograničena[14] jer je, s obzirom na trenutačne uvjete zaštite, utvrđeno da dubina iskopa iznad 10 – 15 cm može dodatno destabilizirati zapadni dio južne strane profila. Iskopavanja u sljedeća dva tjedna stoga su bila usmjerena na uklanjanje naslaga na predviđenoj površini u skladu s maksimalno dopuštenom dubinom od 10 do 15 cm.

Uz iskopavanja na južnoj strani profila provedena su i uzorkovanja naslaga u svrhu provedbe različitih analiza. Odabrane analize značajne su zbog doprinosa rješavanju ključnih pitanja o nastanku pojedinih naslaga, kronologiji pojedinih segmenata stratigrafskoga slijeda te okolišnim uvjetima i prisutnosti pojedinih populacija hominina tijekom druge polovine gornjega pleistocena. Kako je većina analiza i dalje u tijeku i još nije moguće predstaviti dobivene rezultate, u tekstu su prikazane osnovne informacije o metodološkome pristupu, utvrđenome stratigrafskom slijedu, protokolima uzorkovanja i predviđenim analizama. Time prikazani postupci mogu poslužiti kao primjer integracije uzorkovanja orijentiranih na rješavanje znanstvenih pitanja s iskopavanjima iznimno maloga opsega i njihovim operativnim te logističkim ograničenjima.

Metoda iskopavanja i dokumentiranja nalazišta

Profil 3 sačuvan je u visini od oko 4 m te je za potrebe iskopavanja njegova gornjega izbočenog dijela izgrađena drvena skela s dvjema razinama (Sl. 2). Prije postavljanja skele zatečeno stanje laserski je snimljeno te fotogrametrijski dokumentirano, što je omogućilo izradu preciznoga trodimenzionalnog modela profila.

Iskopavanja su obavljana od vrha profila prema dnu izbočenja. Bez obzira na relativno malu površinu, iskopavanje je provedeno uz poštovanje stratigrafskoga slijeda, praćenje formalnih stratigrafskih metoda i terminologije[15] te dokumentiranje specifičnih karakteristika pojedinih stratigrafskih jedinica (sastava, teksture, konzistencije i boje). Stratigrafske jedinice označavane su redom od broja 1 zbog izbjegavanja potencijalnih pro-

14 Odluka je donesena na drugome sastanku održanomu 12. rujna 2023., uz sudjelovanje predstavnika Konzervatorskoga odjela Ministarstva kulture i medija u Varaždinu, Gradskoga muzeja u Varaždinu, Zavoda za paleontologiju i geologiju kvartara HAZU-a, JU Priroda Varaždinske županije te zamjenika voditelja istraživanja.

15 NACSN 2005.

nally planned was intended to remove the protruding deposits along the entire width of the southern side of profile 3. This would have included approximately 4 metres of the southern profile face and involved the removal of sediments to a maximum depth of 45 centimetres. However, the excavations were ultimately significantly limited,[13] and it was decided that the protrusion would be removed to a maximum depth of 20 cm, leaving about 1 metre untouched at both the western and eastern edges of the southern side of the profile. Thus, only the central section of the southern side of the profile, measuring 1.5 metres in width, was excavated.

Ultimately, even this excavation was further limited,[14] because it was determined, given the current protection measures, that excavating deeper than 10–15 cm could further destabilize the western section of the southern profile face. The excavation efforts during the following two weeks were therefore focused on removing the sediments from the designated area, in accordance with the maximally allowed depth of 10 to 15 cm.

In addition to the excavations on the southern side of the profile, sediment sampling was carried out for the purpose of conducting various analyses. The analyses selected are significant for addressing key questions regarding the formation of specific deposits and the chronology of individual segments of the stratigraphic sequence, as well as environmental conditions and the presence of hominin populations during the second half of the Upper Pleistocene. As most of the analyses are still ongoing and the results are not yet available, this text presents basic information on the methodological approach, the stratigraphic sequence identified, sampling protocols and the planned analyses. In this way, the procedures described may serve as an example of integrating scientifically-driven sampling strategies with very limited excavations and their operational and logistical constraints.

The method of excavation and site documentation

Profile 3 is preserved to a height of approximately 4 metres, and a two-level wooden scaffolding was constructed for the purpose of excavating its upper protruding section (Fig. 2). Prior to the construction of the scaffolding, the existing condition of the profile was recorded using laser scanning and photogrammetry, which enabled the creation of a precise three-dimensional model of the profile.

Excavation was conducted from the top of the profile to the base of the protrusion. Despite the relatively small surface area, the excavation was carried out in accordance with the stratigraph-

13 The decision to limit the scope of the excavations was made in accordance with the provisions of the decision issued by the Directorate for Agriculture and Environmental Protection of Varaždin County (KLASA: 352-02/23-01/123, URBROJ: 517-19-2-1-23-2), and the conclusions reached at a meeting held at the site on 29 August 2023. The meeting was attended by representatives of the Conservation Department of the Ministry of Culture and Media in Varaždin, Varaždin City Museum, Public Institution 'Nature of Varaždin County', Donja Voća Municipality, and the research supervisor.

14 The decision was made at a second meeting, held on 12 September 2023 and attended by representatives from the Conservation Department of the Ministry of Culture and Media in Varaždin, the Institute for Quaternary Palaeontology and Geology in Zagreb of the Croatian Academy of Sciences and Arts, Varaždin City Museum, Public Institution 'Nature of Varaždin County' and the excavation co-supervisors.

SLIKA 2. Drvena skela postavljena uz profil 3 za potrebe iskopavanja (snimila F. Sirovica).

FIGURE 2. Scaffolding installed next to profile 3 for the excavation (photo by F. Sirovica).

blema u korelaciji sa stratigrafijom iz prijašnjih istraživanja.[16] Sve utvrđene stratigrafske jedinice dokumentirane su opisom, fotografijom i nacrtom, a izmjera je vršena u Hrvatskome terestičkom referentnom sustavu (HTRS96/TM).

Svi nalazi veći od 2 cm ili jednaki 2 cm zasebno su prikupljeni i popisani pod jedinstvenim oznakama, a njihov točan položaj izmjeren je totalnom stanicom. Isti je postupak primijenjen i na manje kosti s očuvanim dijagnostičkim anatomskim ili taksonomskim elementima. Mokro prosijavanje vršeno je uz potok Šokot pomoću vrtnih pumpi i crijeva. Svi nalazi pohranjeni su u skladu sa stratigrafskom jedinicom i datumom iskopavanja te jedinstvenom oznakom skupa nalaza iz sita. Nalazi su naknadno sortirani prema osnovnim kategorijama – kost/zub, litika, ostalo. Uz to, prikupljani su i uzorci sedimenta za flotaciju kako bi se vidjelo javljaju li se nalazi manji od širine oka sita, koja iznosi 2mm.

Nakon završetka istraživanja i uklanjanja skele završna situacija ponovno je laserski i fotogrametrijski snimljena. U konačnici, južna strana profila prekrivena je geotekstilom te učvršćena drvenim podupiračima. Postavljene su i dvije dodatne kamere za videonadzor te je cijeli sustav nadograđen, odnosno prilagođen radu s više kamera.

ic sequence and following formal stratigraphic methods and nomenclature,[15] with documentation of the specific characteristics of each stratigraphic unit (mineral composition, texture, consistence, colour). Stratigraphic units were labelled sequentially, starting from number 1, in order to avoid potential problems with correlation with the stratigraphy of the earlier excavations.[16] All the stratigraphic units defined were documented through descriptions, photographs and drawings, while measurements were taken in the Croatian Terrestrial Reference System (HTRS96/TM).

All finds greater or equal to 2 centimetres were individually collected and labelled with unique identifiers, while their exact position was recorded by total station. The same procedure was applied to smaller bones with preserved diagnostic anatomical or taxonomic elements. Wet sieving was carried out near the Šokot stream using water pumps and hoses. All finds were stored according to their stratigraphic unit and excavation date, as well as the unique label for the sieved find assemblage. The finds were subsequently sorted into basic categories: bone/tooth, lithic, other. In addition, sediment samples were collected for flotation in order to determine whether materials smaller than the 2-millimetre mesh size of the sieve were present.

After the completion of the excavation and the removal of the scaffolding, the final condition of the profile was once again recorded using laser scanning and photogrammetry. Ultimately, the southern side of the profile was covered with geotextile and reinforced with wooden supports. Two additional surveillance cameras were installed, and the entire monitoring system was upgraded and adapted to support several cameras.

16 npr. Malez, Rukavina 1979.

15 NACSN 2005.

16 e.g. Malez, Rukavina 1979.

Rezultati

Stratigrafija

U iskopavanome dijelu južne strane profila 3 ukupno je određeno 18 stratigrafskih jedinica (SJ). Opis slojeva napravljen je izravnom opservacijom, a boje pojedinih jedinica prema Munsellovu sustavu[17] određene su naknadno, u povoljnijim uvjetima osvjetljenja izvan špilje. Opisi stratigrafskih jedinica dostupni su u Tab. 1, a stratigrafski odnosi vidljivi su iz Sl. 3.

Results

Stratigraphy

A total of 18 stratigraphic units (SU) were identified in the excavated section of the southern side of profile 3. The layers were described through direct observation, and the colours of individual units were determined using the Munsell© Soil Color Charts[17] subsequently, under more favourable lighting conditions outside the cave. Descriptions of the stratigraphic units are provided in Table 1, and their stratigraphic relationships are shown in Fig. 3.

SJ / SU	Boja / Colour (MUN)	Opis	Description	Korelacija / Correlation (Malez, Rukavina 1979)
1	MUN 2.5Y 6/3 light yellowish brown	Žuti siltni sloj koji se proteže cijelom dužinom profila, bez očitih varijacija. Prisutni rijetki klasti kemijski trošenog vapnenca, pretežno male veličine (2 – 0,5 cm dužine), kaotično raspršeni unutar ove jedinice.	Yellow silty layer extending across the length of the excavation surface, without apparent variation. Rare clasts of chemically weathered limestone are present, mostly of small size (2–0.5 cm in length), chaotically dispersed within this unit.	D
2	MUN 2.5Y 5/4 light olive brown	Žutosivi siltni sloj bez sitnih klasta vapnenaca. Nalazi se iznad SJ 1, ali je prisutan samo u desnoj polovini iskopane površine. Položen je ukoso te blago pada nadesno (prema istoku).	Yellow-grey silty layer without small limestone clasts. Found above SU 1, but only in the right-hand half of the excavated surface. Gently slopes towards the right (eastwards).	D
3	/	Postdepozicijska promjena slojeva SJ 2 i SJ 1. Javlja se kao klinasta tvorevina građena od stvrdnutih, uglatih nakupina sedimenta razdvojenih pukotinama, sa smeđim (oksidiranim) prevlakama na površinama pukotina. Tvorevina se sužava od vrha profila prema dnu i nastavlja u dvije vijugave pukotine koje ulaze u SJ 1.	Postdepositional alteration of layers SU 2 and SU 1. Appears as a wedge-shaped feature composed of hardened, angular sediment aggregates separated by cracks, with brown (oxidized) coating on the surfaces of the cracks. The feature narrows from the top of the profile towards the bottom and continues as two winding cracks which enter SU 1.	/
4	MUN 2.5Y 5/4 light olive brown	Sivi siltni sediment s koncentriranim mrljama željezovih i manganovih oksida i s malo ili bez vapnenačkih klasta. Lijevo od veće recentne devastacije SJ 4 sličan je bojom SJ 1, ali ne sadrži klaste.	Grey silty sediment with concentrated patches of iron and manganese oxides and with few or no limestone clasts. To the left of the large recent disturbance, SU 4 is similar in colour to SU 1, but contains no clasts.	D
5	MUN 5Y 4/3 olive (prevladava / prevalent)	Siltno-glinasti sloj u kojem se izmjenjuju zelene, narančaste i sive leće do 5 cm dužine, uglavnom horizontalno položene, ponekad s umjereno razvijenim poliedričnim srednjim do finim agregatima. Granica je nagla, glatka i valovita s najnižom točkom u središnjem dijelu iskopanog profila.	Silty-clayey layer with alternating green, orange and grey lenses up to 5 cm in length, mostly horizontally oriented, occasionally exhibiting moderately developed polyhedral medium-to-fine aggregates. The boundary is abrupt, smooth and undulating, with its lowest point in the central part of the excavated profile.	D (E?)

17 Munsell Color Co. 1992.

17 Munsell Color Co. 1992.

SJ / SU	Boja / Colour (MUN)	Opis	Description	Korelacija / Correlation (Malez, Rukavina 1979)
6	MUN 2.5Y 6/4 light yellowish brown	Siltno-glinasti sloj s crvenom nijansom, koji je prema desnom rubu iskopane površine svjetlije boje. U njemu se nalaze sitni vapnenački klasti te koncentrirani sitni željezovi i manganovi oksidi. Na desnoj strani profila, uključuje dva skupa gusto pakiranih valutica i oblutaka, vjerojatno pretaloženih iz donjih krupnozrnatih jedinica.	A silty-clayey layer with a reddish hue, becoming lighter in colour towards the right-hand edge of the excavated area. It contains small limestone clasts as well as concentrated fine iron and manganese oxides. On the right side of the profile, it includes two clusters of densely-packed pebbles and cobbles, likely redeposited from underlying coarse-grained units.	E
7	MUN 2.5Y 4/4 olive brown	Žučkasto-smeđi siltni sloj koji se nalazi ispod SJ 6 po cijeloj dužini iskopane površine. Varira u teksturi pa je prema lijevom rubu iskopavanja više siltast, a prema desnom više glinast. Sadrži gusto pakirane klaste vapnenca, uglavnom klasta veličine srednjega do sitnoga šljunka (do 0,5 cm dužine). Klasti su često kemijski trošeni, što je vidljivo prema karakteristikama vanjske površine (kore). Mjestimice je na kontaktu sa SJ 6 izmiješan sa sedimentom iz tog sloja. Također, u njemu se naizmjenice sa žučkasto-smeđim matriksom javljaju i sive leće (proslojci) različite debljine.	A yellowish-brown silty layer located beneath SU 6 along the entire length of the excavated area. It varies in texture, being more silty towards the left edge of the excavation and more clayey towards the right. It contains densely-packed limestone clasts, mostly ranging in size from fine to medium gravel (up to 0.5 cm in length). The clasts are often chemically weathered, as indicated by the characteristics of their outer surfaces (rinds). In places, it is mixed with sediment from SU 6 at the contact zone. Additionally, grey lenses of varying thickness alternate with the yellowish-brown matrix throughout the layer.	E
8	MUN 2.5Y 6/2 light brownish gray	Svjetlosivi pjeskovito-siltni sloj s gusto pakiranim nesortiranim vapnenačkim klastima. Svjetliji je od sivih proslojaka unutar SJ 7. Varira u debljini pa je prema desnom rubu iskopavanja tanji, a u sredini iskopane površine se zbog devastacija profila i prisutnosti većih vapnenačkih blokova komparativno slabije ističe od SJ 7 i naslaga ispod njega. Pri dnu lijeve, deblje polovine sloja te prema sredini iskopne površine vidljive su i varijacije u vidu izmjene žutih i sivih mrlja, vjerojatno kao posljedica postdepozicijskog trošenja nekih komponenti. Na lijevom rubu iskopne površine sloj oštro pada prema zapadu (taj je dio sloja arbitrarno odijeljen kao SJ 11), ispunjavajući udubinu na krovini SJ 9 – vjerojatno predstavlja erozijsku površinu.	A light-grey sandy-silty layer with densely packed, unsorted limestone clasts. It is lighter in colour than the grey lenses within SU 7. The thickness of the layer varies – it becomes thinner towards the right-hand edge of the excavation, while in the central part of the excavated area it is less distinct than SU 7 and the underlying deposits, due to profile disturbance and the presence of larger limestone blocks. In the lower portion of the thicker, left-hand half of the layer, as well as towards the centre of the excavated area, variations in the form of alternating yellow and grey patches are visible, likely as a consequence of postdepositional weathering of certain components. At the left edge of the excavated area, the layer slopes sharply to the west (this portion arbitrarily being designated as SU 11), filling a depression in the top of SU 9 – likely representing an erosional surface.	F (Fg?)

SJ / SU	Boja / Colour (MUN)	Opis	Description	Korelacija / Correlation (Malez, Rukavina 1979)
9	MUN 2.5Y 4/3 olive brown	Smeđi siltno-glinasti sloj, koji se nalazi ispod SJ 8, ali samo na desnoj strani površine iskopavanja. Pri desnom rubu je i najdeblji (nekoliko centimetara debljine), a prema sredini iskopane površine isklinjava (na oko 40 cm od desnog ruba iskopavanja). U njemu se nalaze loše sortirani vapnenački klasti (do veličine srednjeg šljunka) koji su najviše koncentrirani pri dnu sloja, a u ostatku sloja prevladavaju sitni klasti.	A brown silty-clayey layer located beneath SU 8, but only on the right-hand side of the excavation surface. It reaches its maximum thickness near the right edge (several centimetres) and thins out towards the centre of the excavated area, petering out approximately 40 cm from the right edge. The layer contains poorly-sorted limestone clasts (up to medium gravel size), most of which are concentrated at the base, while finer clasts predominate in the rest of the layer.	F
10	MUN 2.5Y 5/3 light olive brown	Sivi glinasti sloj bez vapnenačkih klasta, debljine svega nekoliko centimetara. Također se prostire samo do sredine profila, gdje isklinjava.	A grey clayey layer without limestone clasts, only a few centimetres thick. It extends only to the middle of the profile, where it peters out.	F
11	/	Arbitrarno odvojeni donji dio SJ 8, u lijevom dijelu iskopne površine.	Arbitrarily separated lower part of SU 8, located in the left-hand part of the excavated area.	F
12	MUN 5Y 6/3 pale olive	Žuto-sivi siltno-glinasti sloj koji se nalazi ispod SJ 8 i desno od SJ 11. Sloj se prostire u duljini od oko 30 cm nadesno do vertikalno položenog vapnenačkog bloka te se javlja u istoj razini sa SJ 9, 10, 13, 14, 16 i 17. Debljina mu iznosi oko 15 cm. Sadrži nekoliko gruda žućkastog sedimenta koje upućuju na miješanje s drugim jedinicama.	Yellow-grey silty-clayey layer located below SU 8 and to the right of SU 11. The layer extends approximately 30 cm to the right, up to a vertically-positioned limestone block, and occurs at the same level as SU 9, 10, 13, 14, 16 and 17. Its thickness is about 15 cm. It contains several clumps of yellowish sediment, indicating mixing with other units.	F
13	MUN 2.5Y 6/3 light yellowish brown	Žuto-smeđi siltno-glinasti sloj sa sitnim vapnenačkim klastima. Nalazi se ispod SJ 10 te se pruža do sredine iskopavane površine, potencijalno do vertikalno položenog kamena. Po karakteristikama boje i teksture sličan je SJ 9.	Yellow-brown silty-clayey layer with fine limestone clasts. It is located beneath SU 10 and extends to the middle of the excavated area, potentially reaching a vertically-positioned stone. In terms of colour and texture, it is similar to SU 9.	F
14	MUN 2.5Y 5/3 light olive brown	Sivi siltno-glinasti sloj, s manje klasta od SJ 13 i slojeva ispod (SJ 16 i 17). Sloj se proteže od desnog ruba iskopavanja do vertikalno položenog kamena u sredini iskopne površine.	Grey silty-clayey layer with fewer clasts than SU 13 and the underlying layers (SU 16 and 17). The layer extends from the right-hand edge of the excavation to a vertically-positioned stone in the middle of the excavated area.	F

SJ / SU	Boja / Colour (MUN)	Opis	Description	Korelacija / Correlation (Malez, Rukavina 1979)
15	MUN 5Y 5/2 olive gray	Sivi glinasto-siltni sloj koji se proteže cijelom širinom iskopne površine. Nalazi se ispod SJ 12 i SJ 11 (SJ 8) na lijevoj (zapadnoj) strani te SJ 16 i SJ 17 na desnoj strani (istočnoj) iskopne površine. Sadrži manje vapnenačkih klasta i malo je svjetliji od SJ 11 (SJ 8). Nalazi se lijevo od vertikalno položenog kamena u sredini, a desno od njega pada ukoso. U lijevom dijelu vidljive su varijacije u teksturi i boji – smeđe-sive zone s vapnenačkim klastima te svjetlosive zone bez previše klasta (slične SJ 18).	Grey clayey-silty layer extending across the entire width of the excavated area. It lies beneath SU 12 and SU 11 (SU 8) on the left (western) side, and beneath SU 16 and SU 17 on the right (eastern) side of the excavation. It contains fewer limestone clasts and is slightly lighter in colour than SU 11 (SU 8). The layer is located to the left of a vertically-positioned stone in the centre and slopes downwards to the right of it. Variations in texture and colour are visible in the left part of the layer: brownish-grey zones with limestone clasts and light-grey zones with few clasts (similar to SU 18).	F
16	MUN 5Y 5/3 olive	Sivi pjeskovito-siltni sloj ispod SJ 14. Pruža se od desnog ruba iskopne površine do vertikalno položenog kamena. Tamniji je i ima više srednje velikih klasta (c. 5 cm dužine) od SJ 15, iznad kojeg se nalazi.	Grey sandy-silty layer beneath SU 14. It extends from the right-hand edge of the excavated area to a vertically-positioned stone. It is darker and contains more medium-sized clasts (about 5 cm in length) than SU 15, which is below it.	F
17	/	Arbitrarno odijeljeni donji dio SJ 16, koji se prostire od desnog ruba iskopne površine prema sredini, ali ima kraće horizontalno pružanje u odnosu na SJ 16, te stoga SJ 16 djelomice izravno graniči sa SJ 15. Izdvojen je zbog varijacija u tom dijelu SJ 16, odnosno zbog prisutnosti žutih proslojaka. Sadrži sitne vapnenačke klaste. SJ 17 također je tamniji od SJ 15, iznad kojeg se nalazi.	Arbitrarily separated lower part of SU 16, which extends from the right-hand edge of the excavated area towards the centre but has a shorter horizontal extent than SU 16, so SU 16 partially directly borders SU 15. It is separated due to variations in this part of SU 16, specifically the presence of yellow lenses. It contains fine limestone clasts. SU 17 is also darker than SU 15, above which it is located.	F
18	MUN 2.5Y 5/2 grayish brown	Žuto-sivi pjeskovito-siltni sloj. Vapnenački klasti su učestali te su češći u desnoj polovici pružanja ovog sloja, dok je sveukupno manji udio klasta nego u SJ 15. Oblik klasta pretežno je pločast, s dužom osi paralelnom s taložnom površinom.	Yellow-grey sandy-silty layer. Limestone clasts are frequent and more abundant in the right-hand half of the layer's extent, although the overall proportion of clasts is lower than in SU 15. The clasts are predominantly flat in shape, with their long axes parallel to the depositional surface.	F (Fd?)

TABLICA 1. Opisi stratigrafskih jedinica (izradio M. Banda).

TABLE 1. Descriptions of stratigraphic units (made by M. Banda).

Vrh stratigrafskoga slijeda čine siltni slojevi (SJ 1, 2 i 4) žuto do žutosive boje te zasebno dokumentirana postdepozicijska pojava (SJ 3), možda nastala povremenim protjecanjem vode kroz pukotine, koje su rezultat isušivanja i skupljanja izloženoga profila. U sredini iskopne površine te većim dijelom u SJ 1 i SJ 4 nalazi se veća četverokutna devastacija nastala ljudskim djelovanjem (vjerojatno uzorkovanjem), koja je otežavala prepoznavanje granice između tih dvaju slojeva. Sljedeće utvrđene jedinice jesu siltno-glinasti slojevi različitih nijansi, SJ 5, smeđi s izmjenom zelenih, narančastih i sivih leća, a ispod njega SJ 6, s crvenom nijansom. Sve jedinice do podine SJ 6 imaju matriksnu potporu, masivne su i s vrlo malo tragova agregacije. Klasti vapnenaca uglavnom su sitnih dimenzija ili u potpunosti izostaju. Listići tinjca veličine 1 mm i manji vrlo su česti i lako prepoznatljivi golim okom kroz cijeli sediment.

U sljedećemu žućkasto-smeđem siltno(-glinovitom) sloju SJ 7 povećava se udio vapnenačkih klasta, koji su često kemijski trošeni. Vidnu promjenu u boji predstavlja SJ 8, svjetlosivi pjeskovito-siltni sloj s većim udjelom klasta, čiji je najdublji dio arbitrarno odijeljen u SJ 11. Čini se da stratigrafske jedinice od SJ 5 do SJ 8 (i moguće SJ 9), na desnoj strani iskopanoga područja, predstavljaju ispunu relativno duboke erozijske strukture (eng. *scour and fill*) – tj. svojevrsnoga kanala – s glatkim, konkavnim dnom. Ipak, brojne devastacije i ograničena veličina istraženoga područja otežali su prepoznavanje određenih stratigrafskih jedinica i njihovo horizontalno praćenje.

Horizontalna varijabilnost u sedimentaciji nastala je zbog postojanja vapnenačkih blokova i krupnih oblutaka, uglavnom u jedinicama SJ 13 i SJ 16, koji su utjecali na taloženje, a posljedično i na lateralnu varijabilnost taložina. Zbog toga su neke stratigrafske jedinice definirane unutar ograničenih prostornih područja, čime su razdvojene one koje se nalaze u donjim desnim i lijevim dijelovima iskopne površine, a koje se sužavaju ulijevo, odnosno udesno. Općenito, nagib klasta prilično je izražen u gornjim jedinicama i smanjuje se u donjima (unutar i između SJ 10, 11, 12, 13, 14, 16, 17), što upućuje na to da su se akumulirali unutar udubljenoga ili kanalu sličnoga prostora. Sukladno tomu, SJ 17, 16, 14, 13 i 10 te SJ 9, 8, 7, 6 i 5 predstavljaju ispunu jedne zajedničke kanalu slične strukture, vjerojatno nastale tijekom različitih faza taloženja. Taj dio taložnoga slijeda završava pri dnu subhorizontalnim kontaktom, koji se nalazi na erozijskoj površini, što oštro presijeca složenu arhitekturu stratigrafskih jedinica koje se nalaze ispod. Potom se na cijeloj površini iskopavanja nalazi SJ 15, sivi glinasto-siltni sloj, s određenim varijacijama u sedimentaciji i udjelu klasta. Žuto-sivi pjeskovito-siltni sloj SJ 18 najniži je u izbočenju te je djelomično i potkopan. Vrlo blago ponire u središnjemu dijelu iskopane površine prateći pružanje slojeva u potkopanome dijelu.

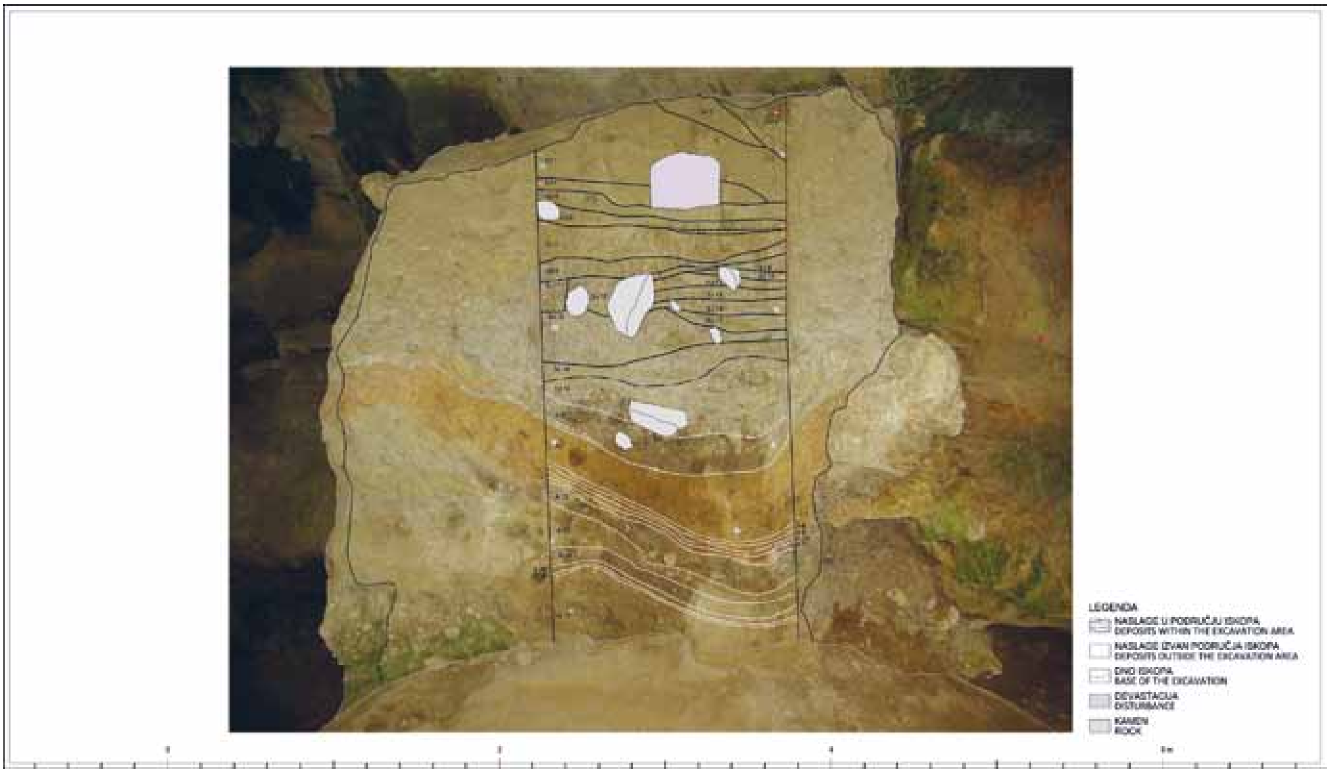
U iskopanome stratigrafskom slijedu jasno su vidljive litološke razlike između skupina naslaga SJ 1–6 te SJ 7–18. U prethodnoj prevladavaju siltni i glinasti slojevi bez većega udjela vapenančkih klasta, a u potonjoj prevladavaju pjeskovito-siltni slojevi, obično sa znatnim udjelom klasta veličine šljunka. Također, gornji slojevi često su bili masivni i kompaktni, a

The top of the stratigraphic sequence consists of silty layers (SU 1, 2 and 4) of yellow to yellow-grey colour, along with a separately documented postdepositional feature (SU 3), possibly formed by intermittent water flow through cracks resulting from the drying and contraction of the exposed profile. In the central part of the excavation surface, and largely within SU 1 and SU 4, there is a large quadrangular disturbance caused by human activity (likely from sampling), which complicated the identification of the boundary between these two layers. The next units identified are silty-clayey layers of varying shades: SU 5 is brown with alternating green, orange and grey lenses, followed by SU 6 with a reddish hue. All units down to the base of SU 6 are matrix-supported, massive, and with very few traces of aggregation. Limestone clasts are mostly small in size or entirely absent. Millimetre- to sub-millimetre-size mica flakes are very frequent and easily identifiable at naked-eye scale throughout the sediment.

In the following yellowish-brown silty(-clayey) layer SU 7, the proportion of limestone clasts increases, many of which show signs of chemical weathering. A noticeable change in colour is visible in SU 8, a light-grey sandy-silty layer with a higher proportion of clasts, whose deepest part has arbitrarily been separated as SU 11. It appears that stratigraphic units from SU 5 to SU 8 (and possibly SU 9), on the right-hand side of the excavated area, represent the fill of a relatively deep erosional structure (scour and fill) – i.e. a kind of channel – with a smooth, concave base. However, extensive disturbances and the limited size of the excavated area have made it difficult to identify certain stratigraphic units and to trace them horizontally.

Horizontal variability in sedimentation has occurred due to the presence of limestone blocks and cobbles, mainly in units SU 13 and SU 16, which affected the deposition, and consequently the lateral variability, of the deposits. For this reason, some stratigraphic units were defined within limited spatial extents, distinguishing those located in the lower right and left parts of the excavation surface, which taper off towards the left and right, respectively. In general, the dip of the clasts is rather pronounced in the upper unit and decreases in the lower ones (within and between SU 10, 11, 12, 13, 14, 16 and 17), suggesting that they accumulated within a depressed or channel-like area. Consequently, SU 17, 16, 14, 13 and 10 and SU 9, 8, 7, 6 and 5 would represent the infill of a single channel-like feature, likely formed during distinct depositional phases. This part of the depositional sequence terminates at the bottom with a subhorizontal limit, which overlies an erosional surface that cuts sharply through the complex architecture of the underlying units. Below, covering the entire excavated surface, is SU 15, a grey clayey-silty layer, showing some variation in sedimentation and clast content. The yellow-grey sandy-silty layer SU 18, found at the base of the protrusion, is party undercut. It dips slightly towards the centre of the excavated area, following the orientation of the layers in the undercut section.

In the stratigraphic sequence, clear lithological differences are visible between two groups of deposits: SU 1–6 and SU 7–18. The former are dominated by silty and clayey layers with little



SLIKA 3. Južna strana profila 3 sa stratigrafskim jedinicama utvrđenima tijekom iskopavanja (izradila F. Sirovica).

FIGURE 3. South side of profile 3 with the stratigraphic units identified during the excavation (made by F. Sirovica).

donji su se raspadali u grumenje[18] zbog svoje dobro razvijene poliedrične agregacije. Naposljetku, u donjim je slojevima zabilježena i veća koncentracija nalaza, poglavito kostiju, što je jednako vidljivo i iz distribucije individualnih nalaza te nalaza iz sita usprkos tomu što u osnovi nema velike razlike u debljini dvaju skupina naslaga.

Slojevi ispod iskopne površine, u potkopanome dijelu, označeni su preliminarnim oznakama za potrebe uzorkovanja, a njihovi opisi vršeni su na temelju postojećih površina, bez dubljega čišćenja profila, što potencijalno predstavlja dodatna ograničenja u determinaciji karakteristika i pružanja slojeva. Ti slojevi nisu iskopavani, nego su iz njih isključivo uzeti uzorci za različite analize.

Oznake od A6 do A16 označavaju slijed slojeva koje karakteriziraju okvirno paralelne konkavne granice, što upućuje na to da tvore ispunu duboke strukture nalik kanalu, oblikovane u sloju A17.

Najgornja oznaka toga slijeda (A6) jest sivi siltno-glinasti sloj koji sadrži nesortirano vapnenačko kršje i nekoliko većih blokova čije duže osi prate oblik konkavno zakrivljene podine. Na dnu A6 nalazi se sivi glinoviti podsloj debljine svega nekoliko

or no limestone clast content, while the latter predominantly consist of sandy-silty layers, usually with a significant proportion of gravel-sized clasts. Additionally, the upper layers were often massive and compact, whereas the lower ones tend to break down into clumps[18] because of their well-developed polyhedric aggregation. Finally, a higher concentration of finds, particularly bones, was recorded in the lower layers, which is evident from both the distribution of individual finds and the material recovered from sieving, despite the fact that there is no substantial difference in the overall thickness between the two groups of deposits.

The layers beneath the excavated area, in the undercut section, were preliminarily labelled for sampling purposes, and their descriptions were based on the visible surfaces, without deeper cleaning of the profile. This may present additional limitations in determining the characteristics and extent of the layers. These layers were not excavated. Instead, only samples for various analyses were collected from them.

Labels from A6 downwards to A16 represent a sequence of layers characterized by roughly parallel concave-upwards boundaries, suggesting that they fill-up a deep channel-like feature, shaped in unit A17.

18 eng. *peds* ili strukturni agregati prema standardnoj pedološkoj terminologiji (Catt 1990).

18 ‘Peds’, following the standard soil-science terminology (Catt 1990).

centimetara. Ispod se nalazi A7, crveni glinoviti sloj, a koji sadrži česte, nesortirane vapnenačke klaste (u rasponu od sitnoga šljunka do valutica). I u ovome slučaju duže osi klasta paralelne su s erozijskom strukturom koja se nalazi ispod i koja je nalik kanalu. Ispod njega izmjenjuju se tanki slojevi smeđe i intenzivno crvene boje, označeni oznakama od A8 do A11, koji su razdvojeni od sloja A12 lako uočljivom oštrom granicom. Sloj A12 sastoji se od dvaju siltno-glinovitih slojeva: gornjega zelenog i donjega sivo-smeđeg.

Oznake od A13 do A16 predstavljaju slijed slojeva debljine od nekoliko centimetara, uglavnom bogatih glinom i siltom, i s promjenjivim količinama vapnenačkih klasta – obično rijetkima do čestima te nesortiranima (od sitnoga šljunka do valutica). Nijanse variraju od smećkastih do zelenkastih i crvenkastih, s općenito dominantnom zelenkasto-žućkastom bojom, vjerojatno zbog postojanja fosfatnih konkrecija. Dno promatrane sekvence označeno je oznakom A17, a čini je sloj s učestalim nesortiranim vapnenačkim kršjem u smećkastozelenkastom glinasto-ilovastom matriksu. To je ujedno i posljednji vidljivi sloj na južnoj strani profila.

Zanimljivo je da struktura tih slojeva i raspored uklopljenih klasta naizgled upućuju na to da je dugotrajni ciklični slijed izmjenjujućih erozijskih i depozicijskih procesa, više puta i uvijek prema istome obrascu, ispunio te ispraznio površinu nalik kanalu koja je formirana u najdonjemu sloju A17.

Arheološki nalazi

Tijekom istraživanja južne strane profila 3 prikupljeno je ukupno 88 nalaza kojima je položaj zabilježen totalnom stanicom (Tab. 2). Sveukupno 85 nalaza pripada kostima ili zubima (Sl. 4: 1–6), a po jedna litička izrađevina pronađena je u SJ 12 te u SJ 15. Litika iz SJ 12 proksimalni je ulomak odbojka izrađenoga na kvarcu (Sl. 4: 7), dimenzije 12 × 11,5 × 3,1 mm. Drugi primjerak, koji potječe iz SJ 15, jest odbojak (Sl. 4: 8), odnosno prirodni nož hrptenjak koji je izrađen na oblutku tamnozelenoga srednjozrnatog rožnjaka, potencijalno bipolarnom tehnikom. Dimenzije komada jesu 37,9 × 26,1 × 6,6 mm, a desno lateralno i distalno ima kontinuirano oštećenje ruba, koje nije rezultat namjerne obradbe. Oba navedena komada potječu od sirovine koja je gotovo sigurno lokalnoga podrijetla, neovisno o vrsti izvorišta, a po svojim tipo-tehnološkim obilježjima nisu indikativni za pojedino razdoblje paleolitika. Međutim, prema stratigrafskome položaju može se zaključiti da su nastala tijekom gornjega paleolitika. Osim toga, u SJ 1 pronađena je i veća nodula željezovog oksida, koja je svrstana u kategoriju ostalo. Kao što je već navedeno, znatno je veći broj nalaza utvrđen u donjim (SJ 7 – SJ 18) nego u gornjim slojevima (SJ 1 – SJ 6), najviša učestalost utvrđena je u SJ 15, ali i u SJ 8/11 (Tab. 2).

Prilikom prosijavanja pronađeno je ukupno 2794 nalaza kostiju manjih od 2 cm te jedan ulomak litike manji od 2 cm (Tab. 2). Od toga, 2060 nalaza kostiju te ulomak litike dolaze iz definiranih stratigrafskih jedinica, a ostatak nalaza pomiješan je pri čišće-

The topmost label (A6) of this sequence is a grey silty-clayey layer that contains unsorted limestone clasts and several larger blocks whose longer axes follow the concave shape of the base. Beneath it, A7 is a red clayey layer including frequent unsorted limestone clasts (ranging from fine gravel to small pebbles); also in this case, the longer axes of the clasts lie parallel to the underlying channel-like erosional feature. Below it, there is a sequence of thin layers of alternately brown and intensely red colour, labelled A8 to A11, which are separated from layer A12 by a clearly visible sharp boundary. Layer A12 consists of two silty-clayey sublayers: an upper green one and a lower grey-brown one.

Labels A13 to A16 represent a sequence of layers, each several centimetres thick, mostly consisting of clay- and silt-rich units, and also including rare to frequent and unsorted (from fine gravel to pebbles) limestone clasts. The colours range from brownish to greenish and reddish, with a generally dominant greenish-yellowish hue, likely due to extensive phosphate concretions. The base of the observed sequence is marked by layer A17, which is a layer with frequent unsorted calcareous rubble embedded in a brownish-green clay-loam matrix. This is also the last visible layer on the southern side of the profile.

Interestingly, the architecture of these layers, and the organization of the embedded clasts, apparently indicates that a long cyclical sequence of alternating erosional and depositional processes, always following the same scheme, several times filled and emptied a channel-like surface that started from the lowermost layer, A17.

Archaeological finds

During the investigation of the southern side of profile 3, a total of 88 finds were recovered and spatially recorded by total station (Table 2). Of these, 85 finds are of bone or teeth (Fig. 4: 1–6), while one lithic artefact was found in SU 12 and another in SU 15. The lithic artefact from SU 12 is a proximal fragment of a flake made of quartz (Fig. 4: 7), measuring 12 × 11.5 × 3.1 mm. The second piece, found in SU 15, is a flake (Fig. 4: 8), more precisely a naturally backed knife, made from a pebble of dark green medium-grained chert, and potentially produced using a bipolar-on-anvil technique. Its dimensions are 37.9 × 26.1 × 6.6 mm, and it has continuous edge damage on the right lateral and distal margins, which is not the result of intentional retouch. Both pieces are made from raw material that is almost certainly of local origin, regardless of the exact source type; and, on the basis of their techno-typological characteristics, they are not indicative of any specific Palaeolithic period. However, their stratigraphic context suggests they were produced during the Upper Palaeolithic. In addition, a larger nodule of iron oxide, categorized as ‘other’, was found in SU 1. As previously noted, a significantly greater number of finds were identified in the lower layers (SU 7 - SU 18) than in the upper ones (SU 1 - SU 6), with the highest concentrations found in SU 15 and also in SU 8/11 (Table 2).

A total of 2794 bone fragments less than 2 cm in size, and one lithic fragment also under 2 cm, were recovered during siev-

KONTEKST CONTEXT	*IN SITU*				SITO SIEVE	
SJ SU	Kost/Zub Bone/Tooth	Litika Lithic	Ostalo Other	Ukupno Total	Kost/Zub Bone/Tooth	Litika Lithic
1	1		1	2	178	
4	1			1	0	
5					9	
6					15	
7	6			6	187	
8	14			14	191	
9	3			3	43	
10	1			1	40	
11	5			5	33	
12	6	1		7	97	
13	6			6	73	
14	8			8	163	
15	19	1		20	656	1
16	6			6	76	
17	6			6	107	
18	3			3	192	
POMIJEŠANO MIXED	-	-	-	-	734	
UKUPNO TOTAL	85	2	1	88	2794	1

TABLICA 2. Zastupljenost nalaza po stratigrafskim jedinicama nađenih *in situ* i tijekom prosijavanja (izradili F. Sirovica i M. Banda).

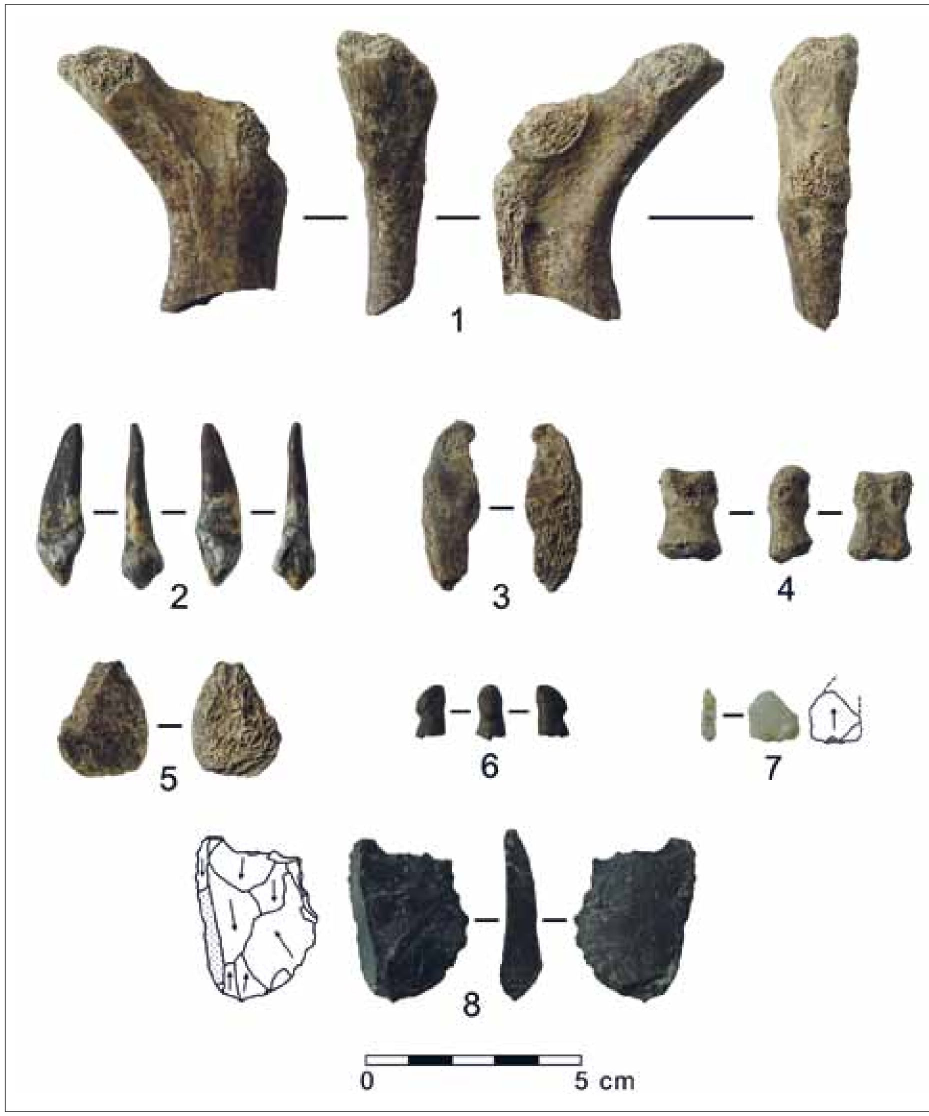
TABLE 2. Distribution of finds by stratigraphic unit found *in situ* and during sieving (made by F. Sirovica and M. Banda).

nju više stratigrafskih jedinica ili dolazi iz donjega, potkopanoga dijela profila. Kao i u slučaju pojedinačno prikupljenih nalaza, većina nalaza iz sita potječe iz SJ 15 iako sada višestruko nadilazi broj nalaza u svim drugim slojevima. Iz iste jedinice potječe i jedini komad litike pronađen tijekom prosijavanja. Riječ je o proksimalnome ulomku odbojčića ili pločice, dužine 9 mm, a izrađen je na finozrnoj sirovini nelokalnoga podrijetla.

Nalazi su oprani, dokumentirani i uvedeni u bazu podataka. Nakon istraživanja privremeno su pohranjeni u Arheološkome muzeju u Zagrebu.

ing (Table 2). Of these, 2060 bone finds, plus the lithic fragment, come from defined stratigraphic units, while the rest were mixed during the cleaning of numerous stratigraphic units or come from the lower, undercut part of the profile. As with individually collected finds, the majority of the sieved material comes from SU 15, although now in significantly greater quantities than in all other layers. The only lithic found during sieving also comes from this unit. It is a proximal fragment of a small flake or bladelet, 9 mm in length, made from fine-grained raw material of non-local origin.

The finds were washed, documented and entered into a database. After the excavation, they were temporarily stored at the Archaeological Museum in Zagreb.



SLIKA 4. Odabrani nalazi litike, kostiju i zuba pronađenih tijekom iskopavanja (izradio M. Banda).

FIGURE 4. Selected lithic, bone and tooth finds recovered during the excavation (made by M. Banda).

Uzorkovanje

Osim mjera zaštite profila 3, u novo iskopavanje integrirano je i prikupljanje uzoraka za više analiza, koje mogu doprinijeti rješavanju otvorenih pitanja o starosti naslaga u pojedinim segmentima stratigrafskoga slijeda Vindije, procesima nastanka naslaga, paleookolišnim uvjetima te populacijskoj dinamici pojedinih skupina hominina na prostoru sjeverne Hrvatske. Naime, kronologija naslaga u Vindiji uglavnom je okvirno konstruirana na temelju stratigrafske pozicije, klimatskih indikatora i malobrojnih, nepouzdanih i danas većinom zastarjelih rezultata radiometrijskoga datiranja.

U svrhu doprinosa rješavanju problematike kronologije dosad slabo datiranih slojeva, na datiranje metodom radioaktivnoga ugljika (^{14}C) u laboratorij *Oxford Radiocarbon Accelerator Unit* poslano je pet novih uzoraka kostiju iz SJ 7, 9, 11, 13 i 15, koji su korelirani s kompleksima E i F iz prijašnjih istraživanja. Kosti su odabrane na temelju stratigrafskoga položaja, ali i veličine ulomka i debljine kortikalne kosti, što bi moglo uvjetovati višu koncentraciju kolagena. Nažalost, prilikom obrade svih pet uzoraka (P-55101, P-55102, P-55103, P-55104, P-55105) nije dobiveno dovoljno kolagena za uspješno određivanje njihove starosti.

Sampling

In addition to protective measures for profile 3, the new excavation also integrated the collection of samples for several analyses that may help address open questions regarding the age of deposits in specific segments of the Vindija stratigraphic sequence, the formation processes of the sediments, palaeoenvironmental conditions, and the population dynamics of hominin groups in northern Croatia. The chronology of the Vindija deposits has so far been constructed largely on the basis of stratigraphic position, climatic indicators and a limited number of unreliable and, for the most part, outdated radiometric dating results.

To help address the issue of the poorly dated layers, five new bone samples from SU 7, 9, 11, 13 and 15 were sent for radiocarbon (^{14}C) dating to the Oxford Radiocarbon Accelerator Unit. These samples were correlated with complexes E and F from previous excavations. The bones were selected on the basis of their stratigraphic position, as well as the size of the fragments and the thickness of the cortical bone, which could indicate a higher collagen content. Unfortunately, during the preparation of all five samples (P-55101, P-55102, P-55103, P-55104, P-55105), Osim slanja uzoraka kostiju za radiokarbonsko datiranje, u svrhu poboljšanja kronologije naslaga prikupljeni su i uzorci sedimenata za detektiranje (kripto)tefre, odnosno piroklastičnoga materijala nastaloga vulkanskom erupcijom koji se taložio na površini krajolika.[19] Naime, takvi sedimenti mogu imati široku geografsku rasprostranjenost, a s obzirom na to da nastaju u geološki kratkome vremenu, tvore vremenski sinkrone horizonte.[20]

Kako bi se spriječila naknadna kontaminacija, u skladu s preporukom,[21] uzorci sedimenata za detekciju kriptotefre prikupljani su kontinuirano od dna do vrha profila u vertikalnome stupcu. Stupac je smješten na lijevoj polovici istraživane površine, a podijeljen je na manje segmente visine 5 cm. Sediment je iz pojedinoga segmenta prikupljen površinskim struganjem, pa svaki segment predstavlja jedan uzorak. Drugi manji stupac postavljen je na desnu stranu iskopane površine kako bi se obuhvatili slojevi koji nisu zastupljeni na lijevoj strani.[22] Po potrebi je mjestimice segment izmaknut lijevo ili desno od ravnine stupca kako bi se pri uzorkovanju izbjegli veći vapnenački klasti koji bi umanjili količinu sedimenta. S ciljem izbjegavanja kontaminacije, između uzorkovanja pojedinih segmenata korišteni je alat očišćen te su ukupno prikupljena 52 uzorka sedimenta.

Uzorkovanja na južnome licu profila 3 provedena su i u svrhu rekonstrukcije paleookolišnih odnosa naslaga. Analizom drevne DNA u sedimentu (sedaDNA) nastoji se nadopuniti spektar zastupljene faune, a osim paleookolišnih pokazatelja, iz dobivenih podataka moguće je prepoznati i životinjske vrste koje su mogle nastanjivati špilju. Osim toga, ovom analizom nastoji se utvrditi i prisutnost pojedinih ljudskih populacija u različitim dijelovima stratigrafskoga slijeda, koja bi se ubuduće mogla upotrebljavati za dublje razumijevanje populacijskih dinamika u regiji i vremenske faze nastanjivanja.

Uzorci za sedaDNA analizu prikupljeni su u trima stupcima, označeni slovima A, B i C. Stupci A i B postavljeni su unutar iskopne površine u širini od 20 cm uz lijevi rub, odnosno desni rub iskopavane površine. Stupac C postavljen je naknadno izvan iskopne površine, lijevo od stupca A. Uzroci sedimenata prikupljani su iz svake stratigrafske jedinice, iz manjih rupica promjera svega nekoliko centimetara (Sl. 5). Radi izbjegavanja kontaminacije, sediment je prikupljan u sterilne tubice, uz korištenje maske i plastičnih rukavica. Nakon svakoga uzorkovanja upotrijebljene su nove rukavice, a korišteni alat očišćen je 3 % otopinom izbjeljivača. Uzorci su poslani na analizu u laboratorij *Ancient DNA Genomics and Biological Anthropology*, Sveučilišta u Beču.

19 Alloway *et al.* 2013; Smith, Albert 2023.

20 Lane *et al.* 2014.

21 prema Lane *et al.* 2014.

22 v. Lane *et al.* 2014.

insufficient collagen was extracted to determine their ages successfully.

In addition to submitting bone samples for radiocarbon dating, sediment samples were also collected to improve the chronology of the deposits by detecting (crypto)tephra, i.e. pyroclastic material produced by volcanic eruptions that was deposited across the landscape.[19] Such sediments can have a wide geographical distribution; and, since they form over geologically short time spans, they create time-synchronous horizons.[20]

To prevent subsequent contamination, and in accordance with recommendations,[21] sediment samples for cryptotephra detection were collected continuously from the bottom to the top of the profile in a vertical column. The column was placed on the left-hand half of the excavated area and divided into smaller segments, each 5 cm in height. Sediment from each segment was collected by surface scraping, with each segment representing one sample. A second, smaller column was positioned on the right side of the excavated area to include layers not represented on the left side.[22] When necessary, individual segments were slightly shifted left or right from the column axis to avoid large limestone clasts that would reduce the amount of sediment collected. To avoid contamination, the sampling tools were cleaned between each segment, and a total of 52 sediment samples were collected.

Sampling on the southern face of profile 3 was also carried out for the purpose of reconstructing the palaeoenvironmental context of the deposits. Through the analysis of sedimentary ancient DNA (sedaDNA), the aim is to complement the spectrum of represented fauna. In addition to providing palaeoenvironmental indicators, the data obtained may help identify animal species that could have inhabited the cave. Furthermore, this analysis seeks to determine the presence of specific human populations in various parts of the stratigraphic sequence, which could, in the future, contribute to a deeper understanding of population dynamics in the region and the temporal phases of occupation.

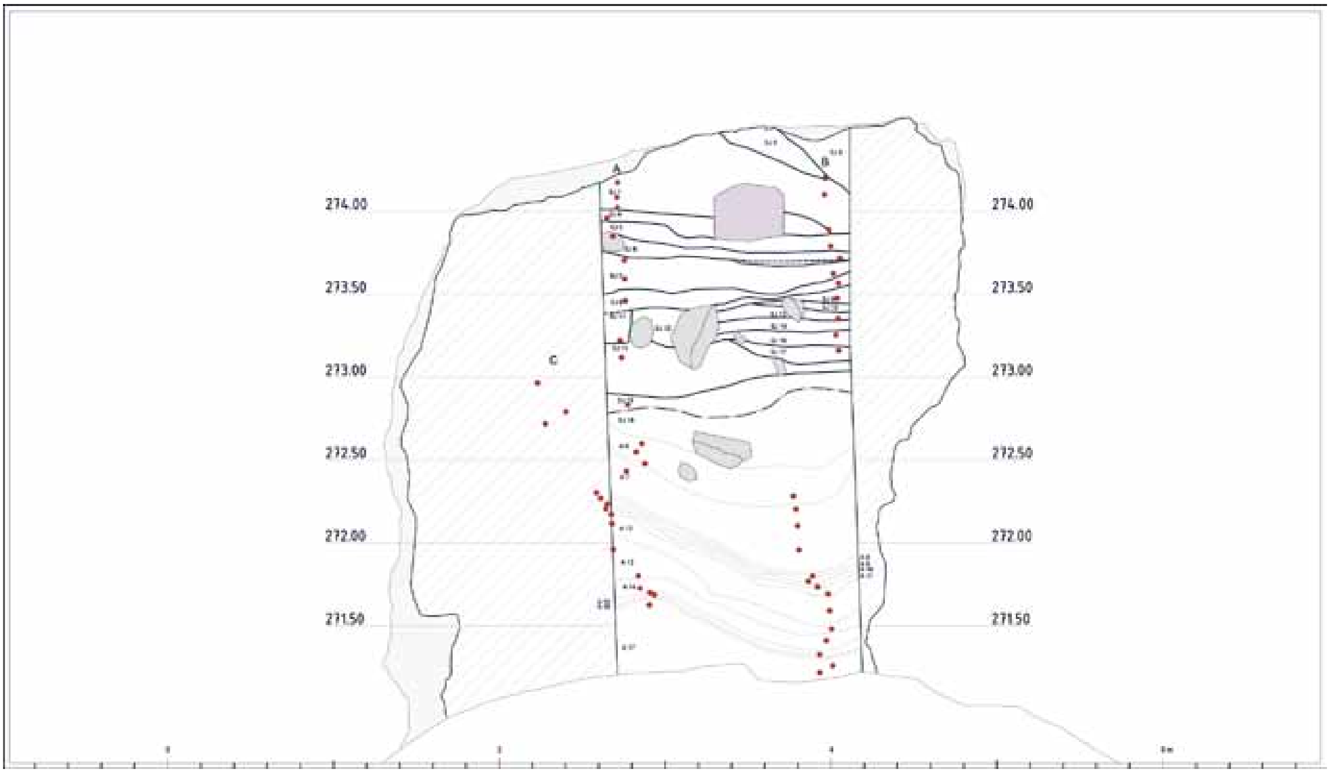
Samples for sedaDNA analysis were collected from three columns, labelled A, B and C. Columns A and B were placed within the excavation area, each 20 centimetres wide, along the left and right edges of the excavated surface, respectively. Column C was added later, positioned outside the excavation area, to the left of Column A. Sediment samples were taken from each stratigraphic unit, using small holes just a few centimetres in diameter (Fig. 5). To avoid contamination, the sediment was collected in sterile tubes, using masks and plastic gloves. New gloves were used for each sampling, and the tools were cleaned with a 3% bleach solution. The samples were sent for analysis to the Ancient DNA Genomics and Biological Anthropology laboratory at the University of Vienna.

19 Alloway *et al.* 2013; Smith, Albert 2023.

20 Lane *et al.* 2014.

21 After Lane *et al.* 2014.

22 See Lane *et al.* 2014.



SLIKA 5. Raspored uzoraka prikupljenih za analizu sedaDNA (izradila F. Sirovica).

FIGURE 5. Layout of samples collected for sedaDNA analysis (made by F. Sirovica).

Geogeni procesi, kao i tragovi uzastopnoga korištenja špilje, ostavili su iza sebe složene naslage, pa geoarheološke analize sedimenata mogu pružiti vrijedne uvide u procese formiranja nalazišta, promjene okoliša te aktivnosti i ponašanja ljudi u prošlosti, kao i u postdepozicijske preinake.[23] Stoga je jedan od ključnih ciljeva ovoga istraživanja mikrostratigrafska analiza konteksta naslaga i nalaza koja može omogućiti komparativne analize promjena u skupovima artefakata i ekofakata prikupljenih na nalazištu u odnosu na okolišne uvjete te definiranje vrsta i dinamika taloženja i stupnja poremećenosti, odnosno postdepozicijskoga miješanja slojeva.

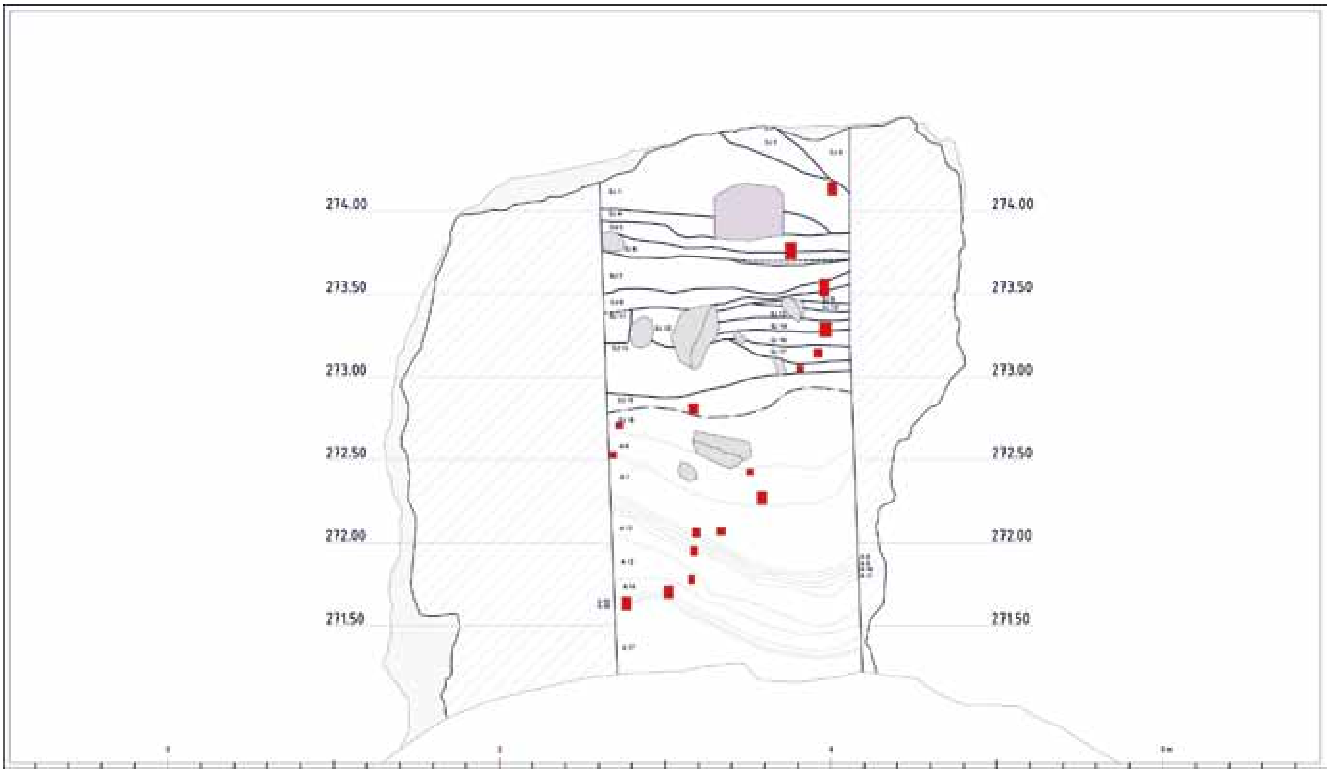
Iako je strategija uzorkovanja za geoarheološke analize u Vindiji morala biti prilagođena uvjetima istraživanja u špilji, odnosno ograničena na profil dostupan za iskopavanje, osigurana je reprezentativnost stratigrafskih jedinica. Skupni uzorci za granulometrijsku analizu frakcije < 2 mm prikupljeni su za svaku od stratigrafskih jedinica kada je to bilo moguće ili je uzorkovana reprezentativna jedinica određenoga skupa jedinica istoga sedimentacijskog facijesa. Istodobno su iz profila iskopne površine izdvojeni cjeloviti, orijentirani uzorci sedimenta za mikromorfološku analizu. Za mikromorfološku analizu prikupljeno je 17 uzoraka koji obuhvaćaju jednu stratigrafsku jedinicu ili, ovisno o debljini slojeva, više njih (Sl. 6). Više jedinica obuhvaćeno je pojedinim uzorcima i kako bi se istražili kontakti među

23 Mallol, Goldberg 2017.

Geogenic processes, as well as traces of successive human use of the cave, have resulted in complex deposits, making geoarchaeological sediment analysis a valuable tool for understanding site formation processes, environmental changes, and past human activities and behaviour, as well as postdepositional modifications.[23] Therefore, one of the key objectives of this research is the microstratigraphic analysis of the context of deposits and finds. This can enable comparative analysis of changes in assemblages of artefacts and ecofacts recovered from the site in relation to environmental conditions, as well as the identification of the types and dynamics of sedimentation and the degree of disturbance or postdepositional mixing of layers.

Although the sampling strategy for geoarchaeological analysis at Vindija had to be adapted to the conditions of cave excavation – i.e. limited to the profile accessible for excavation – the representativeness of the stratigraphic units was ensured. Bulk samples for grain-size analysis of the <2 mm fraction were collected for each stratigraphic unit whenever possible, or a representative unit was sampled from a set of units of the same depositional facies. At the same time, intact, oriented sediment samples were extracted from the excavation profile for micromorphological analysis. A total of 17 samples were collected for micromorphological analysis, each covering either a single stratigraphic unit or, depending on the thickness of the layers,

23 Mallol, Goldberg 2017.



SLIKA 6. Raspored uzoraka prikupljenih za mikromorfološku analizu (izradila F. Sirovica).

FIGURE 6. Layout of samples collected for micromorphological analysis (made by F. Sirovica).

njima. Uzorke čine neporemećeni blokovi sedimenta veličine oko 10 × 6 × 5 cm, pažljivo omotani u celulozni papir s označenim usmjerenjem. Poslani su u specijalizirani laboratorij za rezanje i brušenje izbrusaka koji će biti pregledani pod petrografskim polarizacijskim mikroskopom.

Rasprava

Korelacija stratigrafskoga slijeda

Na temelju makroskopskih karakteristika stratigrafskih jedinica definiranih tijekom novoga istraživanja moguće je provesti korelaciju sa stratigrafskom podjelom naslaga iz istraživanja M. Maleza,[24] a rezultati toga prikazani su na Sl. 7. Međutim, nije moguće svaku naslagu nedvojbeno povezati s određenim ekvivalentom. Taj problem nije neočekivan s obzirom na izraženu lateralnu raznolikost sedimentacijskih facijesa u špiljskim depozicijskim uvjetima. Pojedini slojevi prepoznatljiviji su po svojim svojstvima od drugih, pa stoga služe kao referentne točke za korelaciju stratigrafije. U većini slučajeva pojedine naslage moguće je relativno smjestiti prema Malezovoj stratigrafiji, ali je znatno teže strogo determinirati granice između prije definiranih naslaga. Jednako tako, moguće je da i pojedine Malezove

a number of units (Fig. 6). In some cases, several units were included in a single sample to investigate the contacts between them. The samples consist of undisturbed sediment blocks approximately 10 × 6 × 5 cm in size, carefully wrapped in cellulose paper, marked with indication of orientation, and labelled. They were sent to a specialized laboratory for cutting and polishing into thin sections, which will be examined under a petrographic polarizing microscope.

Discussion

Stratigraphic sequence correlation

On the basis of the macroscopic characteristics of the stratigraphic units defined during the new investigation, it is possible to correlate them with the stratigraphic division of the deposits from Mirko Malez's research,[24] with the results shown in Fig. 7. However, it is not possible to definitively link each deposit to a specific equivalent. This issue is not unexpected, considering the high lateral variability of sedimentary facies in cave depositional environments. Some layers are more clearly identifiable, due to their properties, and therefore serve as reference points for stratigraphic correlation. In most cases, individual deposits can be relatively positioned within Malez's stratigraphy, but it is significantly more difficult to precisely determine the boundaries between the previously-defined layers. It is also possible

24 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

24 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

naslage svojim granicama prolaze kroz neke od novodefiniranih stratigrafskih jedinica, ali s obzirom na to da novija istraživanja imaju tendenciju minucioznijega bilježenja promjena u naslagama, ta se mogućnost čini malo vjerojatnom. Treba imati na umu da su opisi slojeva iz prijašnjih istraživanja temeljeni na kompozitnim opservacijama dvaju profila, onoga na ulaznome dijelu špilje (profil 1) te onoga iz unutrašnjosti (profil 3),[25] zbog čega su moguće diskrepancije sa stratigrafskom shemom iz novoga istraživanja koja je vršena samo u unutrašnjosti špilje. K tomu je važno istaknuti i to da su opisi slojeva u dostupnim radovima sažeti,[26] zbog čega u cijelosti ne odražavaju ni varijacije u pojedinim naslagama ni neke, za potrebe ove korelacije, ključne razlike među slojevima.

Uzevši prethodno iznesene probleme u obzir, slojevi od SJ 1 do SJ 5 najvjerojatnije odgovaraju sloju D iz prijašnjih stratigrafskih shema, koji Malez i Rukavina[27] opisuju kao „fino pjeskuljasti sediment, lesolikog izgleda…uglavnom bez kamenja…U svježem stanju je sivkastonarančaste boje (po Munsellu 10 YR 7/4).“ Riječ je o siltnim i siltno-glinovitim slojevima koji se poklapaju s navedenim opisom i vidno se razlikuju od nižih slojeva po boji i teksturi. Zbog toga treba imati na umu i to da sedimentološka istraživanja pokazuju da se u unutrašnjosti špilje blizu istraživanoga profila 3 naslaga D jasno izdvajala od naslaga kompleksa E po većemu udjelu granulometrijske frakcije manje od 0,06 mm, odnosno udjelu silta i gline.[28] Alternativno tumačenje koreliralo bi SJ 5 s gornjim dijelom sloja E iz Malezove stratigrafije, što odražava činjenicu da postoje nesigurnosti oko određivanja granica među pojedinim slojevima.

Stratigrafske jedinice 6 i 7 vjerojatno zajedno tvore naslage koje su u prijašnjim istraživanjima označene kao sloj E. Malez i Rukavina[29] navode da je riječ o „pjeskuljastom sedimentu s mnoštvo sitnog kamenog kršja…U svježem stanju je sive boje (po Munsellu 5 Y 5/2 /E1/ i 5 Y 6/1 /E2/)“, a uz to ističu da je mjestimično kršje kemijski korodirano. Navedeni opisi odgovaraju opisima slojeva SJ 6 i SJ 7, u kojima se u novim istraživanjima zabilježila veća količina sitnih klasta, koji su naročito kemijski trošeni u SJ 7.

Shodno tomu, stratigrafske jedinice 8–18 moguće je prilično sigurno korelirati s Malezovim F kompleksom. SJ 8 iznimno je svjetlosive boje i vidno je različit od gornjega SJ 7, što se poklapa s opisom Maleza i Rukavine[30] koji navode da krovni sloj kompleksa F, odnosno sloj Fg, ima boju MUN N6. Naime, u opisima slojeva u stratigrafskome slijedu,[31] slojevima F kompleksa jedinima su dodijeljene neutralne sive boje prema Munsellu (N4-N7), iz čega se može zaključiti da su po boji vidno odstupali od superpozicioniranih i subpozicioniranih naslaga. Osim toga, donja granica kompleksa F lako je prepoznatljiva jer postoji oš-

that some of Malez’s layers extend across several of the newly-defined stratigraphic units. However, given that recent investigations tend to record sediment changes in more detail, this possibility seems unlikely. It is important to keep in mind that the descriptions of layers from earlier research were based on composite observations from two profiles – one at the cave entrance (profile 1) and the other in the interior (profile 3)[25] – which may explain discrepancies with the stratigraphic framework of the new investigation, which was conducted exclusively in the interior of the cave. Additionally, it is worth noting that the descriptions of layers in the available publications are concise,[26] and therefore do not fully reflect the variations within individual deposits or certain differences between layers that are crucial for this correlation.

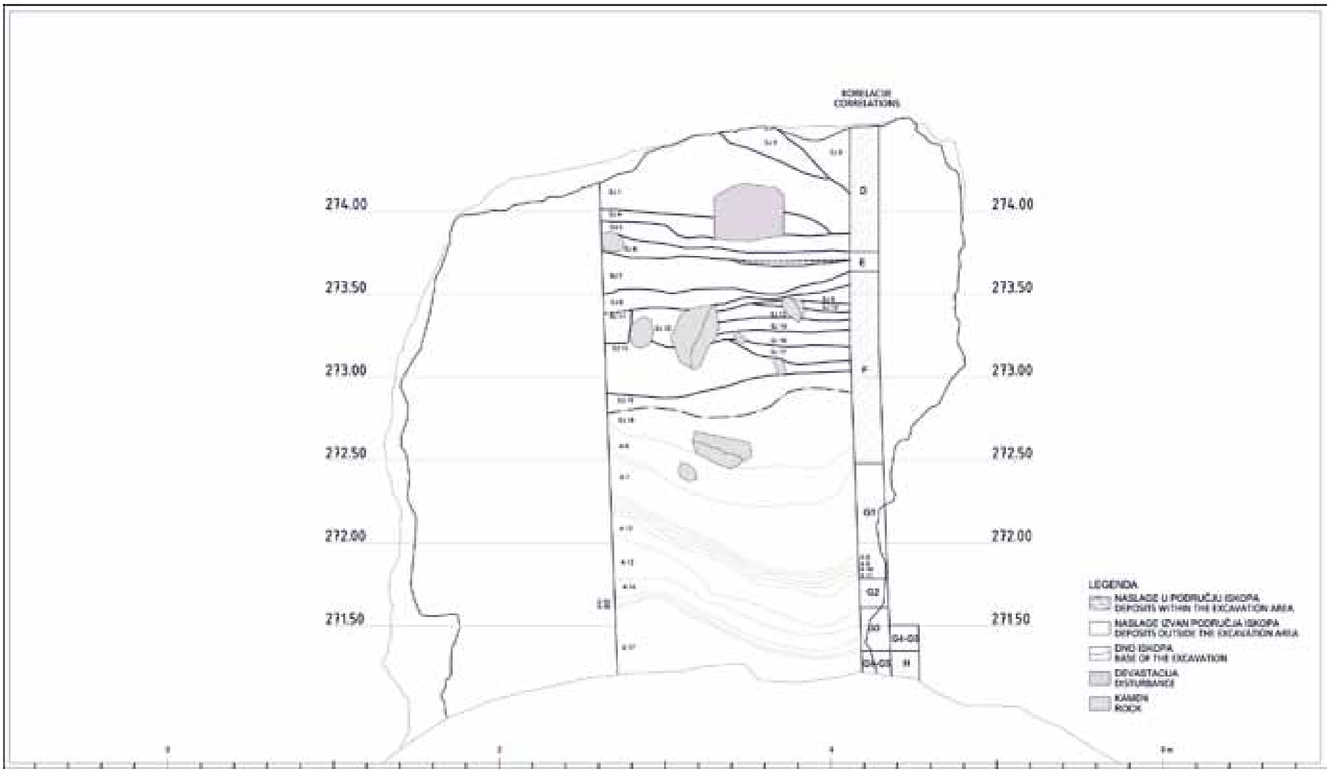
Taking the aforementioned issues into account, layers SU 1 through SU 5 most likely correspond to layer D from earlier stratigraphic schemes, which Malez and Rukavina[27] describe as a “fine sandy sediment with a loess-like appearance… mostly stone-free… in its fresh state, greyish-orange in colour (according to Munsell 10 YR 7/4)”. These are silty and silty-clayey layers that match the given description and are visibly distinct from the underlying layers in both colour and texture. In view of that, it is important to note that sedimentological research shows that, in the interior of the cave near the investigated profile 3, layer D clearly stands out from the deposits of complex E by a higher proportion of the granulometric fraction smaller than 0.06 mm, i.e. the silt and clay content.[28] An alternative interpretation would correlate SU 5 with the upper part of layer E from Malez’s stratigraphy, reflecting the uncertainty in defining precise boundaries between individual layers.

Stratigraphic units 6 and 7 together likely correspond to the deposits designated as layer E in earlier investigations. Malez and Rukavina[29] describe it as a “sandy sediment with a large amount of small limestone rubble… In its fresh state, it is grey in colour (according to Munsell 5 Y 5/2 for E1 and 5 Y 6/1 for E2)”, and they also note that the clasts are chemically corroded in some areas. These descriptions align with the characteristics of SU 6 and SU 7, where the new research recorded a greater number of small clasts, which are especially chemically weathered in SU 7.

Accordingly, stratigraphic units 8 to 18 can be fairly confidently correlated with Malez’s F complex. SU 8 is distinctly light grey in colour and clearly different from the overlying SU 7, which aligns with the description by Malez and Rukavina,[30] who state that the top layer of the F complex, namely layer Fg, has a Munsell colour of N6. In fact, in their descriptions of the stratigraphic sequence,[31] only the layers of the F complex are assigned neutral grey tones according to Munsell (N4–N7), sug-

25 Malez, Rukavina 1979, 188.
26 Malez, Rukavina 1975; 1979; Malez, Šimunić, Šimunić 1984.
27 Malez, Rukavina 1979, 189.
28 Malez, Šimunić, Šimunić 1984.
29 Malez, Rukavina 1979, 189.
30 Malez, Rukavina 1979, 189.
31 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

25 Malez, Rukavina 1979, 188.
26 Malez, Rukavina 1975; 1979; Malez, Šimunić, Šimunić 1984.
27 Malez, Rukavina 1979, 189. Translated from the original by M. Banda.
28 Malez, Šimunić, Šimunić 1984.
29 Malez, Rukavina 1979, 189. Translated from the original by M. Banda.
30 Malez, Rukavina 1979, 189.
31 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.



SLIKA 7. Korelacija novoutvrđenih stratigrafskih jedinica sa stratigrafskom podjelom naslaga iz istraživanja M. Maleza (izradili M. Banda i F. Sirovica).

FIGURE 7. Correlation of newly-identified stratigraphic units with the stratigraphic division from the research of Mirko Malez (made by M. Banda and F. Sirovica).

tra granica sa slojem G1.[32] Prema tome, najniži sloj iz iskopne površine, odnosno SJ 18, te prvi sloj u potkopanome dijelu (A6), zasigurno pripadaju prije definiranomu kompleksu F. S druge strane, zasad nije moguće u potpunosti povezati stratigrafske jedinice iz novih istraživanja s podslojevima kompleksa F – Fg, Fs, Fd/s, Fd, Fd/d, kako su ih redom definirali Malez i Rukavina.[33] Dio problema korelacije proizlazi iz već navedene horizontalne varijabilnosti u slojevima SJ 9–14 i SJ 16–17, uzrokovane poremećajima i razlikama u sedimentaciji zbog postojanja vapnenačkih blokova, čime je otežano horizontalno, ali i vertikalno praćenje stratigrafskih jedinica.

Eventualno je moguće, i to barem djelomično, na temelju stratigrafskoga položaja korelirati sloj Fg sa SJ 8, a sloj A6 sa Fd/d. Osim toga, postoji potencijalna korelacija između SJ 10 i sloja Fd/s jer obje jedinice predstavljaju glinovite slojeve bez kršja,[34] ali s obzirom na to da je SJ 10 otkrivena samo na dijelu iskopne površine i da ju nije jednostavno pratiti, moguće je da se radi o manjemu proslojku, koji stoga nije istovjetan sloju Fd/s. Uz to, u sloju Fd, prema Malezu i Rukavini,[35] uz sivi matriks (MUN N5 i MUN 5 Y 4/4) javljaju se i žućkastozeleni proslojci, što okvirno odgovara opisu SJ 18, koji predstavlja žuto-sivi pjeskovito-siltni sloj, iako slične karakteristike ima i sloj A6 iz potkopanoga dijela koji se nalazi ispod SJ 18.

gesting that they visibly differed in colour from the overlying and underlying deposits. In addition, the lower limit of complex F is easily recognizable, as there is a sharp boundary with layer G1.[32] Therefore, the lowest layer within the excavated area, SU 18, as well as the first layer in the undercut section (A6), can confidently be assigned to the previously-defined F complex. On the other hand, it is currently not possible to fully correlate the stratigraphic units from the new excavations with the sublayers of the F complex – Fg, Fs, Fd/s, Fd, Fd/d – as defined by Malez and Rukavina.[33] Part of the difficulty in establishing this correlation stems from the aforementioned horizontal variability within layers SU 9–14 and SU 16–17, caused by disturbances and differences in sedimentation due to the presence of limestone blocks, which complicates both horizontal and vertical tracing of the stratigraphic units.

It is potentially possible at least partially to correlate layer Fg with SU 8, and layer A6 with Fd/d, on the basis of their stratigraphic positions. In addition, there is a potential correlation between SU 10 and layer Fd/s, as both units represent clay-rich layers without clasts.[34] However, since SU 10 was identified only in part of the excavated area and is not easily traceable, it may represent a smaller lens, and therefore may not be identical to Fd/s. Furthermore, according to Malez and Rukavina,[35] layer Fd

32 v. Malez, Rukavina 1979.

33 Malez, Rukavina 1979.

34 Malez, Rukavina 1979, 189.

35 Malez, Rukavina 1979.

32 See Malez, Rukavina 1979.

33 Malez, Rukavina 1979.

34 Malez, Rukavina 1979, 189.

35 Malez, Rukavina 1979.

Ipak, slojevi označeni oznakama od A6 do A17 nisu iskopavani, te je korelaciju sa slojevima iz prijašnjih istraživanja potrebno izvršiti uz prikladne ograde, istodobno pružajući mogućnost jasnijega definiranja konteksta iz kojih potječu novoprikupljeni uzorci. Ako je sloj A6 moguće smatrati ekvivalentnim donjemu dijelu kompleksa F, odnosno sloju Fd/d iz prijašnjihi straživanja,[36] tada se crveni sloj A7 može smatrati ekvivalentnim sloju G1, a istomu sloju vjerojatno pripadaju i tanke naslage od A8 do A11.[37] Jasno izraženi kontakt i razlika u boji između A11 i A12 upućuje na to da je A12 najvjerojatnije ekvivalentan sloju G2, što dodatno podupire prepoznatljivost slojeva G1 i G3, obilježenih specifičnim značajkama boje i sastava. Naime, na temelju boje i sastava, slojevi označeni oznakama od A13 do A16 odgovaraju opisu sloja G3.[38] Prema alternativnome tumačenju, slojeve A14 –A16 moguće je korelirati s donjim dijelom kompleksa G (slojevi G4 i G5), iz čega proizlazi da je taj dio stratigrafskoga slijeda samo preliminarno koreliran sa starijom stratigrafskom shemom. Posljednji vidljivi sloj A17 mogao bi biti ekvivalentan jednomu od slojeva donjega dijela kompleksa G (G4 ili G5), ali i sloju H iz starijih istraživanja.[39]

contains, in addition to a grey matrix (MUN N5 and MUN 5 Y 4/4), yellowish-green lenses, which roughly corresponds to the description of SU 18, representing a yellow-grey sandy-silty layer, although similar characteristics are also present in layer A6 of the undercut section located beneath SU 18.

However, the layers labelled A6 to A17 were not excavated, so their correlation with layers from earlier investigations must be approached with appropriate caution, while still allowing for a clearer definition of the context from which the newly collected samples originate. If layer A6 can be considered equivalent to the lower part of complex F, specifically to layer Fd/d of the previous research,[36] then the red layer A7 may correspond to layer G1, and the thin deposits A8 through A11 likely also belong to the same layer.[37] The clearly-defined contact and colour difference between A11 and A12 suggest that A12 is most likely equivalent to layer G2, which is further supported by the recognisability of layers G1 and G3, marked by their specific colour and composition. That is to say, on the basis of their colour and composition, that the layers labelled A13 to A16 correspond to the description of layer G3.[38] According to an alternative interpretation, layers A14–A16 could be correlated with the lower part of complex G (layers G4 and G5), indicating that this portion of the stratigraphic sequence has only been preliminarily correlated with the older stratigraphic framework. The last visible layer, A17, could be equivalent either to one of the layers of the lower part of complex G (G4 or G5) or to layer H of earlier investigations.[39]

Analiza kronološkoga slijeda

Provedenu korelaciju moguće je primijeniti za definiranje okvirne starosti za naslage dokumentirane novim istraživanjima, uz nezaobilaznu suzdržanost koja je nužan rezultat nesigurnosti u dostupne podatke. Starosti determinirane u okviru kronologije stadija izotopa kisika[40] proizlaze iz prijašnjih relativno kronoloških determinacija na temelju tzv. alpske kronologije,[41] paleoklimatskih indikatora skupova faune[42] i objavljenih rezultata apsolutnoga datiranja.[43] Doduše, samo su pojedine naslage i pripadajući skupovi nalaza, koji su bili predmet intenzivnih rasprava o podrijetlu modernih ljudi i nestanku neandertalaca, poput slojeva Fd/d, G1 i G3, prethodno radiokarbonski datirani s nešto većim brojem uzoraka, pri čemu su primijenjene različite metode pripreme i mjerenja.[44] S druge strane, dosadašnje uran-torij (U-Th) datiranje pojedinih slojeva nije rezultiralo pouzdanim podatcima zbog problema „otvorenoga sustava“, odnosno vremena unosa urana nakon smrti organizma i naknad-

Analysis of the chronological sequence

The established correlation can be used to define the approximate age of the deposits documented in the new investigations, with the necessary caution due to the uncertainty of the available data. The ages determined within the framework of the marine isotope stage (MIS) chronology[40] are derived from earlier relative chronological determinations based on the so-called Alpine chronology,[41] palaeoclimatic indicators from faunal assemblages,[42] and published results of absolute dating.[43] However, only certain layers and associated assemblages – those that have been the focus of intense debate regarding the origins of modern humans and the disappearance of Neandertals, such as layers Fd/d, G1 and G3 – have previously been radiocarbon-dated using a somewhat larger number of samples and through the application of various preparation and measurement techniques.[44] On the other hand, uranium-thorium (U-Th) dating of some layers conducted thus far has not yielded reliable results,

36 Malez, Rukavina 1979.

37 Malez, Rukavina 1979.

38 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

39 Malez, Rukavina 1979.

40 Lisiecki, Raymo 2005.

41 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

42 Malez, Rukavina 1979; Miracle, Mauch Lenardić, Brajković 2010.

43 Wild *et al.* 2001; Devièse *et al.* 2017; Karavanić *et al.* 2024.

44 Srdoč *et al.* 1979; 1984; Obelić *et al.* 1994; Wild *et al.* 2001; Higham *et al.* 2006; Devièse *et al.* 2017; Karavanić *et al.* 2024.

36 Malez, Rukavina 1979.

37 Malez, Rukavina 1979.

38 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

39 Malez, Rukavina 1979.

40 Lisiecki, Raymo 2005.

41 Malez, Rukavina 1979; Malez, Šimunić, Šimunić 1984.

42 Malez, Rukavina 1979; Miracle, Mauch Lenardić, Brajković 2010.

43 Wild *et al.* 2001; Devièse *et al.* 2017; Karavanić *et al.* 2024.

44 Srdoč *et al.* 1979; 1984; Obelić *et al.* 1994; Wild *et al.* 2001; Higham *et al.* 2006; Devièse *et al.* 2017; Karavanić *et al.* 2024.

ne razmjene izotopa urana i torija s okolišem.[45] Takav proces razlog je zašto su U-Th rezultati sustavno mlađi od rezultata radiokarbonskoga datiranja uzoraka iz slojeva kompleksa G.[46] Parcijalno poznavanje starosti pojedinih dijelova stratigrafskoga slijeda razlog je zbog kojega su moguća različita tumačenja kronologije naslaga,[47] a pogotovo je izraženo slabo poznavanje kronologije F, E i D kompleksa.

Iako radiokarbonske analize na novoprikupljenim uzorcima za sada nisu bile uspješne, prema svim pokazateljima, gornje stratigrafske jedinice označene kao SJ 1, 2, 4 i 5 pripadale bi razdoblju kasnoga glacijala, odnosno drugoj polovini MIS 2, nakon kasnoglacijalnoga maksimuma (LGM). Takva pretpostavka temelji se na rezultatu radiokarbonskoga datiranja od 23,1 do 21,7 tisuća kalibriranih g. prije sadašnjosti[48] (Z-2447) na kosti špiljskoga medvjeda iz sloja E,[49] koji je pak koreliran s jedinicama označenima kao SJ 6 i 7. Sukladno tomu, SJ 6 i 7 moguće je također pripisati razdoblju MIS 2, a moguće je da iste naslage obuhvaćaju i razdoblje LGM-a,[50] na što upućuju i rezultati analize faune koja upućuje na postojanje nekih vrsta prilagođenih glacijalnim uvjetima.[51]

Kompleks F, odnosno stratigrafske jedinice od SJ 8 do SJ 18, kao i sloj A6, datiraju se u vrijeme MIS 3 na temelju triju rezultata datiranja uzoraka ugljena raspona od 48 do 22 tisuća kalibriranih g. prije sadašnjosti (Z-551, Z-612, Z-613).[52] Dodatni uzorak medvjeđe kosti iz sloja Fd/d pružio je rezultat od 33,4 do 29,1 tisuća kalibriranih g. prije sadašnjosti (Z-2433).[53] Međutim, treba imati na umu da su ti rezultati nastali u vremenu prije uporabe akceleratorske masene spektrometrije pa su, osim što imaju jako široke raspone, pojedine starosti naslaga kompleksa F vjerojatno nešto podcijenjene, što podupiru i noviji rezultati datiranja kostiju iz sloja F/d koji upućuju na kalibrirane starosti od 43 do 49 tisuća godina prije sadašnjosti (1σ).[54]

Shodno tomu, slojevi kompleksa G većim dijelom, ako ne i u cijelosti, pripadaju vremenu MIS 3 jer rezultati datiranja smještaju uzroke kostiju iz sloja G1 između 43 i 52 tisuća kalibriranih g. prije sadašnjosti,[55] a one iz sloja G3 u raspon od 44 do 52 tisuće kalibriranih g. prije sadašnjosti (1σ).[56] Stoga se ista starost može pretpostaviti za slojeve označene oznakama od A7 do A13, a sta-

due to the 'open system' problem – that is, the timing of uranium uptake after the organism's death and the subsequent exchange of uranium and thorium isotopes with the environment.[45] This process explains why U-Th results are systematically younger than radiocarbon dates from samples in complex G.[46] The partial understanding of the age of certain segments of the stratigraphic sequence creates a context in which various interpretations of the chronology of the deposits are possible.[47] This is particularly true for the poorly-understood chronologies of complexes F, E and D.

Although radiocarbon analysis on the newly collected samples has so far been unsuccessful, all available indicators suggest that the upper stratigraphic units labelled SU 1, 2, 4, and 5 likely belong to the Late Glacial period – that is, the second half of MIS 2, after the Last Glacial Maximum (LGM). This assumption is based on a radiocarbon date ranging from 23.1 to 21.7 ka cal. BP[48] (Z-2447), obtained from a cave bear bone found in layer E,[49] which has been correlated with units SU 6 and 7. Accordingly, SU 6 and 7 can also be attributed to MIS 2, and it is possible that these deposits include the LGM period as well,[50] as suggested by faunal analysis results indicating the presence of species adapted to glacial conditions.[51]

Complex F, i.e. stratigraphic units SU 8 through SU 18, as well as layer A6, are dated to MIS 3 on the basis of three charcoal-dating results ranging from 48 to 22 ka cal. BP (Z-551, Z-612, Z-613).[52] An additional sample of a bear bone from layer Fd/d provided a date between 33.4 and 29.1 ka cal. BP (Z-2433).[53] However, it is important to note that these results were obtained prior to the use of accelerator mass spectrometry (AMS), and therefore, in addition to having very broad ranges, the ages of some of the complex F deposits are likely somewhat underestimated. This is supported by more recent radiocarbon dating of bones from layer F/d, which indicate calibrated ages ranging from 43 to 49 ka BP (1σ).[54]

Accordingly, the layers of complex G for the most part, if not entirely, belong to the period of MIS 3, because dating results of bone samples from layer G1 range between 43 and 52 ka cal. BP,[55] and those from layer G3 from 44 to 52 ka cal. BP (1σ).[56] There-

45 Grün *et al.* 2014.

46 v. Devièse *et al.* 2017; Karavanić *et al.* 2024; cf. Wild *et al.* 2001; Karavanić *et al.* 2021.

47 Zilhão 2009; cf. Karavanić, Smith 2013.

48 Svi radiokarbonski rezultati kalibrirani su u programu OxCal, v. 4.4.4 (Bronk Ramsey 2021) koristeći se kalibracijskom krivuljom IntCal20 (Reimer *et al.* 2020). Starosti su iznesene u rasponu od 95,4 % (2σ) vjerojatnosti, osim ako nije navedeno drukčije.

49 Obelić *et al.* 1994.

50 v. Zilhão 2009.

51 Miracle, Mauch Lenardić, Brajković 2010.

52 Srdoč *et al.* 1979; 1984.

53 Obelić *et al.* 1994.

54 Karavanić *et al.* 2024.

55 Devièse *et al.* 2017.

56 Karavanić *et al.* 2024.

45 Grün *et al.* 2014.

46 See Devièse *et al.* 2017; Karavanić *et al.* 2024; cf. Wild *et al.* 2001; Karavanić *et al.* 2021.

47 Zilhão 2009; cf. Karavanić, Smith 2013.

48 All radiocarbon results were calibrated in OxCal, v. 4.4.4 (Bronk Ramsey 2021), using the IntCal20 calibration curve (Reimer *et al.* 2020). Ages are reported with 95.4% (2σ) probability, unless stated otherwise.

49 Obelić *et al.* 1994.

50 See Zilhão 2009.

51 Miracle, Mauch Lenardić, Brajković 2010.

52 Srdoč *et al.* 1979; 1984.

53 Obelić *et al.* 1994.

54 Karavanić *et al.* 2024.

55 Devièse *et al.* 2017.

56 Karavanić *et al.* 2024.

rost A14, A15 i A16 ostaje otvorena jer nije sigurno odgovaraju li sloju G3 ili slojevima G4 i G5 po prijašnjoj stratigrafskoj podjeli.

S tim u vidu ostaje otvoreno i pitanje starosti sloja A17, za koji nije sigurno predstavlja li donji dio kompleksa G ili sloj H. Dostupan je samo jedan rezultat radiokarbonskoga datiranja kosti iz sloja H, koji je u kontekstu novih datiranja vidno podcijenjen (od 42,7 do 34,5 tisuća kalibriranih g. prije sadašnjosti; VRI-1125),[57] dok rezultat datiranja kosti metodom U-Th s granice slojeva H/I pokazuje prosječni rezultat od 88,2 ± 2,3 tisuća g.[58] Okvirno usporedivi rezultati dobiveni su i novijim U-Th datiranjima koji upućuju na starosti od 88,7 ± 13 tisuća g. i 102 ± 6 tisuća g. prije sadašnjosti.[59] Ipak, ovi rezultati ostavljaju široke mogućnosti datiranja sloja H, od završnoga dijela MIS 5 pa sve do početka MIS 3, a rezultati revizije faunskih ostataka sugeriraju na postojanje umjerenih okolišnih uvjeta kao i u kompleksu G. To znači da su klimatske oscilacije na tome prostoru bile relativno blage i da je stoga teško prepoznati obrasce koji odražavaju paleoklimatske promjene tipične za pojedine stadije izotopa kisika.[60]

Budući znanstveni doprinos

Dodatnu perspektivu boljemu razumijevanju kronologije pećinskih naslaga mogli bi osigurati novi pokušaji radiokarbonskih analiza, ali bitan doprinos istoj problematici mogu pružiti i druga uzorkovanja provedena tijekom iskopavanja.

To se ponajprije odnosi na analizu prisutnosti tefre koja se, na temelju jedinstvenih mineralnih i geokemijskih svojstava, može povezati s pojedinačnim erupcijama i geografskom lokacijom pojedine erupcije. Zbog toga je korisna za dobivanje referentnih kronostratigrafskih razina,[61] što je temelj tefrokronologije.[62] Starost određene erupcije, odnosno depozicija pojedine tefre često je određena na temelju radiometrijskoga datiranja vulkanskih formacija i materijala pronađenoga u njima u proksimalnome području erupcije, ali i na temelju položaja tefre u drugim naslagama te zapisima gdje postoje povoljni i konzistentni depozicijski uvjeti kao što su jezerski sedimenti i ledene jezgre.[63] Determiniranjem naslaga tefre na arheološkim nalazištima i njihovim povezivanjem sa specifičnim erupcijama dobivaju se kronostratigrafski referetne razine koje omogućuju određivanje starosti stratigrafskoga slijeda te korelacije među različitim arheološkim i paleookolišnim zapisima koji imaju iste naslage tefre.[64]

fore, the same age can be assumed for the layers labelled A7 to A13, while the ages of layers A14, A15 and A16 remain uncertain, as it is unclear whether they correspond to layer G3 or to layers G4 and G5 of the earlier stratigraphic framework.

With that in mind, the age of layer A17 remains an unresolved issue, as it is uncertain whether it represents the lower part of complex G or corresponds to layer H. Only one radiocarbon date is available for a bone from layer H, which, when viewed in light of newer datings, is clearly underestimated (ranging from 42.7 to 34.5 ka cal. BP; VRI-1125).[57] In contrast, a bone from the boundary between layers H and I, dated by U-Th, yielded an average result of 88.2 ± 2.3 ka.[58] Roughly comparable results were obtained from more recent U-Th datings, indicating ages of 88.7 ± 13 ka and 102 ± 6 ka BP.[59] However, these results leave open wide possibilities for the age of layer H – from the final part of MIS 5 to the beginning of MIS 3. Moreover, a revision of the faunal remains suggests the presence of temperate environmental conditions, similar to those in complex G. This implies that climatic oscillations in this area were relatively mild, making it difficult to identify patterns reflecting the palaeoclimatic changes typically associated with specific marine isotope stages.[60]

Future scientific contributions

Additional insight into the chronology of the cave deposits could be gained through new attempts at radiocarbon analysis, but other sampling conducted during the excavation may also provide an important contribution to this issue.

This, first and foremost, refers to the analysis of tephra presence, which, on the basis of its unique mineralogical and geochemical characteristics, can be linked to specific volcanic eruptions and their geographic locations. Therefore, it serves as a valuable tool for establishing reference chronostratigraphic horizons,[61] which forms the basis of tephrochronology.[62] The age of a particular eruption, or the deposition of individual tephra layers, is often determined through radiometric dating of volcanic formations and materials found in the proximal eruption region, as well as by correlating tephra layers within other sequences and records where favourable and consistent depositional conditions exist, such as lake sediments and ice cores.[63] By identifying tephra deposits at archaeological sites and associating them with specific eruptions, chronostratigraphic reference horizons are established, enabling age determination of stratigraphic sequences and facilitating correlations between various archaeological and palaeoenvironmental records containing the same tephra layers.[64]

57 Wild *et al.* 2001.
58 Wild *et al.* 2001.
59 Karavanić *et al.* 2021.
60 Miracle, Mauch Lenardić, Brajković 2010.
61 Alloway *et al.* 2013.
62 Lowe 2011; Lane *et al.* 2014.
63 Alloway *et al.* 2013; Lane *et al.* 2017; Smith, Albert 2023.
64 Lane *et al.* 2014.

57 Wild *et al.* 2001.
58 Wild *et al.*2001.
59 Karavanić *et al.* 2021.
60 Miracle, Mauch Lenardić, Brajković 2010.
61 Alloway *et al.* 2013.
62 Lowe 2011; Lane *et al.* 2014.
63 Alloway *et al.* 2013; Lane *et al.* 2017; Smith, Albert 2023.
64 Lane *et al.* 2014.

Istodobno, vulkanski pepeo koji nije moguće makroskopski uočiti, ali je zastupljen u naslagama u formi koncentracije sitnih krhotina stakla i kristala, naziva se kriptotefra.[65] Kriptotefra predstavlja (ultra)distalnu depoziciju piroklastičnoga materijala, koja se u određenim slučajevima događa i više od nekoliko tisuća kilometara od izvorišne erupcije,[66] te posljedično omogućava determinaciju sinkronih referentnih horizonata na širemu geografskom prostoru.[67] Uzorci kriptotefre za tefrokronološku determinaciju izdvajaju se iz uzoraka sedimenta mikroskopskim tehnikama ekstrakcije krhotina vulkanskoga stakla, koji se potom podvrgavaju geokemijskoj analizi, a specifičan horizont depozicije određuje se na temelju vertikalne koncentracije stakla.[68] Depozicija tefre može se sigurno datirati u vrijeme određene erupcije samo ako se pokaže da nije došlo do naknadne pretaložbe, a za procjenu stupnja tafonomskih poremećaja, osim distribucije čestica stakla,[69] upotrebljavaju se i mikroskopske karakteristike čestica.[70]

Na prostoru srednje i jugoistočne Europe detektiran je niz važnih (kripto)tefri iz razdoblja gornjega pleistocena,[71] čiji bi se ostatci stoga mogli potencijalno detektirati u naslagama iz Vindije. Na taj način moguće je dobiti bolji uvid u starost pojedinih naslaga i vremenski raspored njihove depozicije pomoću stratigrafskoga slijeda nalazišta. Osim toga, horizonti tefre mogli bi dodatno poslužiti i za praćenje stratigrafskih jedinica koje se makroskopski ponekad teško razlikuju, a možda i poznavanje mikrotopografskih situacija u špilji tijekom gornjega pleistocena koji bi se mogli povezati s geomorfološkim procesima.

Uz kronološke analize, uzorkovanja su provedena i u svrhu rekonstrukcije paleookolišnih odnosa naslaga. Naime, posljednje revizije zastupljene faune u gornjemu dijelu stratigrafskoga slijeda pokazale su da nema značajnih razlika u klimatskim uvjetima među kompleksima E, F i G, odnosno da osim nekoliko glacijalno prilagođenih vrsta iz sloja E, općenito prevladavaju umjereni uvjeti s mješavinom otvorenih i šumskih okoliša.[72] Iako su ti podatci važni, oni su nešto niže rezolucije i gotovo u potpunosti predstavljaju podatke na razini kompleksa. Time otežavaju paleoklimatsku i kronološku korelaciju s glavnim klimatskim fazama gornjega pleistocena, istodobno potencijalno prikrivajući promjene na kraćim vremenskim relacijama, koje bi mogle biti vidljive među pojedinim slojevima.

Drevna DNA iz sedimenta (sedaDNA) postala je ključna metoda u proučavanju nekadašnjih ekosustava i ljudskih aktivnosti gdje skeletni materijal nije dostupan.[73] DNA očuvana u sedimentu potječe od različitih bioloških tvari kao što su izmet, urin, dlaka, stanice kože i mikroskopska kost ili fragment koprolita,

At the same time, volcanic ash that cannot be detected macroscopically but is present in deposits in the form of concentrations of small glass and crystal shards is called cryptotephra.[65] Cryptotephra represents (ultra)distal deposition of pyroclastic material, which in certain cases occurs thousands of kilometres away from the source eruption,[66] thereby enabling the identification of synchronous reference horizons across a wider geographic area.[67] Samples of cryptotephra for tephrochronological determination are extracted from sediment samples using microscopic techniques to isolate volcanic glass shards, which are then subjected to geochemical analysis, and the specific deposition horizon is determined on the basis of the vertical concentration of the glass.[68] The deposition of tephra can only be reliably dated to the time of a particular eruption if it can be shown that no subsequent redeposition has occurred, and to assess the degree of taphonomic disturbance, in addition to the distribution of glass particles,[69] microscopic characteristics of the particles are also used.[70]

In the region of Central and Southeastern Europe, a number of significant (crypto)tephras from the Upper Pleistocene have been identified,[71] the remnants of which could potentially be detected in the Vindija deposits. In this way, it is possible to gain better insight into the ages of individual deposits and the timing of their deposition throughout the site's stratigraphic sequence. Additionally, tephra horizons could further aid in tracking stratigraphic units that are sometimes difficult to distinguish macroscopically, and perhaps also in understanding microtopographic conditions within the cave during the Upper Pleistocene, which may be linked to geomorphological processes.

In addition to chronological analysis, sampling was also carried out for the purpose of reconstructing the palaeoenvironmental conditions of the deposits. Recent revisions of the faunal remains from the upper part of the stratigraphic sequence have shown that there are no significant climatic differences among complexes E, F and G. Aside from a few glacially-adapted species from layer E, temperate conditions generally prevail, with a mix of open and forested environments.[72] Although these data are important, they are of relatively low resolution and are almost entirely limited to the level of sedimentary complexes. This complicates palaeoclimatic and chronological correlations with the major climatic phases of the Upper Pleistocene and potentially obscures short-term environmental changes that might be detectable between individual layers.

65 Lowe 2011; Alloway *et al.* 2013.
66 Smith, Albert 2023.
67 Lane *et al.* 2014.
68 Lane *et al.* 2014; Smith, Albert 2023.
69 Lane *et al.* 2014; Smith, Albert 2023.
70 Lowe 2011.
71 Blockley *et al.* 2014; Lane *et al.* 2014.
72 Miracle, Mauch Lenardić, Brajković 2010.
73 Willerslev *et al.* 2003; Slon *et al.* 2017.

65 Lowe 2011; Alloway *et al.* 2013.
66 Smith, Albert 2023.
67 Lane *et al.* 2014.
68 Lane *et al.* 2014; Smith, Albert 2023.
69 Lane *et al.* 2014; Smith, Albert 2023.
70 Lowe 2011.
71 Blockley *et al.* 2014; Lane *et al.* 2014.
72 Miracle, Mauch Lenardić, Brajković 2010.

koje postaju inkorporirane u matriks sedimenta i adsorbirane na površine minerala.[74] Kada se jednom zaštite na taj način, čak i kratke i oštećene molekule mogu se očuvati desetcima tisuća godina.[75] Kako bi se taj materijal prikupio, uzorci sedimenta prikupljaju se tijekom iskopavanja u uvjetima kontrole kontaminacije, sterilnim oruđem i strategijom koja je usmjerena na stratigrafiju neporemećenih profila.[76] Uzorkovanjem slojeva u slijedu dobiva se vremenski okvir za otkrivanje genetskih signala, zajedno s arheološkim i paleookolišnim kontekstom.[77] U laboratoriju se DNA ekstrahira s protokolima na bazi silicija, koji su optimizirani za vrlo fragmentirane molekule,[78] a zatim se pretvara u knjižnice sekvenciranja te, ovisno o istraživačkome pitanju, analizira metodom nasumičnoga sekvenciranja, metabarkodiranja ili pristupima ciljanoga obogaćivanja.[79] Zajedno, te metode omogućuju otkrivanje ljudske prisutnosti, raznolikosti faune i okolišne promjene izravno iz sedimenata.[80]

Naposljetku, uzorkovanja za geoarheološke i mikromorfološke analize, osim pružanja paleookolišnih podataka, imaju potencijal doprinijeti boljemu razumijevanju depozicijskih i postdepozicijskih uvjeta u Vindiji tijekom gornjega pleistocena. Naime, već su asocijacije neandertalskih fosila i gornjopaleolitičkih izrađevina u istim slojevima kod nekih autora izazvale sumnju u stratigrafski integritet nalazišta,[81] a Malez i Rukavina upućivali su na postojanje krioturbacijskih poremećaja u početnome dijelu špilje koji su zahvatili slojeve od E do J.[82] Bruner je sastavljanjem litičkih izrađevina izravno pokazala da je došlo do miješanja slojeva.[83] Međutim, krioturbacijske pojave nisu postojale u svim dijelovima špilje,[84] a postotak sastavljenih artefakata mali je s obzirom na njihov ukupni broj,[85] što upućuje na neporemećenost slojeva u određenim dijelovima nalazišta. Ipak, opservacije proizašle iz tih istraživanja, uključujući i novu reviziju geoarheologije špilje, upućuju na kompleksne odnose depozicijskih i erozijskih procesa u formiranju danas očuvanih naslaga, čijim bi se dubljim razumijevanjem stratigrafski integriteti skupova nalaza mogli znatno bolje procijeniti.

74 Slon *et al.* 2017; Massilani *et al.* 2022.

75 Dabney, Meyer, Pääbo 2013.

76 Slon *et al.* 2017; Masilani *et al.* 2022.

77 Willerslev *et al.* 2003; Slon *et al.* 2017.

78 Dabney, Meyer, Pääbo 2013.

79 Willerslav *et al.* 2003; Gelabert *et al.* 2021.

80 Willerslev *et al.* 2003; Slon *et al.* 2017; Gelabert *et al.* 2021.

81 Kozlowski 1996; Zilhão, d'Errico 1999a; 1999b; Zilhão 2009; cf. Karavanić, Smith 2000.

82 Malez, Rukavina 1975.

83 Bruner 2009.

84 Karavanić, Smith 1998.

85 Smith *et al.* 2024.

Sedimentary ancient DNA (sedaDNA) has become a key method to investigate past ecosystems and human activity where skeletal material is not available.[73] The DNA preserved in sediment originates from various biological materials, such as faeces, urine, hair, skin cells, microscopic bone, or coprolite fragments, which become incorporated into the sediment matrix and adsorbed onto mineral surfaces.[74] Once protected in this way, even short and damaged molecules can survive for tens of thousands of years.[75] To recover this material, sediment samples are collected during excavation under contamination-controlled conditions, with sterile tools and a strategy that targets undisturbed interior sections of stratigraphic layers.[76] Sampling across successive layers provides a chronological framework for detecting genetic signals, in relation to the archaeological and palaeoenvironmental context.[77] In the laboratory, DNA is extracted using silica-based protocols optimized for highly fragmented molecules,[78] converted into sequencing libraries, and subsequently analysed by shotgun sequencing, metabarcoding or targeted enrichment approaches, depending on the research question.[79] Together, these methods enable the detection of human presence, faunal diversity and environmental change directly from the sediment record.[80]

Finally, geoarchaeological and micromorphological sampling, in addition to providing palaeoenvironmental data, has the potential to contribute to a better understanding of depositional and postdepositional conditions in Vindija during the Upper Pleistocene. Associations of Neandertal fossils and Upper Palaeolithic artefacts within the same layers have already led some researchers to question the site's stratigraphic integrity.[81] Malez and Rukavina point out the presence of cryoturbation disturbances in the cave's entrance area, affecting layers E to J.[82] Bruner, through refitting of lithic artefacts, demonstrates directly that mixing of layers had occurred.[83] However, cryoturbation structures were not present throughout the cave,[84] and the percentage of refitted artefacts was small relative to the total number,[85] indicating a lack of disturbance in certain parts of the site. Nevertheless, observations from these investigations, including the current revision of the cave's geoarchaeology, point to complex relationships between depositional and erosional processes in the formation of the preserved deposits, and a deeper understanding of these processes could allow for a much more accurate assessment of the stratigraphic integrity of the assemblages.

73 Willerslev *et al.* 2003; Slon *et al.* 2017.

74 Slon *et al.* 2017; Massilani *et al.* 2022.

75 Dabney, Meyer, Pääbo 2013.

76 Slon *et al.* 2017; Masilani *et al.* 2022.

77 Willerslev *et al.* 2003; Slon *et al.* 2017.

78 Dabney, Meyer, Pääbo 2013.

79 Willerslev *et al.* 2003; Gelabert *et al.* 2021.

80 Willerslev *et al.* 2003; Slon *et al.* 2017; Gelabert *et al.* 2021.

81 Kozlowski 1996; Zilhão, d'Errico 1999a; 1999b Zilhão 2009; cf. Karavanić, Smith 2000.

82 Malez, Rukavina 1975.

83 Bruner 2009.

84 Karavanić, Smith 1998.

85 Smith *et al.* 2024

Zaključak

Tijekom opsegom iznimno ograničenoga iskopavanja i uzorkovanja središnjega dijela profila 3 špilje Vindije, provedenoga 2023., korištena je standardna metodologija iskopavanja paleolitičkih nalazišta uz bilježenje individualnih nalaza, prosijavanje sedimenata i uzorkovanje u skladu s utvrđenim stratigrafskim slijedom nalazišta.

Tijekom iskopavanja dokumentirano je 18 stratigrafskih jedinica te dodatnih 12 slojeva koji nisu iskopavani, nego su razdvojeni na temelju vidljivih promjena. Istodobno su primijećene i brojne tvorevine koje upućuju na određene depozicijske uvjete u špilji tijekom dijela gornjega pleistocena. Dio novodefiniranih naslaga bilo je moguće izravno korelirati s kronostratigrafskom shemom izrađenom nakon istraživanja iz 1970-ih i 1980-ih godina, a pojedini dijelovi stratigrafskoga slijeda uvjetno su korelirani na temelju stratigrafskoga odnosa s pouzdano koreliranim stratigrafskim jedinicama. Tijekom iskopavanja prikupljeni su mnogobrojni uzorci za različite vrste analiza koje mogu doprinijeti daljnjemu razjašnjenju procesa nastanka pojedinih slojeva i rekonstrukciji djelovanja depozicijskih i postdepozicijskih procesa, zatim pružiti nove podatke o starosti naslaga i nalaza te omogućiti nove rekonstrukcije okoliša. Kumulativno, ti podatci pokazuju da postoji potencijal za dodatne razrade prije definiranoga stratigrafskog slijeda, bolje razumijevanje kronologije deponiranja naslaga iz gornjega pleistocena te nadopunjavanje podataka dobivenih klasičnom arheozoološkom i paleontološkom analizom. Time ta istraživanja daju primjer integracije uzorkovanja, provedenih u svrhu rješavanja dugotrajnih istraživačkih pitanja, s realnim potrebama i ograničenjima koja čine sastavni dio zaštitnih iskopavanja, posebno u kontekstu istraživanja iznimno ograničenoga opsega.

Naposljetku je važno istaknuti da je nakon završetka iskopavanja južna strana profila 3 zaštićena od osipanja i devastacija postavljanjem geotekstila i drvenih potpornja. Ipak, ostali profili i ostatci naslaga u špilji Vindiji i dalje su izloženi procesima trošenja, te je nužno što prije definirati prikladna rješenja zaštite i konzervacije toga neprocjenjivog arheološkog, paleontološkog i paleookolišnog zapisa.

Conclusion

During the spatially highly limited excavation and sampling of the central section of profile 3 in Vindija Cave, conducted in 2023, standard methodology for the excavation of Palaeolithic sites was employed. This included the recording of individual finds, sediment sieving, and sampling in accordance with the established stratigraphic sequence of the site.

During the excavation, 18 stratigraphic units were documented, along with an additional 12 layers that were not excavated but were distinguished on the basis of visible changes. At the same time, numerous features were observed that indicate specific depositional conditions in the cave during parts of the Upper Pleistocene. Some of the newly-defined deposits could be directly correlated with the chronostratigraphic scheme developed following excavations in the 1970s and 1980s, while certain parts of the stratigraphic sequence were conditionally correlated on the basis of their stratigraphic relationship with reliably correlated units. A large number of samples were collected during the excavation for various types of analysis, which may contribute to further clarification of the formation processes of individual layers and the reconstruction of depositional and postdepositional processes, as well as provide new data on the ages of the deposits and finds and enable new environmental reconstructions. Collectively, these data indicate the potential for further refinement of the previously-defined stratigraphic sequence, a better understanding of the chronology of Upper Pleistocene deposits, and the broadening of data obtained through classical archaeozoological and palaeontological analysis. In this way, the research serves as an example of integrating sampling strategies aimed at addressing long-standing research questions with the practical needs and constraints that are an inherent part of rescue excavations, particularly in the context of investigations of extremely limited scope.

Finally, it is important to highlight that, following the excavation, the southern side of profile 3 was protected from erosion and damage by the installation of geotextile and wooden supports. However, other profiles and remaining deposits at the Vindija cave remain exposed to degradation processes, making it essential to urgently define appropriate protection and conservation measures for this invaluable archaeological, palaeontological and palaeoenvironmental record.

Translated from Croatian by M. Banda.

ZAHVALE
ACKNOWLEDGEMENTS

Autori rada zahvaljuju suradnicima i studentima koji su sudjelovali u terenskom istraživanju, kao i Općini Donja Voća na pruženoj podršci. Posebne zahvale duguju Robertu Vazdaru na izradi drvene skele, bez koje provedba istraživanja ne bi bila moguća. Zahvaljuju i Hrvatskom geološkom institutu na izradi 3D modela unutrašnjosti špilje i profila 3, Dinku Tresiću Pavičiću na izradi karte priložene radu te posebno Jurici Jagetiću iz SU „Kraševski zviri“ na geodetskoj potpori i nacrtu špilje koji je poslužio kao podloga za Sliku 1. Naposljetku, zahvaljuju i svim članovima SU „Kraševski zviri" iz Ivanca na logističkoj podršci prije i tijekom iskopavanja, kao i na njihovoj kontinuiranoj i entuzijastičnoj potpori arheološkim istraživanjima kroz aktivan speleološki istraživački rad na području Varaždinske županije.

The authors would like to thank the collaborators and students who participated in the field research, as well as the Donja Voća Municipality for the provided support. They owe special thanks to Robert Vazdar for constructing the wooden scaffolding, without which the research could not have been carried out. They also thank the Croatian Geological Survey for producing the 3D models of the cave interior and Profile 3, Dinko Tresić Pavičić for preparing the map included in the paper, and especially Jurica Jagetić from the Speleological Association “Kraševski zviri” for the geodetic support and for the cave drawings that served as the basis for Figure 1. Finally, they thank all members of the Speleological Association “Kraševski zviri” from Ivanec for logistical support before and during the excavation, as well as for their continuous and enthusiastic support of archaeological research through active speleological fieldwork in the Varaždin County area.

KRATICE
ABBREVIATIONS

NACSN 2005 – North American Commission on Stratigraphic Nomenclature, North American Stratigraphic Code, *American Association of Petroleum Geology Bulletin* 89, 2005, 1547–1591.

Bronk Ramsey 2021 – C. Bronk Ramsey, OxCal v4.4.4, 2021, https://c14.arch.ox.ac.uk/oxcal.html, (15 September 2025).

BIBLIOGRAFIJA
BIBLIOGRAPHY

Ahern *et al.* 2004 – J. C. Ahern, I. Karavanić, M. Paunović, I. Janković, F. H. Smith, New discoveries and interpretations of hominid fossils and artifacts from Vindija Cave, Croatia, *Journal of Human Evolution* 46/1, 2004, 27–67.

Alloway *et al.* 2013 – B. V. Alloway, D. J. Lowe, G. Larsen, P. A. R. Shane, J. A. Westgate, Tephrochronology, in Elias, S. A. (ed.), *The Encyclopedia of Quaternary Science* 4, Elsevier, 2013, 277 –304.

Blockley *et al.* 2014 – S. P. E. Blockley, A. J. Bourne, A. Brauer, S. M. Davies, M. Hardiman, P. R. Harding, C. S. Lane, A. Macleod, I. P. Matthews, S. D. F. Pyne-O’Donnell, S. O. Rasmussen, S. Wulf, G. Zanchetta, Tephrochronology and the extended intimate (integration of ice-core, marine and terrestrial records) event stratigraphy 8–128 ka b2k, *Quaternary Science Reviews* 106, 2014, 88–100.

Bruner 2009 – K. M. Bruner, *Testing Stratigraphic Integrity of Upper and Middle Paleolithic Deposits in Vindija Cave (Croatia): A Chipped Stone Refitting Analysis*, unpublished MA thesis, University of Kansas, 2009.

Catt 1990 – J. A. Catt, Paleopedology manual, *Quaternary International* 6, 1990, 2–95.

Dabney, Meyer, Pääbo 2013 – J. Dabney, M. Meyer, S. Pääbo, Ancient DNA damage, *Proceedings of the National Academy of Sciences* 110/44, 2013, 22261–22265.

Devièse *et al.* 2017 – T. Devièse, I. Karavanić, D. Comeskey, C. Kubiak, P. Korlević, M. Hajdinjak, S. Radović, N. Procopio, M. Buckley, S. Pääbo, T. Higham, Direct dating of Neanderthal remains from the site of Vindija Cave and implications for the Middle to Upper Paleolithic transition, *Proceedings of the National Academy of Sciences* 114/40, 2017, 10606–10611.

Gelabert *et al.* 2021 – P. Gelabert, S. Sawyer, A. Bergström, A. Margaryan, T. C. Collin, T. Meshveliani, A. Belfer-Cohen, D. Lordkipanidze, N. Jakeli, Z. Matskevich, G. Bar-Oz, D. M. Fernandes, O. Cheronet, K. T. Özdoğan, V. Oberreiter, R. N. M. Feeney, M. C. Stahlschmidt, P. Skoglund, R. Pinhasi, Genome-scale sequencing and analysis of human, wolf, and bison DNA from 25,000-year-old sediment, *Current Biology* 31/16, 2021, 3564–3574.e9.

Green *et al.* 2010 – R. E. Green, J. Krause, A. W. Briggs, T. Maricic, U. Stenzel, M. Kircher, N. Patterson, H. Li, W. Zhai, M. Hsi-Yang Fritz, N. F. Hansen, E. Y. Durand, A.-S. Malaspinas, J. D. Jensen, T. Marques-Bonet, C. Alkan, K. Prüfer, M. Meyer, H. A. Burbano, J. M. Good, R. Schultz, A. Aximu-Petri, A. Butthof, B. Höber, B. Höffner, M. Siegemund, A. Weihmann, C. Nusbaum, E. S. Lander, C. Russ., N. Novod, J. Affourtit, M. Egholm, C. Verna, P. Rudan, D. Brajkovic, Ž. Kucan, I. Gušic, V. B. Doronichev, L. V. Golovanova, C. Lalueza-Fox, M. de la Rasilla, J. Fortea, A. Rosas, R. W. Schmitz, P. L. F. Johnson, E. E. Eichler, D. Falush, E. Birney, J. C. Mullikin, M. Slatkin, R. Nielsen, J. Kelso, M. Lachmann, D. Reich, S. Pääbo, A draft sequence of the Neandertal genome, *Science* 328/5979, 2010, 710–722.

Grün *et al.* 2014 – R. Grün, S. Eggins, L. Kinsley, H. Moseley, M. Sambridge, Laser ablation U-series analysis of fossil bones and teeth, *Palaeogeography, Palaeoclimatology, Palaeoecology* 416, 2014, 150–167.

Higham *et al.* 2006 – T. Higham, C. B. Ramsey, I. Karavanić, F. H. Smith, E. Trinkaus, Revised direct radiocarbon dating of the Vindija G1 Upper Paleolithic Neandertals, *Proceedings of the National Academy of Sciences* 103, 2006, 553–557.

Karavanić, Smith 1998 – I. Karavanić, F. H. Smith, The Middle/Upper Paleolithic interface and the relationship of Neanderthals and early modern humans in the Hrvatsko Zagorje, Croatia, *Journal of Human Evolution* 34/3, 1998, 223–248.

Karavanić, Smith 2000 – I. Karavanić, F. H. Smith, More on the Neandertal problem: The Vindija case, *Current Anthropology* 41, 2000, 838–840.

Karavanić, Smith 2013 – I. Karavanić, F. H. Smith, Alternative interpretations of the Middle/Upper Paleolithic interface at Vindija Cave (northwestern Croatia) in the context of central Europe and the Adriatic, *Archaeology, Ethnology and Anthropology of Eurasia* 41/4, 2013, 11–20.

Karavanić *et al.* 2021 – I. Karavanić, J. Hellstrom, G. Rabeder, N. Vukosavljević, M. Banda, F. H. Smith, New U-Th dates from Vindija, Velika pećina (Kličevica) and Mujina pećina and their implications for chronology of the Middle Paleolithic in Croatia, *Collegium antropologicum* 45/1, 2021, 1–10.

Karavanić *et al.* 2024 – I. Karavanić, I. K. Bronić, A. Sironić, S. Radović, M. Banda, F. H. Smith, Chronology of hominin activity at Vindija Cave, Croatia: new dates recorded via standard and ultrafiltration AMS, *Antiquity* 98/398, 2024, e7.

Kozlowski 1996 – J. K. Kozlowski, Cultural context of the last Neanderthals and early Modern Humans in Central-Eastern Europe, in Bar-Yosef, O., Cavalli-Sforza, L. L., March, R. J., Piperno, M. (eds.), *Proceedings of the XIII UISPP Congress, The Lower and the Middle Palaeolithic* 5, Abaco, 1996, 205–218.

Lane *et al.* 2014 – C. S. Lane, V. L. Cullen, D. White, C. W. F. Bramham-Law, V. C. Smith, Cryptotephra as a dating and correlation tool in archaeology, *Journal of Archaeological Science* 42, 2014, 42–50.

Lane *et al.* 2017 – C. S. Lane, D. J. Lowe, S. P. E. Blockley, T. Suzuki, V. C. Smith, Advancing tephrochronology as a global dating tool: Applications in volcanology, archaeology, and palaeoclimatology, *Quaternary Geochronology* 40, 2017, 1–7.

Lisiecki, Raymo 2005 – L. E. Lisiecki, M. E. Raymo, A Pliocene-Pleistocene stack of 57 globally distributed benthic δ18O records, *Paleoceanography* 20/1, 2005, PA1003.

Lowe 2011 – D. J. Lowe, Tephrochronology and its application: A review, *Quaternary Geochronology* 6/2, 2011, 107–153.

Malez 1975 – M. Malez, Die Höhle Vindija – eine neue Fundstelle fossiler Hominiden in Kroatien, *Bulletin scientifique du Conseil des académies des sciences de la RSF de Yougoslavie* A 20/5–6, 1975, 139–141.

Malez 1988 – M. Malez, Prethistorijske koštane rukotvorine iz spilje Vindije (Hrvatska, Jugoslavija), *Radovi Zavoda za znanstveni rad Jugoslavenske akademije znanosti i umjetnosti* 2, 1988, 217–252.

Malez, Rukavina 1975 – M. Malez, D. Rukavina, Krioturbacijske pojave u gornjopleistocenskim naslagama pećine Vindije kod Donje Voće u sjeverozapadnoj Hrvatskoj, *Rad Jugoslavenske akademije znanosti i umjetnosti* 371/17, 1975, 245–265.

Malez, Rukavina 1979 – M. Malez, D. Rukavina, Položaj naslaga spilje Vindije u sustavu članjenja kvartara šireg područja Alpa, *Rad Jugoslavenske akademije znanosti i umjetnosti* 383/18, 1979, 187–218.

Malez, Šimunić, Šimunić 1984 – M. Malez, A. Šimunić, A. Šimunić, Geološki, sedimentološki i paleoklimatski odnosi spilje Vindije i bliže okolice, *Rad Jugoslavenske akademije znanosti i umjetnosti* 411, 1984, 231–264.

Mallol, Goldberg 2017 – C. Mallol, P. Goldberg, Cave and Rockshelter Sediments, in Nicosia, C., Stoops, G. (eds.), *Archaeological Soil and Sediment Micromorphology*, Wiley Blackwell, 2017, 359–381.

Massilani *et al.* 2022 – D. Massilani, M. W. Morley, S. M. Mentzer, V. Aldeias, B. Vernot, B. C. Miller, M. Stahlschmidt, M. B. Kozlikin, M. V. Shunkov, A. P. Derevianko, N. J. Conard, S. Wurz, C. S. Henshilwood, J. Vasquez, E. Essel, S. Nagel, J. Richter, B. Nickel, R. G. Roberts, S. Pääbo, V. Slon, P. Goldberg, M. Meyer, Microstratigraphic preservation of ancient faunal and hominin DNA in Pleistocene cave sediments, *Proceedings of the National Academy of Sciences* 119/1, 2022, e2113666118.

Miracle, Mauch Lenardić, Brajković 2010 – P. T. Miracle, J. Mauch Lenardić, D. Brajković, Last Glacial Climates, “Refugia”, and Faunal Change in Southeastern Europe: Mammalian Assemblages from Veternica, Velika pećina, and Vindija Caves (Croatia), *Quaternary international* 212, 2010 137–148.

Munsell Color Co. 1992 – Munsell Color Co., Inc., *Munsell Soil Color Charts*, revised ed., Munsell Color Co., Inc., 1992.

Obelić *et al.* 1994 – B. Obelić, N. Horvatinčić, D. Srdoč, I. Krajcar Bronić, A. Sliepčević, S. Grgić, Rudjer Bošković Institute radiocarbon measurements XIII, *Radiocarbon* 36/2, 1994, 303–324.

Patou-Mathis, Karavanić, Smith 2018 – M. Patou-Mathis, I. Karavanić, F. H. Smith, The evidence from Vindija Cave (Croatia) reveals diversity of Neandertal behaviour in Europe, *Quaternary International* 494, 2018, 314–326.

Reimer *et al.* 2020 – P. J. Reimer, W. E. N. Austin, E. Bard, A. Bayliss, P. G. Blackwell, C. Bronk Ramey, M. Butzin, H. Cheng, R. L. Edwards, M. Friedrich, P. M. Grootes, T. G. Guilderson, I. Hajdas, T. J. Heathon, A. G. Hogg, K. A. Hughen, B. Kromer, S. W. Manning, R. Muscheler, J. G. Palmer, C. Pearson, J. van der Plicht, R. W. Reimer, D. A. Richards, E. M. Scott, J. R. Southon, C. S. M. Turney, L. Wacker, F. Adolphi, U. Büntgen, M. Capano, S. M. Fahrni, A. Fogtmann-Schulz, R. Friedrich , P. Köhler, S. Kudsk , F. Miyake, J. Olsen, F. Reinig, M. Sakamoto, A. Sookdeo, S. Talamo, The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP), *Radiocarbon* 62/4, 2020, 725–757.

Rukavina 1983 – D. Rukavina, O stratigrafiji gornjeg pleistocena s osvrtom na topla razdoblja i njihov odraz u naslagama na području Jugoslavije, *Rad Jugoslavenske akademije znanosti i umjetnosti* 404, 1983, 199–221.

Slon *et al.* 2017 – V. Slon, C. Hopfe, C. L. Weiß, F. Mafessoni, M. de la Rasilla, C. Lalueza-Fox, A. Rosas, M. Soressi, M. V. Knul, R. Miller, J. R. Stewart, A. P. Derevianko, Z. Jacobs, B. Li, R. G. Roberts, M. V. Shunkov, H. de Lumley, C. Perrenoud, I. Gušić, Ž. Kućan, P. Rudan, A. Aximu-Petri, E. Essel, S. Nagel, B. Nickel, A. Schmidt, K. Prüfer, J. Kelso, H. A. Burbano, S. Pääbo, M. Meyer, Neandertal and Denisovan DNA from Pleistocene sediments, *Science* 356/6338, 2017, 605–608.

Smith, Albert 2023 – V. C. Smith, P. G. Albert, An introduction to tephrochronology and the correlation of sedimentary sequences using volcanic ash layers, in Pollard, M., Armitage, R. A., Makarewicz, C. A. (eds.), *Handbook of Archaeological Sciences*, John Wiley & Sons, 2023, 133–149.

Smith, Boyd, Malez 1985 – F. Smith, D. D. Boyd, M. Malez, M., Additional upper Pleistocene human remains from Vindija cave, Croatia, Yugoslavia, *American Journal of Physical Anthropology* 68/3, 1985, 375–383.

Smith, Janković, Karavanić 2005 – F. H. Smith, I. Janković, I. Karavanić, The assimilation model, modern human origins in Europe, and the extinction of Neandertals, *Quaternary International* 137/1, 2005, 7–19.

Smith *et al.* 2024 – F. H. Smith, I. Karavanić, I. Janković, J. Mauch Lenardić, S. Radović, *Vindija cave: A late Neandertal site in northern Croatia*, Faculty of Humanities and Social Sciences, University of Zagreb, 2024.

Srdoč *et al.* 1979 – D. Srdoč, A. Sliepčević, B. Obelić, N. Horvatinčić, Rudjer Bošković Institute Radiocarbon Measurements V, *Radiocarbon* 21/1, 1979, 131–137.

Srdoč *et al.* 1984 – D. Srdoč, N. Horvatinčić, I. Krajcar, A. Sliepčević, Rudjer Bošković Institute Radiocarbon Measurements VIII, *Radiocarbon* 26/3, 1984, 131–137.

Vuković 1935 – S. Vuković, Istraživanje prethistorijskog nalazišta spilje Vindije kod Voće, in *Spomenica Varaždinskog muzeja 1925 – 1935*, Gradski muzej Varaždin, Hrvatska akademija znanosti i umjetnosti, Zavod za znanstveni rad u Varaždinu, 1935, 73–80.

Vuković 1949 – S. Vuković, Prethistorijsko nalazište spilje Vindije, *Historijski zbornik* 2, 1949, 243–249.

Vuković 1950 – S. Vuković, Paleolitska kamena industrija spilje Vindije, *Historijski zbornik* 3, 1950, 241–256.

Wild *et al.* 2001 – E. M. Wild, M. Paunovic, G. Rabeder, I. Steffan, P. Steier, Age determination of fossil bones from the Vindija Neanderthal site in Croatia, *Radiocarbon* 43/2B, 2001, 1021–1028.

Willerslev *et al.* 2003 – E. Willerslev, A. J. Hansen, J. Binladen, T. B. Brand, M. T. P. Gilbert, B. Shapiro, M. Bunce, C. Wiuf, D. A. Gilichinsky, A. Cooper, Diverse plant and animal genetic records from Holocene and Pleistocene sediments, *Science* 300/5620, 2003, 791–795.

Wolpoff *et al.* 1981 – M. H. Wolpoff, F. H., Smith, M. Malez, J. Radovčić, D. Rukavina, Upper pleistocene human remains from Vindija cave, Croatia, Yugoslavia, *American Journal of Physical Anthropology* 54/4, 1981, 499–545.

Zilhão 2009 – J. Zilhão, Szeletian, not Aurignacian: A review of the chronology and cultural associations of the Vindija G1 Neandertals, in Camps, M., Chauhan, P. (eds.), *Sourcebook of Paleolithic Transitions: Methods, Theories, and Interpretations*, Springer, 2009, 407–426.

Zilhão, d’Errico 1999a – J. Zilhão, F. d’Errico, The chronology and taphonomy of the earliest Aurignacian and its implications for the understanding of Neandertal extinction, *Journal of World Prehistory* 13/1, 1999, 1–68.

Zilhão, d’Errico 1999b – J. Zilhão, F. d’Errico, The Neanderthal problem continued: Reply, *Current Anthropology* 40, 1999, 355–364.