

# An Anthropological Interpretation of the Subterranean Ravne Tunnel System (Central Bosnia)

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## Abstract

The subterranean Ravne tunnel system in central Bosnia contains a dense concentration of architectural features, artifacts, and environmental conditions that point to sustained human activity underground. Archaeological documentation, spatial mapping, stratigraphic observations, and recently published environmental studies are combined to examine how these tunnels were shaped, used, and modified over time. Dry-stone walls, blocked passages, shifts in tunnel direction, and water-bearing sections indicate deliberate organization of space rather than accidental or short-term use. Artifacts recovered from within the tunnels, including tools and organic material, provide direct evidence of repeated human presence and activity. Stable microclimatic conditions and the presence of structured subterranean water are considered as part of a broader human-environment relationship. The Ravne system is interpreted here as a managed subterranean landscape with clear cultural and behavioral significance.

## Keywords

Anthropological Interpretation, Subterranean Archaeology, Ravne Tunnels, Human Behavior, Cultural Landscape

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## 1. Introduction

Subterranean spaces have played varied roles in human history, serving at different times as shelters, ritual settings, storage areas, movement corridors, or managed components of wider cultural landscapes. While caves and underground structures are often approached as marginal or exceptional environments, archaeological research increasingly recognizes that such spaces were frequently integrated

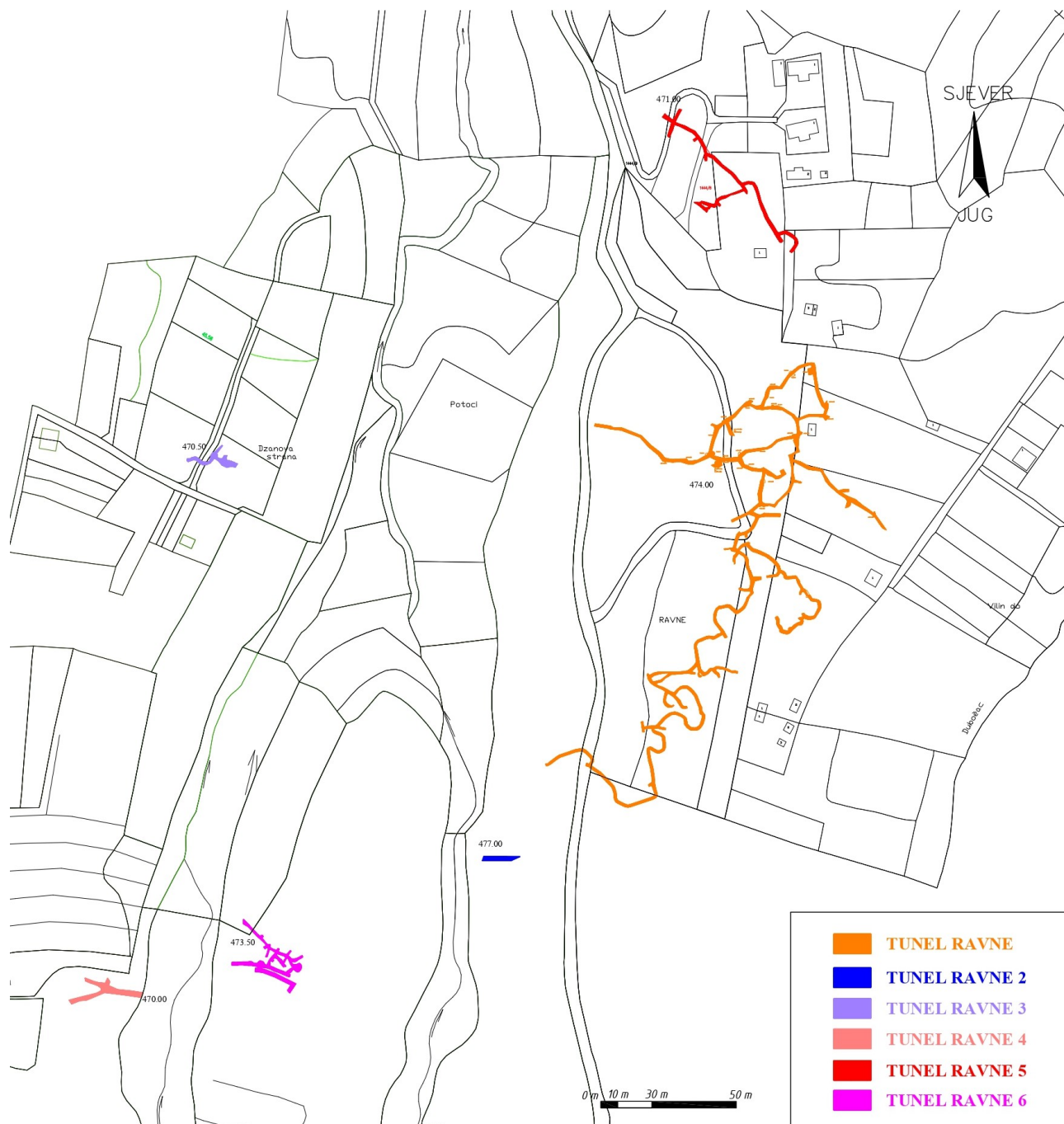
into long-term patterns of human behavior. The Ravne tunnel system in central Bosnia represents one such case, in which the scale, internal organization, and preserved material evidence underground invite closer anthropological examination.

Located near the town of Visoko (**Figure 1**), the Ravne tunnels form a branching network excavated within river pebble conglomerate beneath the Ravne Valley (**Figure 2**). Systematic exploration and documentation conducted over the past decade have revealed a complex internal structure characterized by repeated directional changes, intersecting passages, and segments that appear deliberately modified or sealed. These features distinguish the Ravne system from short-lived mining works or natural cavities, suggesting sustained engagement with the underground environment.

One of the most prominent architectural elements documented within the tunnels is the widespread presence of dry-stone walls constructed from rounded river pebbles (**Figure 3** and **Figure 4**). These structures occur in multiple tunnel branches, including Ravne 3, Ravne 6, and the main Ravne corridor, and exhibit consistent construction techniques. Walls vary in size and configuration, from shorter blocking features that seal side passages to longer segments that extend



**Figure 1.** Geographic location of the Ravne tunnel system near Visoko, central Bosnia, shown in regional context.



**Figure 2.** Plan view of the subterranean Ravne tunnel system showing mapped passages and their spatial distribution beneath the Ravne Valley. Individual tunnel segments are indicated by color. Scale bar in meters.

along tunnel walls. Their repeated appearance across the system indicates a shared construction logic rather than isolated or ad hoc interventions.

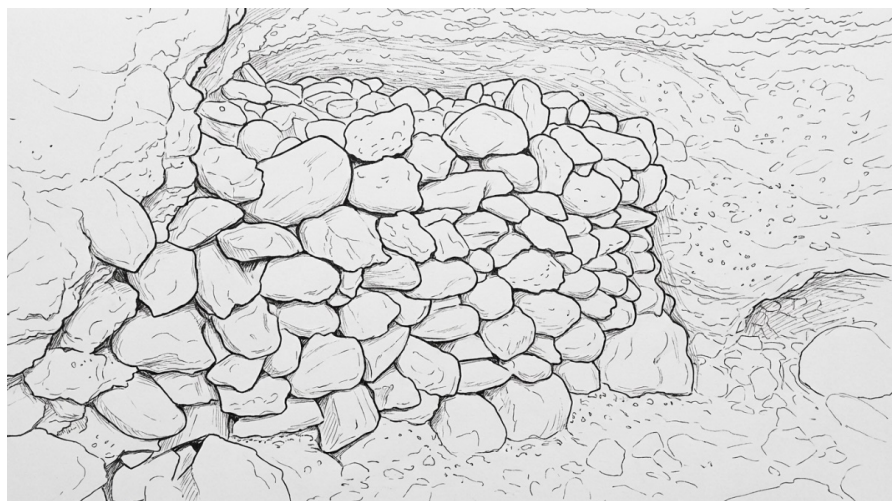
Spatial organization within the tunnels further reinforces this impression. Cleared intersections reveal branching points where passages meet at distinct angles and maintain stable cross-sectional profiles (Figure 5). Such intersections do not follow obvious geological fractures and are not randomly distributed; rather,

they suggest patterned movement and navigation within the subsurface. When considered alongside the placement of dry-stone walls, these features indicate intentional management of circulation and access.

Material culture recovered from within the tunnel fill provides additional evidence



(a)



(b)

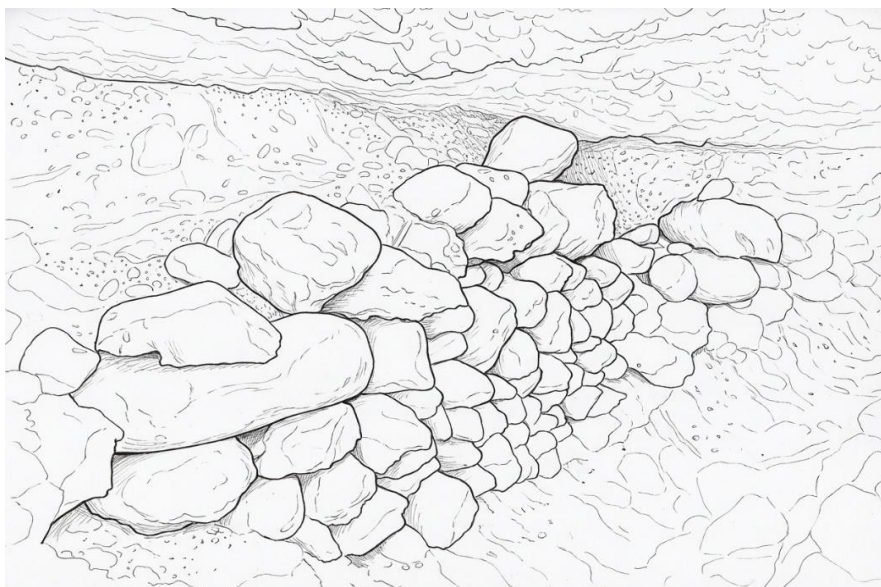
**Figure 3.** Dry-stone wall constructed from rounded river pebbles within the Ravne tunnel system (Ravne 6 tunnels). (a) Photograph of a dry-stone wall segment composed of stacked, water-worn pebbles and cobbles, documented during excavation works in the Ravne 6 tunnels. Measuring rods are used to indicate scale and orientation within the tunnel profile. (b) Profile drawing of the corresponding dry-stone wall structure from the Ravne 6 tunnels, illustrating the organized arrangement of rounded pebbles forming a constructed wall segment embedded within the surrounding conglomerate matrix. Individual stone elements, wall geometry, and stratigraphic context are represented schematically.

for repeated human presence. Artifacts documented to date include fragments of Roman building material, ceramic assemblages spanning multiple chronological periods, and organic objects preserved within the sedimentary fill (**Figure 6**). Although many of these finds occur in secondary contexts, their distribution across different tunnel branches and stratigraphic units indicates that human activity within the Ravne system was not limited to a single episode or period.

Stratigraphic observations further support this interpretation. Excavation profiles from Ravne 3 reveal sharply defined fill deposits intruding into consolidated conglomerate, as well as constructed walls sealed behind rubble backfill (**Figure 7**).



(a)



(b)



(c)

**Figure 4.** Dry-stone wall constructed from rounded river pebbles within the Ravne tunnel system. (a) Photograph of a ca. 5 m long dry-stone wall (S9) documented in the Ravne 6 tunnel. (b) Drawing of dry-stone wall no. 9 showing construction detail and stone arrangement. (c) Dry-stone wall constructed from rounded river pebbles in the Ravne tunnel. The wall blocks a side passage and represents a typical example of the dry-stone walling technique documented throughout the Ravne tunnel system. Stones were carefully stacked without mortar in horizontal courses, with larger elements forming the base and smaller cobbles stabilizing upper sections. Similar walls are frequently associated with unconsolidated backfill material behind the constructed face.



**Figure 5.** Tunnel intersection within the Ravne tunnel system, view from the main corridor toward adjoining side passages. The image shows a characteristic branching point with intersecting passages and rounded arch-like profiles formed within compacted river pebble conglomerate. The walls and ceiling remain structurally stable without artificial reinforcement. The intersection has been cleared of fill material, allowing the geometry and orientation of passages to be observed.



(a)



(b)

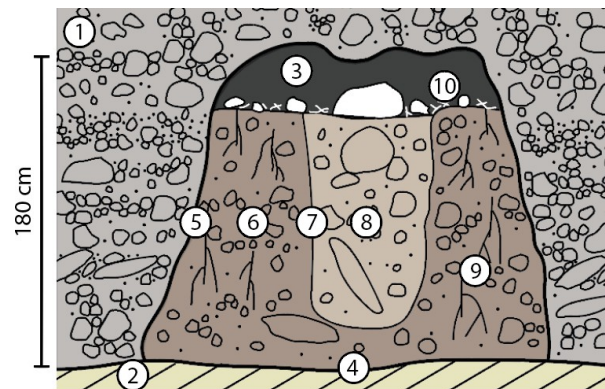


(c)

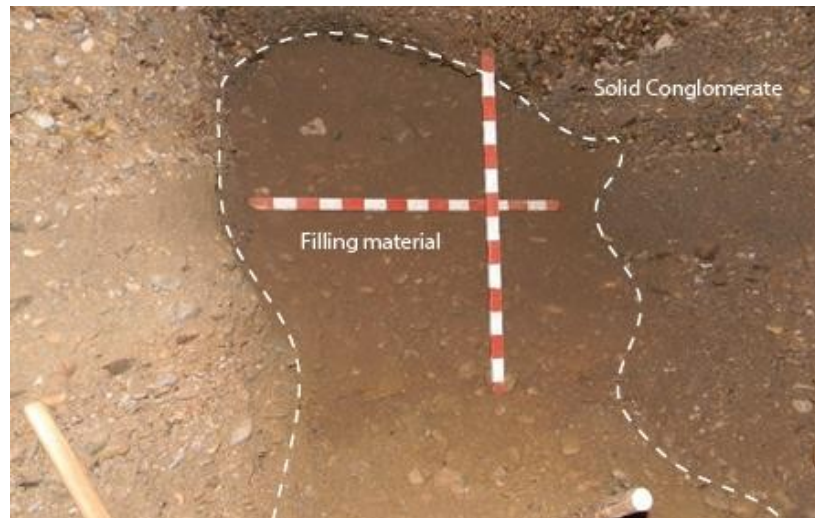
**Figure 6.** Artifacts recovered from the Ravne tunnel system. (a) Fragmented Roman tegula recovered from the Ravne 3 tunnel (2019). (b) Organic wooden object recovered in 2025 from tunnel fill within the Ravne 6 tunnel, documented in stratigraphic unit SJ 001 near a side passage; scale in centimeters. (c) Representative ceramic fragments recovered from the Ravne tunnel system during excavation campaigns between 2019 and 2024.



(a)



(b)

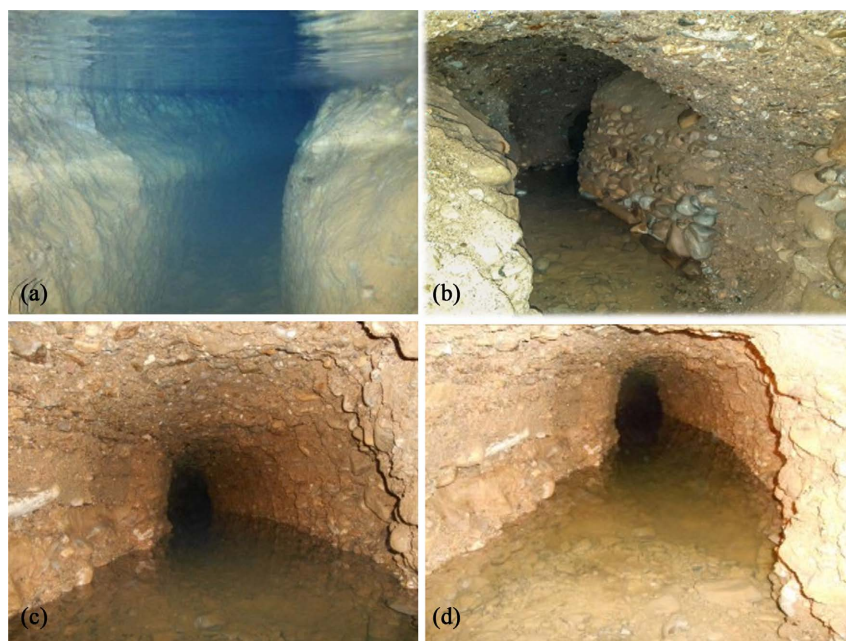


(c)

**Figure 7.** Stratigraphic context of dry-stone walls and tunnel infill within the Ravne 3 tunnel. (a) Photograph of the first documented dry-stone wall constructed from stacked river pebbles, uncovered in 2019 within compact tunnel fill. A calcified stone mass is visible to the left of the structure. (b) Cross-sectional drawing of dry-stone wall 1 showing its position relative to open tunnel space, rubble backfill, and surrounding Ravne conglomerate. (c) Excavation profile showing a sharply defined pocket of filling material intruding into consolidated conglomerate, distinguished by contrasting texture and boundary, with measuring rod indicating scale.

These relationships demonstrate sequences of excavation, construction, infilling, and subsequent modification, pointing to a dynamic history of use rather than a static or purely natural formation process.

Environmental conditions within the Ravne tunnels form an additional dimension of this anthropological context. Certain tunnel sections contain persistent water-bearing passages and partially submerged corridors, often in close association with constructed stone features (**Figure 8**). The stable presence of water within these subterranean spaces highlights a sustained human-environment relationship in which underground architecture, hydrology, and movement were closely intertwined.



**Figure 8.** Water-bearing sections of the Ravne tunnel system. (a) Dry-stone wall constructed along a water-bearing passage within the tunnel network. (b) Partially submerged tunnel corridor showing standing water within a pebble-lined passage. (c) Clear water channel within a conglomerate-lined tunnel section. (d) Water-filled tunnel corridor illustrating stable water presence within the subterranean environment.

Taken together, the architectural features, spatial organization, stratigraphic sequences, and material remains documented within the Ravne tunnel system suggest that it functioned as a managed subterranean landscape. Rather than approaching the tunnels as isolated anomalies, this study examines them as culturally shaped spaces whose form and modification reflect patterns of human behavior over extended periods. The following sections present the archaeological and environmental evidence in detail and situate the Ravne tunnels within a broader anthropological discussion of long-term underground space use.

## 2. Archaeological and Geological Context

The Ravne tunnel system is situated within the central Bosnian Valley near Visoko,

an area characterized by complex geological formations and a long record of human occupation. The tunnels are excavated primarily within a polymictic river pebble conglomerate, composed of rounded clasts of varying lithology bound within a sandy to silty matrix. This formation is mechanically stable yet workable, allowing for the creation of self-supporting subterranean spaces without the need for extensive artificial reinforcement.

Geodetic mapping indicates that more than 3 kilometers of tunnel passages have been cleared and documented to date, forming a branching underground network beneath the Ravne Valley (**Figure 2**).

Geological observations indicate that the conglomerate exhibits relatively uniform composition across the documented sections of the Ravne tunnels. Tunnel walls and ceilings preserve clear evidence of deliberate shaping, with rounded profiles and consistent cross-sections visible along extended segments. Natural fissures and bedding planes are present but do not appear to dictate tunnel orientation or passage layout, suggesting that excavation decisions were not driven solely by geological weaknesses.

From an archaeological perspective, the Ravne tunnels present a layered record shaped by both construction and subsequent modification. Excavation has revealed sequences in which open tunnel space is followed by the installation of dry-stone walls and the introduction of fill material, often composed of unconsolidated sediment distinct from the surrounding conglomerate. These fills frequently contain cultural material in a secondary context, including ceramics, building fragments, and organic remains, indicating repeated human interaction with the tunnels over time.

Dry-stone walls are among the most diagnostically significant features in this context. Constructed from locally available river pebbles and assembled without mortar, these walls vary in size, thickness, and placement. In some cases, walls fully block side passages, while in others they extend along tunnel flanks, functioning as retaining or stabilizing elements. Stratigraphic relationships indicate that many of these structures were constructed after initial tunnel excavation and subsequently sealed with rubble backfill, suggesting intentional phases of closure or reconfiguration.

The stratigraphy observed in Ravne 3 provides particularly clear evidence of these processes. Excavation profiles show sharply defined boundaries between consolidated conglomerate and softer infill deposits, as well as constructed walls embedded within these sequences. In certain areas, calcified stone masses and speleothem growth occur adjacent to built features, indicating prolonged periods of stability following construction and infilling events. Such relationships argue against rapid or accidental sediment accumulation and instead suggest controlled deposition and long-term abandonment or reuse.

Water-bearing sections of the tunnel system form an additional element of the archaeological and geological setting. Persistent standing or flowing water is documented in several corridors, often in association with dry-stone walls and shaped

tunnel margins. These hydrological conditions appear stable across seasons and are not accompanied by significant erosion or collapse, implying that water movement has been accommodated within the existing tunnel architecture rather than acting as a destructive force.

Taken together, the geological substrate and archaeological evidence indicate that the Ravne tunnels were excavated in a material well-suited to sustained underground construction and modification. The combination of stable conglomerate, repeated architectural interventions, and stratified infill sequences supports an interpretation of the tunnels as spaces that were actively managed and reshaped over extended periods, rather than as ephemeral or purely natural formations. This context provides the foundation for examining the architectural organization and behavioral implications of the Ravne tunnel system in greater detail.

### **3. Materials and Methods**

#### **3.1. Fieldwork Background and Scope**

Archaeological work in the Ravne underground tunnel system has been carried out continuously since 2005 under annually renewed excavation permits. The data discussed here derive primarily from controlled excavations in Ravne 3 and Ravne 6, with particular emphasis on the 2019-2025 field seasons. These investigations were conducted as part of long-term research programs coordinated by the Archaeological Park: Bosnian Pyramid of the Sun Foundation and documented through annual excavation reports and specialist studies.

The present paper draws on primary excavation records, stratigraphic documentation, architectural measurements, geodetic survey data, and laboratory results generated during these campaigns. Earlier excavation phases and comparative observations from other Ravne tunnels are used where relevant to clarify recurring patterns.

#### **3.2. Excavation Methods and Stratigraphic Recording**

All excavation within the Ravne tunnels was conducted manually. Mechanical equipment was not used due to limited space and the need to maintain stratigraphic control in confined underground conditions. Excavation focused on the gradual removal of unconsolidated tunnel fill, proceeding according to observable stratigraphic units rather than fixed depth levels.

Stratigraphic units were defined on the basis of sediment composition, grain size, compaction, color, and inclusions. Particular attention was paid to the boundary between unconsolidated fill and the surrounding lithified conglomerate. These interfaces were treated as key stratigraphic markers, as they frequently correspond to phases of intentional infilling or tunnel modification.

Archaeological sites were opened in areas where stratigraphic complexity or architectural features were present. Where tunnel geometry allowed, sondages measured approximately 1 × 2 m, though dimensions were adapted to local conditions. Profiles were cleaned, photographed, and drawn to document the sequence of de-

posits and constructed features.

### **3.3. Documentation Procedures**

Excavation contexts were documented using a standardized system that included written context descriptions, scaled photography, and measured drawings. Photographs were taken before excavation, during active work, and after completion of each stratigraphic unit. Metric scales and orientation markers were used consistently.

Measured drawings were produced for stratigraphic profiles, dry-stone walls, and significant architectural elements. These drawings emphasize the spatial relationships between tunnel walls, constructed features, fill deposits, and underlying geological layers.

All finds were recorded with reference to their stratigraphic unit and precise location within the tunnel. Artefacts were labeled, bagged, and stored according to standard archaeological practice prior to further analysis.

### **3.4. Recording of Architectural Features**

Dry-stone walls and other constructed features were treated as primary archaeological elements. Each wall was documented in situ before any removal of adjacent fill. Recorded attributes included dimensions, construction technique, stone selection, orientation, and relationship to tunnel walls and surrounding sediments.

Special attention was given to whether walls sealed passages, reinforced tunnel sides, or retained infill material. In many cases, walls were found embedded within fill deposits rather than standing freely in open corridors. These relationships were recorded in the profile to reconstruct the sequence of construction and infilling.

Evidence of calcification or speleothem growth on wall surfaces was noted, as this provides a relative chronology of periods of stability following construction.

### **3.5. Geodetic Survey and Spatial Control**

Geodetic documentation of the Ravne tunnel system was carried out using total station instruments. Survey points were recorded for tunnel walls, floors, ceilings, junctions, and architectural features. These data were tied to surface reference points to ensure spatial consistency between excavation seasons.

Geodetic measurements were used to produce plan views and longitudinal profiles of individual tunnel branches. This allowed comparison of passage geometry, orientation, and architectural features across different parts of the system, including Ravne 3 and Ravne 6.

### **3.6. Sampling Strategy and Laboratory Analyses**

Samples for laboratory analysis were collected from stratigraphically secure contexts. Organic materials selected for radiocarbon dating included charcoal, worked wood, and organic-rich sediments embedded within tunnel fill. Samples were taken only from contexts showing no evidence of modern disturbance.

Radiocarbon ( $C^{14}$ ) dating was used to establish chronological constraints for phases of tunnel use and infilling. In addition, carbonate deposits and speleothems associated with dry-stone walls were sampled for uranium-thorium (U-Th) dating in order to provide independent chronological markers related to post-construction mineral formation.

Sediment characterization was conducted primarily through macroscopic observation during excavation. Differences in grain size distribution, sorting, and composition were used to distinguish heterogeneous tunnel fill from in situ conglomerate.

### **3.7. Environmental Observations**

Environmental conditions within the Ravne tunnels were recorded during multiple field seasons. Temperature and relative humidity were measured at fixed points within deeper tunnel sections and compared with surface conditions. These measurements showed minimal seasonal fluctuation.

Hydrological observations focused on water-bearing tunnel segments where standing or slowly flowing water is present year-round. The relationship between water flow and architectural features, particularly dry-stone walls in these areas, was documented in detail.

Measurements of air ionization and background radiation were conducted between 2018 and 2025. These data were recorded for comparative purposes and are treated as environmental parameters rather than as indicators of physiological or therapeutic effects.

### **3.8. Legal and Institutional Framework**

All archaeological work in the Ravne tunnel system was conducted under permits issued by the competent cantonal and federal heritage authorities of Bosnia and Herzegovina. Excavations were carried out in cooperation with designated local museum institutions and under the supervision of licensed archaeologists.

Annual excavation reports were submitted to the relevant authorities, and all work followed established professional and legal standards for archaeological research.

## **4. Tunnel Architecture and Construction Features**

The internal architecture of the Ravne tunnel system is defined by a combination of shaped passages, constructed stone features, and repeated modifications that collectively indicate deliberate organization of subterranean space. Rather than presenting a uniform or linear layout, the tunnels display variability in orientation, width, and treatment of walls and floors, suggesting that different sections served different purposes or were modified at different times.

### **4.1. Tunnel Morphology and Passage Profiles**

Documented tunnel corridors are generally characterized by rounded or gently

arched profiles, with relatively consistent widths and heights maintained over extended distances. Passage walls and ceilings follow smooth contours cut into conglomerate, with few abrupt changes attributable to natural fracturing. This consistency is visible in both straight segments and curved sections, indicating controlled excavation rather than opportunistic enlargement of pre-existing voids.

Tunnel intersections represent a notable architectural feature. Cleared junctions reveal branching passages that meet at defined angles, often near right angles, rather than irregular or sinuous connections (**Figure 5**). These intersections are not aligned with readily identifiable geological weaknesses and recur across different parts of the system, suggesting a patterned approach to underground circulation. The regularity of these nodes suggests intentional planning of movement routes rather than random extension.

#### **4.2. Sedimentological Differentiation of Tunnel Fill and Host Conglomerate**

Sedimentological distinctions within the Ravne tunnel system were established through direct observation during excavation, stratigraphic profiling, and comparative assessment of sediment texture and composition. Particular attention was paid to differentiating unconsolidated tunnel fill from the surrounding lithified river-pebble conglomerate and from deposits attributable to natural weathering processes.

The host geological formation consists of a polymictic conglomerate composed of rounded river pebbles and cobbles set within a compact sandy-clayey matrix. This material exhibits high cohesion, clear lithification, and resistance to hand excavation. Pebbles within the conglomerate are tightly bound, show no internal sorting, and cannot be removed individually without fracturing the surrounding matrix. Tunnel walls cut into this material preserve stable profiles and sharp boundaries.

By contrast, the fill material encountered within many tunnel sections differs markedly in both structure and composition. Tunnel fill is typically unconsolidated to weakly compacted and composed of mixed pebble sizes embedded within a loose sandy matrix. Pebbles are easily dislodged by hand and show no cementation. Sorting is poor, with fine sediments, medium gravel, and larger clasts occurring together without stratification consistent with fluvial deposition. The texture of this material contrasts sharply with the surrounding conglomerate and is immediately apparent during excavation.

Stratigraphic profiles repeatedly show clear and abrupt interfaces between consolidated conglomerate and overlying or intruding fill deposits. These boundaries are irregular but distinct, indicating episodes of secondary introduction rather than gradual in situ weathering. In several cases, fill deposits truncate earlier tunnel surfaces or abut constructed dry-stone walls, demonstrating that sediment accumulation occurred after tunnel excavation and wall construction rather than as a result of natural erosion of the host rock.

Natural weathering products were observed in limited quantities, primarily as fine sandy residues or localized pebble fall directly adjacent to tunnel walls and ceilings. These materials occur in small volumes and remain spatially restricted. They do not form thick, laterally extensive deposits and do not account for the bulk of fill observed in sealed or partially sealed tunnel segments.

In Ravne 3 and Ravne 6, unconsolidated fill frequently incorporates cultural material, including ceramic fragments and organic remains, further distinguishing it from natural geological deposits. The presence of such material within poorly sorted, heterogeneous sediment reinforces the interpretation that these fills represent deliberately introduced or reworked deposits rather than products of hydraulic transport or slow natural infilling.

Taken together, sedimentological observations demonstrate a consistent pattern: intact conglomerate forms the structural fabric of the tunnels, while unconsolidated fill represents a secondary deposit introduced during discrete episodes of tunnel modification, closure, or reconfiguration. The clear physical contrast between these materials provides a reliable basis for distinguishing anthropogenic infill from natural geological processes during excavation and interpretation.

### 4.3. Dry-Stone Walls and Constructed Features

Dry-stone walls constructed from rounded river pebbles constitute the most distinctive built elements within the Ravne tunnels. To date, more than eighty such structures have been documented across different tunnel branches, including Ravne 3, Ravne 6, and the main Ravne corridor (**Figure 3** and **Figure 4**). Despite variation in size and placement, these walls share consistent construction principles. (Osmanagich, 2025a).

The walls are assembled without mortar, relying instead on careful selection and placement of stones. Larger cobbles typically form basal courses, whereas mid-sized pebbles predominate in the upper sections, with smaller stones used to fill gaps. In several cases, walls incorporate large boulders as central or terminal elements, around which pebble courses are arranged. This technique yields stable structures capable of withstanding the pressure of surrounding fill.

Wall placement varies according to context. In many instances, walls fully block side passages or chambers, sealing spaces behind them. Elsewhere, particularly in water-bearing corridors, walls run parallel to passage edges, functioning as retaining or reinforcing elements rather than closures. The recurrence of these forms across separate tunnel segments suggests shared construction knowledge and repeated application of similar solutions to different spatial needs.

### 4.4. Architectural Sequencing and Modification

Stratigraphic relationships demonstrate that dry-stone walls were not part of a single construction phase. Instead, they appear within sequences that include initial tunnel excavation, wall construction, introduction of fill material, and later stabilization or abandonment. Walls are frequently found embedded within tun-

nel fill rather than standing freely within open corridors, indicating that they were erected prior to infilling and subsequently buried.

In Ravne 3, profiles show walls sealed behind rubble backfill and overlain by sediments distinct from the surrounding conglomerate (Figure 7). These relationships suggest intentional closure events rather than gradual accumulation from natural collapse alone. In some cases, calcification and speleothem growth adjacent to walls indicate prolonged periods of inactivity following construction, further supporting a multi-phase history.

#### **4.5. Architectural Consistency across the System**

One of the most significant observations is the architectural consistency across the Ravne tunnel system. Walls from Ravne 3, Ravne 6, and the main Ravne tunnel display comparable techniques, materials, and spatial logic, despite being discovered at different times and locations. Similarly, passage morphology and intersection geometry show recurring patterns across the system.

This consistency argues against isolated or short-term construction carried out by unrelated groups. Instead, it supports the interpretation of the Ravne tunnels as a coordinated subterranean environment shaped by repeated human actions guided by shared practices and constraints. Architectural choices appear to reflect an understanding of the material properties of conglomerate, the management of underground space, and the long-term stability of constructed features.

Taken together, the architectural evidence demonstrates that the Ravne tunnel system was not merely excavated and abandoned, but actively shaped, partitioned, and modified over time. The following section examines the material remains recovered from these contexts, which provide further insight into the human activities associated with this subterranean landscape.

### **5. Material Evidence and Artifacts**

Material remains recovered from the Ravne tunnel system provide an important line of evidence for interpreting human activity within this subterranean environment. Although much of the cultural material occurs in a secondary context, its quantity, distribution, and chronological breadth indicate repeated episodes of human interaction with the tunnels rather than isolated or incidental use.

#### **5.1. Nature and Distribution of Finds**

Artifacts have been recovered from multiple tunnel branches, most notably Ravne 3 and Ravne 6, during systematic excavation and cleaning campaigns conducted between 2019 and 2025. The majority of finds derive from tunnel-fill deposits rather than from primary occupational surfaces, reflecting the complex history of excavation, infilling, and reopening documented stratigraphically. Despite this secondary positioning, the recurrence of cultural material across different sections of the system suggests sustained human presence over extended periods.

Among the most diagnostically identifiable finds are fragments of Roman build-

ing material, including tegulae recovered from Ravne 3 (**Figure 6(a)**). These fragments attest to activity in the wider landscape during the Roman period and demonstrate that material from surface or near-surface contexts entered the tunnel system at some stage in its history. Their presence within the fill highlights the tunnel's permeability to materials introduced during later phases of use or modification.

## 5.2. Ceramic Assemblages

Ceramic material represents the most abundant category of artifacts recovered to date. More than 3,300 ceramic fragments have been documented from various tunnel sections during the 2019-2024 excavation campaigns (**Figure 6(c)**). Preliminary typological assessment indicates a broad chronological range spanning from the Neolithic through the late medieval period. This temporal diversity underscores the long-term interaction between human communities and the Ravne tunnels, even if the specific nature of that interaction varied across periods.

The ceramics are generally fragmentary and occur within unconsolidated fill deposits, precluding straightforward interpretation as *in situ* occupation debris. Nevertheless, their widespread distribution across the tunnel network suggests that the tunnels repeatedly intersected with human activity at the surface or in nearby settlement areas. The consistent appearance of ceramics within sealed or partially sealed tunnel segments further indicates that infilling events incorporated material from culturally active contexts rather than resulting solely from natural sediment movement ([Osmanagich, 2025a](#)).

## 5.3. Organic Material

Organic artifacts are comparatively rare within the Ravne tunnels, reflecting preservation conditions and the dynamic nature of tunnel infill. One notable exception is a worked wooden object recovered in 2025 from the Ravne 6 tunnel, documented within stratigraphic unit SJ 001 (**Figure 6(b)**). The object was found embedded within a tunnel fill near a side passage, oriented vertically with its pointed end downward.

Radiocarbon analysis of this object yielded a calibrated date range of 1485-1515 AD, placing it in the late medieval period. Although recovered in a secondary context, the preservation of organic material and its secure dating provide an important chronological anchor for at least one phase of tunnel infilling or modification. The find demonstrates that the Ravne tunnel system remained accessible or was re-engaged during the late medieval period, long after earlier phases of activity suggested by ceramic evidence ([Osmanagich, 2025a](#)).

## 5.4. Radiocarbon Dating: Laboratory and Calibration Details

Radiocarbon dating was carried out on selected organic samples recovered from stratigraphically secure contexts within the Ravne 6 tunnel system. Samples were chosen from sealed or clearly defined fill deposits associated with tunnel modifi-

cation features, with particular care taken to avoid material from disturbed or ambiguous contexts.

One set of samples discussed here derives from worked and unworked wood recovered during the 2025 excavation season in Ravne 6. Radiocarbon analysis was performed at the Accelerator Mass Spectrometry Laboratory, Center for Physical Sciences and Technology, Vilnius, Lithuania. Measurements were obtained using a single-stage accelerator mass spectrometer (SSAMS, NEC, USA). Sample preparation included standard acid-base-acid (ABA) pretreatment with additional bleaching procedures, following established protocols for the removal of secondary carbon contaminants. Reference standards used during analysis included IAEA C3, IAEA C9, and NIST-OXII.

Three subsamples from the same excavation context were dated independently. Conventional radiocarbon ages are reported in radiocarbon years BP (before AD 1950) and corrected for isotopic fractionation using measured  $^{13}\text{C}/^{12}\text{C}$  ratios. Analytical uncertainty is reported at one standard deviation ( $\pm 1\sigma$ ).

The resulting conventional radiocarbon ages are:

- **R6-1 (FTMC-DT95-1): 415 BP  $\pm$  29 BP**
- **R6-2 (FTMC-DT95-2): 433 BP  $\pm$  28 BP**
- **R6-3 (FTMC-DT95-3): 402 BP  $\pm$  29 BP**

Calibration was performed using the IntCal calibration curve (as applied by the laboratory), producing calibrated date ranges that fall consistently within the late medieval to early post-medieval period. At the 95.4% probability level ( $2\sigma$ ), the calibrated ranges cluster between the late fifteenth and early seventeenth centuries AD, with the highest probability density centered in the fifteenth and sixteenth centuries (**Figure 9** and **Table 1**).

These dates provide a terminus ante quem for the infill deposits from which the samples were recovered and confirm that sections of the Ravne tunnel system remained accessible or were deliberately re-entered during the late medieval period. As the dated material derives from fill rather than from construction elements themselves, the results constrain phases of tunnel use and closure rather than initial excavation.

### 5.5. Interpretive Implications of Secondary Context

The predominance of secondary-context artifacts within the Ravne tunnels does not diminish their interpretive value. On the contrary, the repeated incorporation of cultural material into tunnel fill aligns with the architectural and stratigraphic evidence for intentional closure, reconfiguration, and reuse of subterranean spaces. Artifacts embedded within fill deposits reflect moments when surface materials were deliberately or inadvertently introduced into the subsurface environment, linking tunnel-modification events to broader patterns of human activity in the surrounding landscape.

Rather than viewing the Ravne tunnels as a single-period archaeological site, the material evidence supports an interpretation of the system as a persistent



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Radiocarbon**

Performed by

Page 1 of 3

# DATING CERTIFICATE

No. 2025-10-09-FTMC-DT95

28<sup>th</sup> October 2025

1. Applicant for analysis: Ms Ajla Šabanija Softić, Foundation "Archaeological park: Bosnian Pyramid of the Sun", Ravne bb, Visoko
2. Material of sample: Wood
3. Date of sample receiving: 2025-10-15
4. Analysis date: 2025-10-28
5. Equipment used for analysis: Single stage accelerator mass spectrometer (SSAMS, NEC, USA), Low-Energy Accelerator (LEA, Ionplus AG, Zürich), Automated Graphitization Equipment AGE-3 (Ionplus AG, Zürich).
6. Method of analysis: Samples were pretreated with an acid-base-acid-bleaching protocol. IAEA C3, IAEA C9, and NIST-OXII were used as reference materials.
7. Results of analysis:

Sample designation	Lab. code	Radiocarbon age, BP	pMC
R6 - 1	FTMC-DT95-1	415±29	94.97±0.34
R6 - 2	FTMC-DT95-2	433±28	94.76±0.33
R6 - 3	FTMC-DT95-3	402±29	95.13±0.34

The results are given in years before 1950 (radiocarbon age BP). The uncertainty in the age determination is given +/- one standard deviation. All radiocarbon ages are corrected for isotopic fractionation using the measured  $^{13}\text{C}/^{12}\text{C}$ -ratio. The radiocarbon ages must be translated to calibrated radiocarbon years.

8. Calibrated radiocarbon dates:

**Figure 9.** Radiocarbon dating certificate and calibration results for organic samples from Ravne 6 (2025 field season). Radiocarbon dating certificate issued by the Accelerator Mass Spectrometry Laboratory, Center for Physical Sciences and Technology (Vilnius, Lithuania), documenting AMS  $^{14}\text{C}$  analysis of three wood samples (R6-1, R6-2, R6-3) recovered from stratigraphically defined fill contexts in the Ravne 6 tunnel. The figure includes laboratory metadata (lab codes FTMC-DT95-1 to FTMC-DT95-3), conventional radiocarbon ages (BP), pretreatment protocol, and calibrated probability distributions based on the IntCal calibration curve. The results place the dated material within the late medieval to early post-medieval period and provide chronological constraints for phases of tunnel infilling and reuse.

**Table 1.** Radiocarbon dates from Ravne 6 (2025 field season).

Sample ID	Lab Code	Material	$^{14}\text{C}$ Age BP ( $\pm 1\sigma$ )	Calibration Curve	Calibrated Range ( $2\sigma$ )
R6-1	FTMC-DT95-1	Wood	415 ± 29	IntCal	Late 15th to early 17th c. AD
R6-2	FTMC-DT95-2	Wood	433 ± 28	IntCal	Late 15th to early 17th c. AD
R6-3	FTMC-DT95-3	Wood	402 ± 29	IntCal	Late 15th to early 17th c. AD

feature within the cultural landscape, repeatedly encountered, modified, and re-contextualized over time. In this sense, artifacts function less as indicators of occupation and more as markers of long-term engagement with a managed subterranean space.

The following section considers how stratigraphic relationships and environmental conditions further inform this interpretation, particularly with respect to

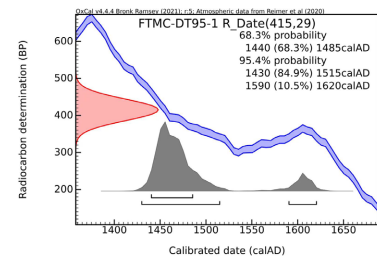


Fig. 1. Radiocarbon date 415±29BP (red), part of the calibration curve (blue) and the calibrated probability density function (grey) calculated in OxCal.

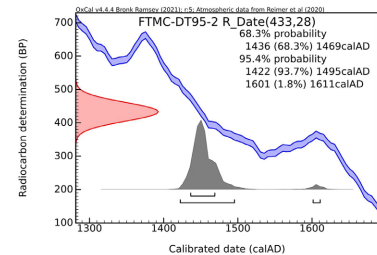


Fig. 2. Radiocarbon date 433±28BP (red), part of the calibration curve (blue) and the calibrated probability density function (grey) calculated in OxCal.

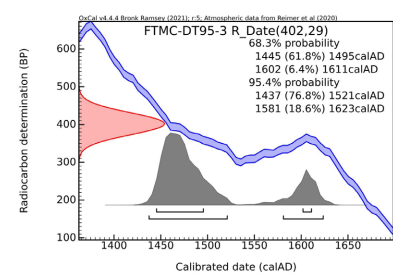


Fig. 3. Radiocarbon date 402±29BP (red), part of the calibration curve (blue) and the calibrated probability density function (grey) calculated in OxCal.

sequences of closure, infilling, and stability within the Ravne tunnel system.

## 6. Stratigraphic Relationships and Environmental Context

Stratigraphic observations within the Ravne tunnel system provide critical insight into the sequence of human actions that shaped the underground space. When examined alongside environmental parameters, these data suggest deliberate management of tunnel interiors rather than passive adaptation to natural cavities.

Environmental psychology and sensory archaeology have long recognized that stable environmental parameters influence how humans perceive and repeatedly use enclosed spaces. Research on subterranean and confined environments indicates that factors such as constant temperature, limited sensory fluctuation, low background radiation, and air ion composition can shape human comfort, attention, and perception without implying direct physiological effects. Environments characterized by reduced external stimuli and stable microclimatic conditions are often described as cognitively distinctive and are associated with heightened spatial awareness and prolonged tolerance for enclosure (Persinger et al., 2003; Harrison, 2011; Chong, 2019). Within this framework, the measured environmental conditions documented in the Ravne tunnel system—particularly microclimatic stability and consistently low levels of environmental noise in physical and electromagnetic terms—may have contributed to the suitability of these spaces for repeated access and sustained presence. This interpretation does not assign symbolic or functional intent to specific environmental parameters but situates them within established observations that human interaction with subterranean spaces is shaped not only by physical architecture, but also by the sensory qualities of the environment itself.

### 6.1. Stratigraphy of Tunnel Fill and Constructed Features

Excavations conducted in Ravne 3 and Ravne 6 reveal a recurring stratigraphic pattern: compacted tunnel fill bounded by consolidated conglomerate walls and intersected by constructed dry-stone barriers. In multiple locations, sharply defined interfaces separate unconsolidated fill from lithified Ravne Conglomerate (Figure 7(c)). These boundaries are often irregular in outline yet consistently distinct in texture and composition, indicating secondary infill episodes rather than gradual sedimentation.

Dry-stone walls are frequently embedded within these fill deposits, with rubble or sediment accumulated behind them. In profile, the walls demonstrate coherent construction using rounded river pebbles arranged in horizontal courses, often terminating against intact tunnel walls (Figure 7(a) & Figure 7(b)). The stratigraphic relationship between walls and overlying fill suggests that wall construction preceded infilling, consistent with intentional closure or compartmentalization of tunnel segments.

Notably, calcified surfaces and speleothem growth are observed on some walls and adjacent sediments. These mineral accretions indicate periods of environ-

mental stability following construction and infilling, during which water movement and atmospheric conditions remained sufficiently constant to support calcification.

## 6.2. Temporal Depth and Reuse

The stratigraphic sequence within the tunnels reflects repeated phases of use, modification, and sealing rather than a single construction event. Walls of varying dimensions and construction styles occur at different depths and positions, suggesting multiple episodes of intervention. In some sections, earlier walls appear partially buried or truncated by later fill, suggesting successive reconfiguration of the underground space.

This interpretation is supported by the broad chronological range of artifacts recovered from tunnel fill, spanning from the Neolithic to the late medieval period. While these materials are not typically associated with primary occupation layers, their stratigraphic embedding within sealed passages indicates that tunnel modification events intersected with culturally active periods on the surface.

## 6.3. Hydrological and Microclimatic Conditions

Environmental measurements conducted within the Ravne tunnel system demonstrate a remarkably stable underground microclimate. Temperature and humidity remain relatively constant throughout the year, with minimal seasonal fluctuation. Such stability contrasts sharply with the surface conditions and would have been perceptible to tunnel users (Osmanagich, 2025b).

Water-bearing sections of the tunnel network, particularly along the southwest-oriented “Water Tunnel,” exhibit steady water levels and high clarity (**Figures 8(a)-(d)**). In these areas, dry-stone structures differ from those blocking side passages elsewhere in the system. Rather than functioning as closures, some walls appear to reinforce tunnel sides or regulate water movement, indicating adaptive architectural responses to hydrological conditions (Osmanagich, 2025c).

Ionization measurements conducted between 2018 and 2025 further document unusually high concentrations of negative air ions within deeper tunnel sections, coupled with low levels of ionizing and electromagnetic radiation. While these measurements are not interpreted here in physiological or therapeutic terms, they demonstrate that the tunnel environment differs markedly from surface conditions and would have constituted a distinctive sensory and atmospheric space (Hirsikko, 2011; Reiter, 1985; Soyka, 1977; UNSCEAR, 2000).

## 6.4. Anthropological Implications of Environmental Stability

From an anthropological perspective, the combination of architectural intervention, stratified modification, and environmental stability supports an interpretation of the Ravne tunnels as a deliberately maintained subterranean landscape. Stable temperature, humidity, and hydrological conditions would have made the tunnels suitable for repeated access and prolonged presence, while dry-stone struc-

tures allowed control over movement, space, and water.

Rather than functioning as accidental or purely natural cavities (Buzjak, 2024; Xuan, 2010; Nguyen, 2020), the tunnels exhibit characteristics consistent with intentional spatial planning underground. Stratigraphy records not only the physical sequence of events but also the cumulative decisions of human actors engaging with a challenging subterranean environment across long periods of time.

The following section synthesizes architectural, material, and environmental evidence to outline an integrated anthropological interpretation of the Ravne tunnel system.

## **7. Anthropological Interpretation of Subterranean Space**

When considered as a whole, the Ravne tunnel system presents a pattern of human engagement with subterranean space that extends beyond utilitarian excavation or short-term use. Architectural regularity, repeated construction practices, stratigraphic modification, and the incorporation of material culture collectively indicate an underground environment that was actively shaped, maintained, and revisited over extended periods.

Distinct sensory and environmental conditions are known to influence patterns of repeated human engagement with enclosed spaces (Persinger et al., 2003; Harrison, 2011).

### **7.1. Subterranean Space as a Managed Environment**

The presence of dry-stone walls throughout the Ravne tunnels indicates that underground space was not treated as an open or neutral void. Instead, passages were selectively closed, reinforced, or partitioned, suggesting a concern with controlling access and circulation. The recurrence of similar construction techniques across different tunnel branches implies shared knowledge and continuity in practice, even as specific interventions varied in scale and function.

Such management is further reflected in the organization of tunnel intersections and passage orientations. The regular geometry observed at branching points suggests that movement through the underground system followed established routes rather than opportunistic exploration. From an anthropological perspective, this implies familiarity with the subterranean landscape and an understanding of how space could be structured to serve particular needs.

### **7.2. Temporal Continuity and Re-Engagement**

The stratigraphic and material evidence indicate that the Ravne tunnels were not used within a single chronological horizon. Instead, they appear to have been repeatedly encountered, modified, and reinterpreted by different communities over time. Ceramic assemblages spanning from the Neolithic to the late medieval period, along with radiocarbon-dated organic material from the fifteenth to sixteenth centuries, demonstrate that the tunnels remained part of the cultural landscape long after their initial excavation.

This pattern of re-engagement suggests that the Ravne tunnels functioned as a persistent feature within collective memory, even as their original purpose may have shifted or been forgotten. Later groups appear to have interacted with an existing underground infrastructure, adapting it to new contexts rather than abandoning it entirely. Such reuse is consistent with anthropological models in which built environments accumulate meaning through repeated interaction rather than fixed function.

### **7.3. Material Culture in Secondary Context**

Although most artifacts recovered from the Ravne tunnels occur in secondary deposits, their interpretive value lies precisely in this context. Objects embedded within tunnel fill reflect moments when surface materials entered the underground space, either intentionally during closure events or incidentally during periods of disturbance. These episodes link tunnel modification to broader patterns of human activity in the surrounding landscape.

From an anthropological standpoint, secondary deposition does not imply randomness. Instead, it records points of contact between surface life and subterranean space. The repeated incorporation of cultural material into tunnel fills suggests that the tunnels were neither isolated nor forgotten but rather remained accessible and meaningful during successive periods of occupation.

### **7.4. Environmental Experience and Human Perception**

Environmental conditions within the Ravne tunnels would have contributed significantly to human perception of the space. Stable temperature, high humidity, low background radiation, and persistent water presence create an underground environment markedly different from surface conditions. Such contrasts are known ethnographically and archaeologically to influence how subterranean spaces are perceived and valued.

Similar stability has been documented in enclosed subterranean environments elsewhere (Chong, 2019).

While the present study does not attribute specific symbolic or ritual meanings to these conditions, it recognizes that sensory experience plays a role in shaping human interaction with place. The consistency of the tunnel environment, combined with architectural control and spatial organization, would have reinforced the distinctiveness of the subterranean realm as a setting for activities separate from everyday surface life.

### **7.5. Ravne as a Cultural Landscape Underground**

Taken together, the evidence supports an interpretation of the Ravne tunnel system as a managed subterranean landscape rather than a purely functional or incidental structure. Architecture, stratigraphy, material culture, and environmental context converge to suggest that underground space was deliberately incorporated into broader patterns of human behavior.

This perspective shifts attention away from singular explanations and toward long-term processes of engagement, adaptation, and reuse. The Ravne tunnels emerge not as anomalies but as part of a wider human tendency to structure and rework subterranean environments across generations. In this sense, they offer a valuable case study for understanding how underground spaces can acquire cultural significance through sustained interaction over time.

## 8. Discussion and Conclusion

The Ravne tunnel system presents a rare opportunity to examine long-term human engagement with a large, deliberately modified subterranean environment. Through the combined analysis of architecture, stratigraphy, material culture, and environmental context, this study has approached the tunnels not as isolated constructions or singular phenomena, but as spaces repeatedly shaped and reinterpreted through human action.

Architectural features such as dry-stone walls, controlled passage orientations, and reinforced water-bearing corridors demonstrate that underground space was actively organized rather than passively occupied. The consistency of construction techniques across different tunnel branches suggests shared practices and accumulated knowledge, even as individual interventions varied in scale and function. Stratigraphic evidence further indicates that excavation, construction, infilling, and stabilization occurred in multiple phases, pointing to a dynamic history of use rather than a single episode of activity.

Material evidence recovered from the tunnels supports this interpretation. Although artifacts are most often found in secondary contexts, their quantity, distribution, and broad chronological range indicate repeated interaction with the subterranean system from the Neolithic through the late medieval period. Rather than diminishing their interpretive value, secondary deposition highlights moments when surface life intersected with underground space, linking tunnel-modification events to broader cultural processes in the surrounding landscape.

The presence of cultural material within underground contexts requires careful consideration of natural processes that could account for sediment accumulation and artefact displacement. In the case of the Ravne tunnel system, several natural transport and deposition mechanisms were evaluated, including hydraulic action, animal activity, roof collapse, and gradual weathering of the host conglomerate.

Hydraulic transport represents a common mechanism for introducing sediment and artefacts into subterranean spaces. However, the characteristics of the tunnel fill observed in Ravne 3 and Ravne 6 are inconsistent with fluvial deposition. Fill deposits are poorly sorted, with fine sediment, medium gravel, and larger pebbles occurring together without stratification or imbrication. In addition, standing or slow-moving water currently present in some tunnel sections shows no evidence of sufficient energy to transport larger clasts or artefacts. Where water-bearing passages exist, architectural features such as dry-stone walls are posi-

tioned in ways that would obstruct, rather than facilitate, large-scale sediment inflow.

Animal burrowing was also considered a potential mechanism for sediment and artefact movement. While small-scale bioturbation is common in near-surface contexts, the depth, extent, and volume of fill within the Ravne tunnels exceed what could reasonably be attributed to animal activity. No burrow networks, nesting structures, or sediment disturbance patterns consistent with sustained faunal excavation were observed. Moreover, animal activity cannot account for the presence of constructed dry-stone walls sealed behind thick deposits of heterogeneous fill.

Roof collapse and gravitational infall represent another possible source of underground sediment accumulation. Localized ceiling collapse was observed in limited areas, typically adjacent to weakened sections of conglomerate. These events produce angular fragments and localized debris cones, which are readily distinguishable from the rounded pebbles and mixed sediments that dominate tunnel fill elsewhere. Importantly, collapse-derived material remains spatially restricted and does not form the laterally extensive, passage-filling deposits documented behind dry-stone walls and within sealed corridors.

Gradual weathering of the conglomerate host rock was likewise evaluated. Weathering products occur as fine sandy residues or occasional pebble detachment near tunnel walls and ceilings. These materials are present in small quantities and do not accumulate in thick stratified deposits. The sharp boundaries repeatedly observed between consolidated conglomerate and unconsolidated fill argue against in situ degradation as the primary source of tunnel infill.

In several locations, fill deposits directly abut or overlie constructed dry-stone walls, indicating that sediment accumulation post-dates wall construction. This stratigraphic relationship cannot be explained by natural processes alone, as walls would have obstructed passive sediment movement from adjacent tunnel sections. Instead, these relationships suggest intentional or managed infilling events linked to phases of tunnel closure or reconfiguration.

While it remains possible that natural processes contributed marginally to sediment accumulation within the Ravne tunnels, the observed sedimentological characteristics, stratigraphic relationships, and association with constructed features indicate that natural transport mechanisms cannot account for the bulk of fill or for the patterned distribution of artefacts. The evidence instead supports a model in which natural processes played a secondary role within a system primarily shaped by repeated human modification.

Environmental conditions within the Ravne tunnels add an additional dimension to this picture. Stable temperature, persistent humidity, low background radiation, and the presence of water-bearing passages create an underground environment markedly different from surface conditions. While this study does not assign specific symbolic or functional meanings to these characteristics, their stability would have shaped human experience of the tunnels and may help explain

their continued accessibility and reuse over time.

Taken together, the evidence supports an anthropological interpretation of the Ravne tunnel system as a managed subterranean landscape. The tunnels appear to have functioned as durable elements within the cultural geography of central Bosnia, repeatedly encountered, modified, and incorporated into human activity over extended periods. This interpretation moves beyond attempts to identify a single original purpose and instead emphasizes processes of continuity, adaptation, and re-engagement.

In a broader context, the Ravne tunnels contribute to ongoing discussions in anthropology and archaeology concerning the role of underground spaces in human societies. They illustrate how subterranean environments can be structured, maintained, and imbued with significance through sustained interaction, even when their meanings evolve over time. As such, the Ravne system offers a valuable comparative case for understanding how humans have navigated, organized, and conceptualized underground space within long-term cultural landscapes.

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### Data Availability Statement

All data supporting the findings of this study are derived from the author's field research, excavation records, geodetic documentation, laboratory reports, and previously published studies cited in this article. Figures and illustrations are original or properly credited. Additional documentation is available from the author upon reasonable request.

### Artificial Intelligence (AI) Usage Statement

Artificial intelligence tools were used in a limited and supportive capacity during the preparation of this manuscript, specifically for language editing, stylistic refinement, and organizational clarity. AI tools were not used for data collection, data analysis, interpretation of results, figure generation, or the formulation of scientific conclusions. All interpretations, arguments, and final editorial decisions remain the sole responsibility of the author.

### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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