Geoinformatics & Geostatistics: An Overview

Research Article

A SCITECHNOL JOURNAL

Establishing Deep Time: Multi-Method Dating of Archaeological and Speleological Features in the Bosnian Valley of the Pyramids

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Received date: 03 May, 2025, Manuscript No. GIGS-25-165105;

Editor Assigned date: 06 May, 2024, PreQC No. GIGS-25-165105 (PQ);

Reviewed date: 20 May, 2024, QC No. GIGS-25-165105;

Revised date: 27 May, 2024, Manuscript No. GIGS-25-165105 (R);

Published date: 03 June, 2024, DOI: 10.4172/2327-4581.1000437.

Abstract

This study presents an integrated chronological framework for the Bosnian Valley of the Pyramids using multiple scientific dating techniques. Radiocarbon dating, uranium-thorium analysis, and soil pedogenesis studies were conducted on archaeological and speleological features including the Bosnian Pyramid of the Sun, the Pyramid of the Moon, and the Ravne tunnel networks. Results suggest construction and usage of these structures as early as 33,800 years BP, with corroborating stratigraphic and geological indicators. The presence of architectural elements beneath undisturbed soil layers and stalagmites over tunnel floors reinforces their antiquity. These findings contribute to the growing evidence of organized human activity in Southeastern Europe during the Late Pleistocene. The application of cross-disciplinary dating methods demonstrates the value of integrated geoarchaeological approaches in establishing deep-time chronologies at complex heritage sites.

Keywords: Radiocarbon dating; Bosnian pyramids; Ravne tunnel complex; Speleothem chronology; Paleoarchaeology; Multi-method geochronology

Introduction

The Bosnian Valley of the Pyramids, located near the town of Visoko in central Bosnia-Herzegovina, has emerged over the past two decades as one of the most debated archaeological landscapes in Southeastern Europe. Since its identification as a site of interest in the early 2000s, the area has undergone continuous excavation and multidisciplinary study led by the Archaeological Park: Bosnian Pyramid of the Sun Foundation. The valley includes prominent geomorphological features such as the Bosnian Pyramid of the Sun, the Pyramid of the Moon, the Pyramid of the Dragon, and an extensive network of subterranean passages known as the Ravne Tunnels.

Despite initial skepticism regarding the anthropogenic nature of these formations, accumulating stratigraphic, architectural, and geophysical evidence has warranted closer scientific investigation. Notably, numerous megalithic terraces, aligned dry-stone walls, and artificially shaped concrete-like blocks have been unearthed at several depths and across multiple pyramid structures. In parallel, the Ravne tunnel systems have yielded dry-stone reinforcements, complex sediment layers, and speleothem formations which provide invaluable temporal markers.

To establish a scientifically grounded chronology for the valley's development, the current research integrates multiple dating techniques. Radiocarbon (C-14) dating, Uranium-Thorium (U-Th) series analysis, and pedogenetic soil assessment have been applied to organic remains, speleothems, and stratified construction materials. These analyses aim to identify both minimum and possible construction dates and offer a framework for interpreting phases of human activity in the region.

This paper presents the results of these multi-method dating efforts and evaluates their implications within the broader context of Balkan prehistory and deep-time archaeology. Emphasis is placed on methodological transparency, cross-validation of results, and careful consideration of post-depositional processes that may affect dating accuracy. By doing so, the study contributes to a more nuanced understanding of long-term human-environment interaction in one of Europe's least explored prehistoric landscapes [1].

Materials and methods

This study applies a multi-method chronological approach to key sites within the Bosnian Valley of the Pyramids, including the Bosnian Pyramids of the Sun and Moon, as well as the Ravne and Ravne 3 tunnel systems. Analytical material included organic remains (charcoal, wood, sediment-bound carbon), carbonate formations (stalagmites, calcite crusts), soil layers and structural elements recovered from systematic excavation campaigns spanning 2006 to 2025.

Excavation strategy and site selection

Excavation was conducted under the supervision of the Archaeological Park: Bosnian Pyramid of the Sun Foundation, with formal permits issued by the Cantonal Ministry of Culture (Zenica-Doboj Canton). A total of 20 trenches were opened on the Bosnian Pyramid of the Sun and 64 trenches on the Bosnian Pyramid of the Moon. Over 2.6 kilometers of tunnels were cleared in the Ravne and Ravne 3 underground complexes. Stratigraphic excavation, trench documentation, and material sampling were conducted according to standard archaeological protocols [2].

Radiocarbon (C-14) dating

Organic material including wood fragments, charcoal, and carbon-containing sediments was submitted for radiocarbon analysis to the following laboratories:

- Institute of Environmental Geochemistry, National Academy of

Sciences, Kyiv (Ukraine)

- Beta Analytic Radiocarbon Dating Laboratory, Miami (USA)
- TÜBİTAK Marmara Research Center AMS Laboratory, Gebze (Turkey)
- Laboratory for Isotope Research, Silesian University of Technology, Gliwice (Poland)
- Angström Laboratory, Uppsala University (Sweden)
- Leibniz Laboratory for Radiometric Dating and Stable Isotope Research, Christian-Albrechts University, Kiel (Germany)

Samples underwent standard pre-treatment protocols including Acid-Base-Acid (ABA) processing or acid dissolution (for carbonates). AMS (Accelerator Mass Spectrometry) and liquid scintillation counting methods were used. Radiocarbon dates were calibrated using the IntCal13 or IntCal20 Northern Hemisphere calibration curves [3].

Uranium-Thorium (U-Th) series dating

U-Th dating was applied to stalagmites and calcite crusts found in undisturbed sections of the Ravne 3 tunnel. Laboratory analysis was conducted as follows:

- Chemical separation of uranium and thorium was performed using TRU-resin chromatographic extraction at the Institute of Geological Sciences, Polish Academy of Sciences (Warsaw).
- Isotopic measurements were completed at the Institute of Geology, Czech Academy of Sciences (Prague), using a double-focusing sector-field ICP-MS (Element 2, Thermo Finnigan) [4].

All results were corrected for blanks and isotopic fractionation using internal laboratory standards.

Soil pedogenesis and relative dating

Soil samples taken from sediment layers overlying structural elements (e.g., concrete blocks) were examined by the Federal Institute for Agropedology (Sarajevo). Chronological estimates were based on depth, humus concentration, and clay mineral content. These data provided a relative terminus ante quem for underlying features.

Documentation and visualization

Each sample context was documented with scaled photography, stratigraphic sketches, and GIS-based mapping. 3D terrain modeling and remote sensing data (including LiDAR and satellite-based elevation models) were integrated into the geomorphological analysis, particularly around the Bosnian Pyramid of the Moon and related alignments [5].

Results

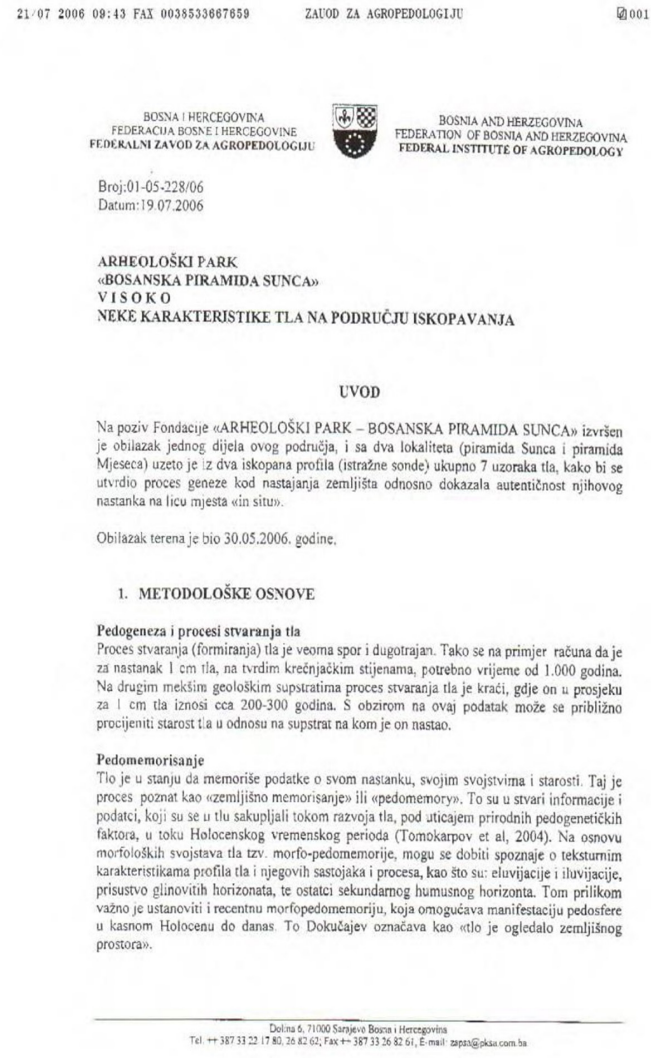
Excavations conducted across 20 archaeological trenches on the Bosnian Pyramid of the Sun uncovered structural features consistent with artificial construction (Figure 1). Large, regularly shaped concrete-like blocks were found approximately 1 meter beneath the surface layer of soil and vegetation (Figure 2). These blocks were arranged in rows and exhibited uniform orientation and smooth surfaces, particularly in Trench 4C and at the uncovered northeastern corner (Figure 3).

Bosnian pyramid of the sun

Radiocarbon dating of organic material found between these concrete layers yielded significant chronological results. A sample submitted to the Kyiv radiocarbon laboratory (IHME-3734) produced an uncalibrated age of 29,200 ± 400 BP, which calibrates to approximately 33,800 years BP using the IntCal calibration curve. An earlier sample from Trench 20 dated to 24,800 ± 200 BP supports this Late Pleistocene construction estimate (Figure 4). These findings are consistent with earlier soil analyses performed by the Federal Institute for Agropedology in Sarajevo, which dated the overlying pedogenic soil to between 12,000 and 15,000 years BP, confirming that the structure beneath must be older (Figure 5). Complementary interpretations by Dr. Paul LaViolette and others have affirmed this chronology, projecting a calibrated construction window of approximately 33,800 BP [6].

Figure 1: The Bosnian Pyramid of the Sun: Aerial view and geomorphological characteristics.

Figure 2: Archaeological excavation on the Bosnian pyramid of the sun: discovery of large concrete-like blocks beneath soil cover.



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FEDERAL INSTITUTE OF AGROPEDOLOGY

Broj:01-05-228/06
Datum:19.07.2006

ARHEOLOŠKI PARK
«BOSANSKA PIRAMIDA SUNCA»
V I S O K O
NEKE KARAKTERISTIKE TLA NA PODRUČJU ISKOPAVANJA

UVOD

Na poziv Fondacije «ARHEOLOŠKI PARK – BOSANSKA PIRAMIDA SUNCA» izvršen je obilazak jednog dijela ovog područja, i sa dva lokaliteta (piramida Sunca i piramida Mjeseca) uzeto je iz dva iskopana profila (istražne sonde) ukupno 7 uzoraka tla, kako bi se utvrdio proces geneze kod nastajanja zemljišta odnosno dokazala autentičnost njihovog nastanka na licu mjesta «in situ».

Obilazak terena je bio 30.05.2006. godine.

1. METODOLOŠKE OSNOVE

Pedogeneza i procesi stvaranja tla
Proces stvaranja (formiranja) tla je veoma spor i dugotrajan. Tako se na primjer računa da je za nastanak 1 cm tla, na tvrdim krečnjačkim stijenama, potrebno vrijeme od 1.000 godina. Na drugim mekšim geološkim supstratima proces stvaranja tla je kraći, gdje on u prosjeku za 1 cm tla iznosi cca 200-300 godina. S obzirom na ovaj podatak može se približno procijeniti starost tla u odnosu na supstrat na kom je on nastao.

Pedomemorisanje
Tlo je u stanju da memoriše podatke o svom nastanku, svojim svojstvima i starosti. Taj je proces poznat kao «zemljišno memorisanje» ili «pedomemory». To su u stvari informacije i podatci, koji su se u tlu sakupljali tokom razvoja tla, pod uticajem prirodnih pedogenetičkih faktora, u toku Holocenskog vremenskog perioda (Tomokarpov et al, 2004). Na osnovu morfoloških svojstava tla tzv. morfo-pedomemorije, mogu se dobiti spoznaje o teksturnim karakteristikama profila tla i njegovih sastojaka i procesa, kao što su: eluvijacije i iluvijacije, prisustvo glinovitih horizonata, te ostatci sekundarnog humusnog horizonta. Tom prilikom važno je ustanoviti i recentnu morfopedomemoriju, koja omogućava manifestaciju pedosfere u kasnom Holocenu do danas. To Dokučajev označava kao «tlo je ogledalo zemljišnog prostora».

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Figure 3: Pedological study of the bosnian pyramid of the sun and bosnian pyramid of the moon: Preliminary soil characterization and age estimation.

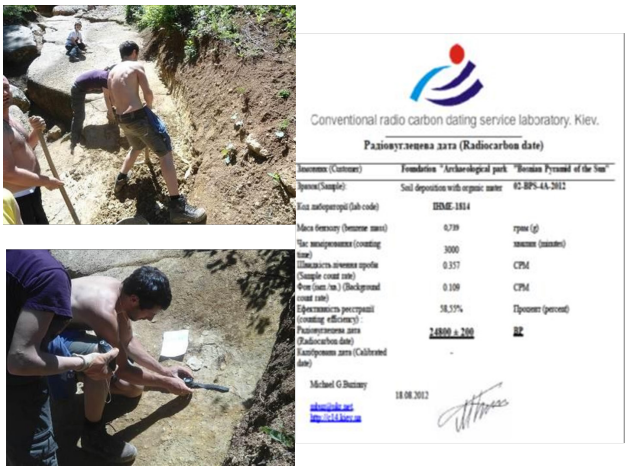


Figure 4: Radiocarbon dating of organic material discovered on the surface of artificial concrete blocks on the Bosnian Pyramid of the Sun.

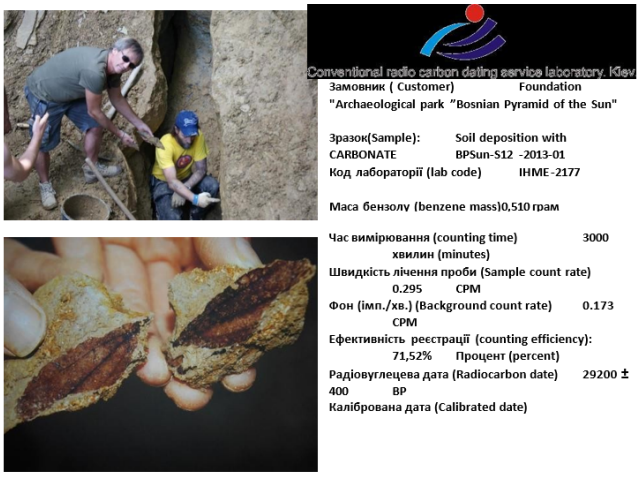


Figure 5: Radiocarbon dating of organic material associated with soil deposition on the Bosnian Pyramid of the Sun.

Bosnian pyramid of the moon

The Bosnian Pyramid of the Moon was investigated through 64 archaeological trenches, which uncovered extensive sandstone terraces arranged in a stepped or cascading pattern from base to summit (Figure 6). Terraces were arranged along a north-south axis and often separated by thin layers of clay, possibly used for acoustic or thermal insulation (Figure 7).

In 2013, radiocarbon analysis was performed on carbon-rich material embedded within these terraces. Laboratory results from Kyiv and Uppsala yielded uncalibrated ages of 10,350 ± 50 BP and 6,450 ± 30 BP, respectively (Figure 8). These dates, though significantly younger than those from the Pyramid of the Sun, still suggest the site's prehistoric occupation.

Astronomical alignments associated with the Pyramid of the Moon further contextualize its importance. Observations indicate that during the summer solstice, the shadow of the Pyramid of the Sun completely envelopes the Pyramid of the Moon just before sunset, touching its summit (Figure 9). Additional astronomical shadow phenomena are observed during the equinoxes and winter solstice (Figures 10-12).

Ravne and ravne 3 tunnel complexes

Systematic clearing of over 2.6 kilometers of the Ravne tunnel network revealed more than 50 dry-stone walls, five side chambers, and several large ceramic megaliths (Figure 13). Radiocarbon dating of organic materials extracted from tunnel fill produced diverse results. Charcoal from near a dry-stone wall in Ravne 3 was dated by TÜBİTAK AMS Laboratory to 1677 ± 23 BP, corresponding to a calibrated range of 261-423 CE, indicating post-construction visitation during Late Antiquity (Figure 14) [8].

Earlier radiocarbon results from the Ravne tunnels provided more ancient dates:

- A wooden artifact embedded in conglomerate dated to 34,000 ± 1,500 BP by Silesian University (Gliwice)
- A second sample from the same object dated to 30,600 ± 525 BP by Leibniz Laboratory, Kiel (Tables 1 and 2)

These dates suggest a much earlier formation or reuse of the tunnels than previously considered. Stalagmites within Ravne 3 provided additional chronological insight. Radiocarbon dating of the S001 sample produced a wide range of ages, including a layer dated to 26,200 ± 250 BP (Figure 15). U-Th dating of nearby stalagmites (US001 and S008) produced ages of 19,000 ± 1,000 BP and 15,000 ± 1,000 BP, respectively, further corroborating the deep antiquity of tunnel formation (Tables 3 and 4).

Calcite crystal formations on the ceilings of the Ravne water section were also dated. A sample analyzed by Beta Analytic returned a calibrated age of approximately 7,430 years BP, indicating water infiltration and mineral deposition well before recorded history (Figure 16).

Figure 6: Dr. Paul LaViolette presents the projected calibrated age of the Bosnian Pyramid of the Sun based on radiocarbon analysis.

Figure 7: Bosnian pyramid of the moon, visoko valley, bosnia-herzegovina.

Figure 8: Bosnian pyramid of the moon – archaeological excavations.

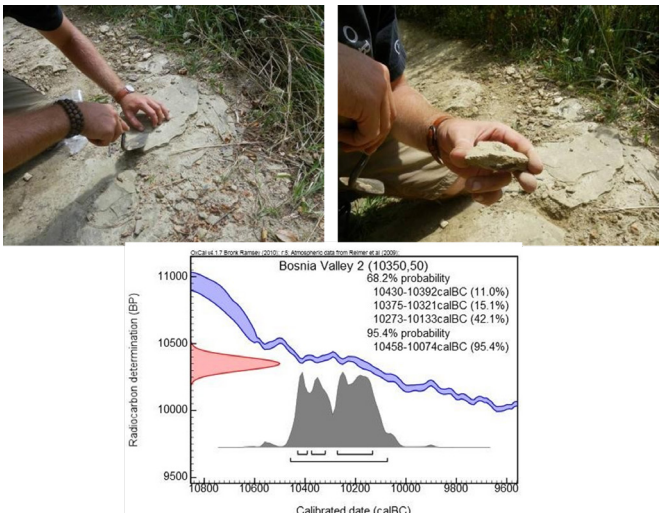


Figure 9: Radiocarbon dating of the paved terrace on the bosnian pyramid of the moon.

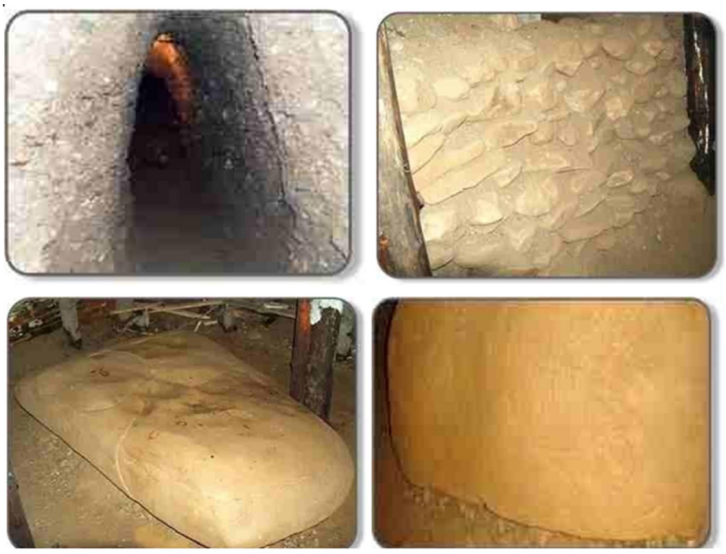


Figure 10: Ravne tunnel labyrinth.

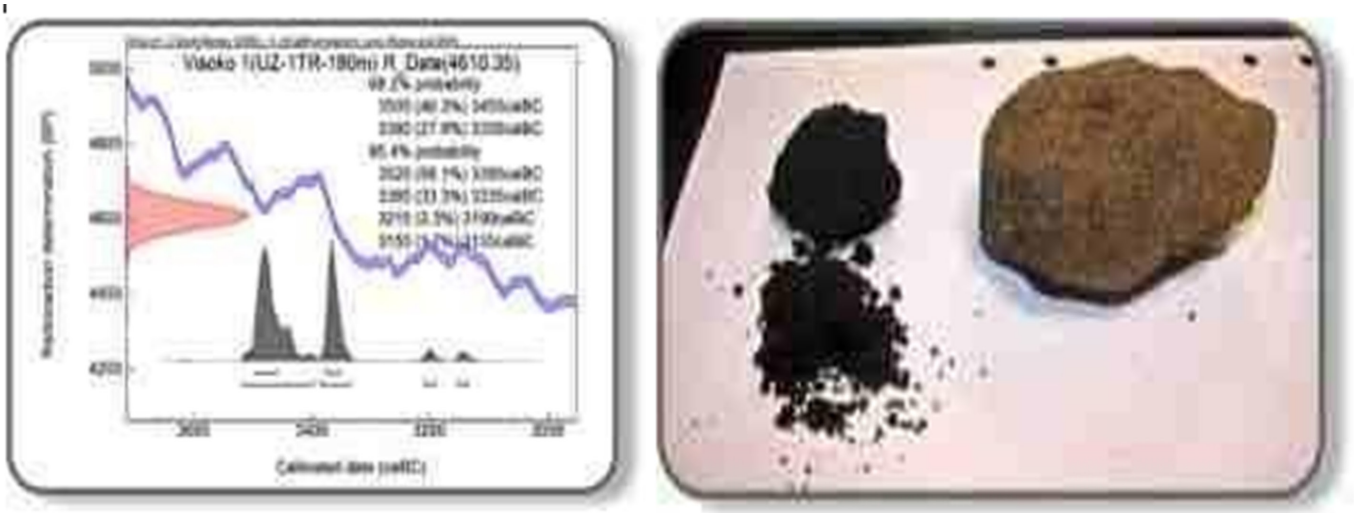


Figure 11: Radiocarbon Dating of Organic Material in Ravne Tunnel Complex.

Figure 12: Wood sample embedded in conglomerate: radiocarbon dating and stratigraphic implications.

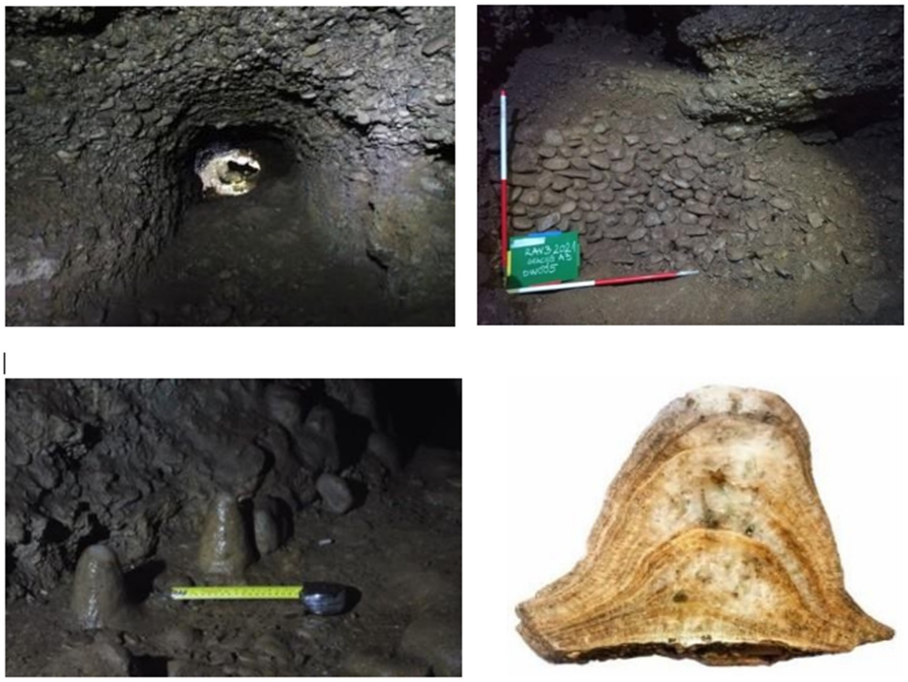


Figure 13: Ravne 3 tunnel complex: Prehistoric construction features and geological indicators.

Figure 14: Stalagmites S001 and S002 discovered in tunnel ravne 3.

Lab No.	Description	Benzene (g)	pMC (%)	Age (years BP)
3729	S001 Layers (B+C)	1.3853	64.5	3520 ± 50
3730	S001 Layers (A)	0.694	72.9	2540 ± 50
3732	S001 Layers (C)	1.2285	61.7	3880 ± 55
3733	S2-018	1.3183	68.3	3070 ± 50
3734	S001 Layers	Lab No.	Lab No.	Lab No.
(B) A	1.0192	3.8	26200 ± 250	Lab No.
3735	S2-025	0.149	26.7	10625 ± 300

Table 1: Radiocarbon Dating Analysis of Sample S001

Замовник(Customer) Зразок(Sample):	**Foundation "Archaeological park Sample S001 (layer B, top)**	**"Bosnian Pyramid of the Sun" (carbonate)**
Код лабораторії (lab code)	IHME-3734	
Маса бензолу (benzene mass)	10,192	грам (g)
Час вимірювання (counting time)	3000	хвилин (minutes)
Швидкість лічення проби (Sample count rate)	0.87	CPM
Фон (імп./хв.) (Background count rate)	0.506	CPM
Ефективність реєстрації (counting efficiency) :	73,51%	Процент (percent)
Радіовуглецева дата (Radiocarbon date)	26200 ± 250	BP

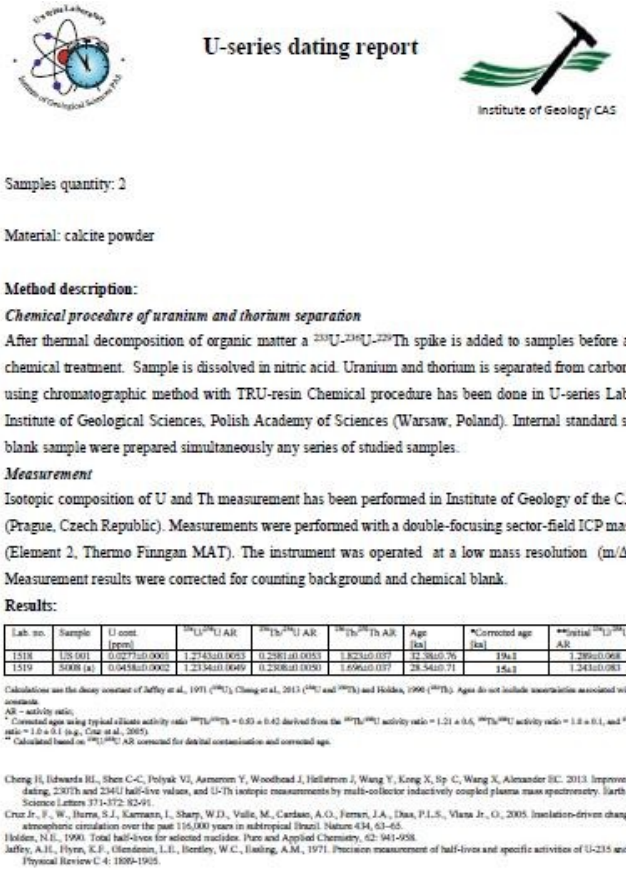
Table 2: Radiocarbon Analysis of Samples from Tunnel Ravne 3: Laboratory Procedures and Results

Report no: 29109288-125.05-4286/29282 Requested by: Dr.Sam Osmanagich Address: ArchaeologicalPark: Bosnian Pyramidof The Sun Foundation-Ravne BB,71300 Visoko Bosnia And Herzegovina	
Sample: Sampletypegivenin table Number of samples 1 Samplehandling: Courier Condition of sampleat reception: Suitable	Barcode No: 23T0001363 Expiry date VP sample register no: 23T/1363 Acceptance date: 05/03/2024 Dateof the analysis: 29/03/2024
Informationon retentionsamples: (x) Samplereturnedto the customer (x) Retentionsampleavailable (x) Retentionsampleis not taken	

Table 3: Sample submission and analysis information

Item No.	Lab. No	Customer No	Radiocarbon Age(BP)	Sample Type	Pretreatment	Calendar Calibration (2o)
1	TÜBİTAK-3259	S001	1677ź23	Charcoal	Acid-Base-Acid	261-278 calAD(%9,7)
						340-423calAD(%85,8)

Table 4: Charcoal radiocarbon dating from ravne 3 tunnel complex



U-series dating report

Institute of Geology CAS

Samples quantity: 2

Material: calcite powder

Method description:

Chemical procedure of uranium and thorium separation

After thermal decomposition of organic matter a ^{233}U-^{236}U-^{229}Th spike is added to samples before any further chemical treatment. Sample is dissolved in nitric acid. Uranium and thorium is separated from carbonate matrix using chromatographic method with TRU-resin Chemical procedure has been done in U-series Laboratory of Institute of Geological Sciences, Polish Academy of Sciences (Warsaw, Poland). Internal standard sample and blank sample were prepared simultaneously any series of studied samples.

Measurement

Isotopic composition of U and Th measurement has been performed in Institute of Geology of the CAS, v. v. i. (Prague, Czech Republic). Measurements were performed with a double-focusing sector-field ICP mass analyzer (Element 2, Thermo Finngan MAT). The instrument was operated at a low mass resolution ($m/\Delta m \geq 300$). Measurement results were corrected for counting background and chemical blank.

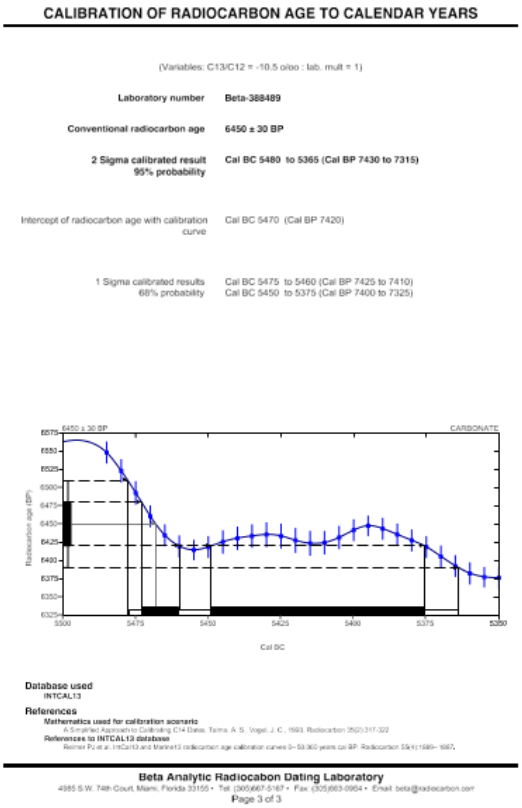
Results:

Lab. no.	Sample	U cont. [ppm]	$^{234}U/^{238}U$ AR	$^{230}Th/^{234}U$ AR	$^{230}Th/^{232}Th$ AR	Age [ka]	*Corrected age [ka]	**Initial $^{234}U/^{238}U$ AR
1518	1/5 001	0.02773±0.0003	1.2743±0.0053	0.2581±0.0053	1.823±0.037	32.38±0.76	19±1	1.289±0.068
1519	5/008 (a)	0.0458±0.0002	1.2334±0.0049	0.2308±0.0050	1.696±0.037	28.54±0.71	15±1	1.243±0.083

Calculations use the decay constant of Jaffey et al., 1971 (^{238}U), Cheng et al., 2013 (^{234}U and ^{230}Th) and Holden, 1990 (^{232}Th). Ages do not include uncertainties associated with decay constants.
AR – activity ratio;
* Corrected ages using typical silicate activity ratio $^{230}Th/^{232}Th = 0.83 \pm 0.42$ derived from the $^{230}Th/^{238}U$ activity ratio = 1.21 ± 0.6, $^{230}Th/^{238}U$ activity ratio = 1.0 ± 0.1, and $^{234}U/^{238}U$ activity ratio = 1.0 ± 0.1 (e.g., Cruz et al., 2005).
** Calculated based on $^{234}U/^{238}U$ AR corrected for detrital contamination and corrected age.

Cheng H, Edwards RL, Shen C-C, Polyak VJ, Asmerom Y, Woodhead J, Hellstrom J, Wang Y, Kong X, Sp C, Wang X, Alexander EC. 2013. Improvements in 230Th dating, 230Th and 234U half-live values, and U-Th isotopic measurements by multi-collector inductively coupled plasma mass spectrometry. Earth and Planetary Science Letters 371-372: 82-91.
Cruz Jr., F., W., Burns, S.J., Karmann, I., Sharp, W.D., Valle, M., Cardaso, A.O., Ferrari, J.A., Dias, P.L.S., Viana Jr., O., 2005. Insolation-driven changes in atmospheric circulation over the past 116,000 years in subtropical Brazil. Nature 434, 63–65.
Holden, N.E., 1990. Total half-lives for selected nuclides. Pure and Applied Chemistry, 62: 941-958.
Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., Essling, A.M., 1971. Precision measurement of half-lives and specific activities of U-235 and U-238. Physical Review C 4: 1889-1905.

Figure 15: Uranium-thorium dating of stalagmites from ravne 3 tunnel complex



CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = -10.5 o/oo ; lab. mult = 1)

Laboratory number	**Beta-388489**
Conventional radiocarbon age	**6450 ± 30 BP**
2 Sigma calibrated result 95% probability	**Cal BC 5480 to 5365 (Cal BP 7430 to 7315)**
Intercept of radiocarbon age with calibration curve	Cal BC 5470 (Cal BP 7420)
1 Sigma calibrated results 68% probability	Cal BC 5475 to 5460 (Cal BP 7425 to 7410) Cal BC 5450 to 5375 (Cal BP 7400 to 7325)

Database used
INTCAL13

References
Mathematics used for calibration scenario
A Simplified Approach to Calibrating C14 Dates. Talma, A. S., Vogel, J. C., 1993. Radiocarbon 35(2):317-322
References to INTCAL13 database
Reimer PJ et al. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55(4):1869– 1887.

Beta Analytic Radiocabon Dating Laboratory
4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • Email: beta@radiocarbon.com
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Figure 16: Radiocarbon dating of calcite crystal formation from Ravne tunnel water section

Summary of dating results

A synthesized chronology, presented in flowchart form (Diagram: Step-by-Step Dating of the Bosnian Pyramid of the Sun), integrates these multi-method dating results. The combined use of radiocarbon, U-Th, and soil profile analysis establishes a multi-phase chronology:

- Construction of the Bosnian Pyramid of the Sun: ~33,800 BP
- Primary activity in Ravne tunnel: ≥ 30,000 BP
- Use of the Pyramid of the Moon: 10,000–6,500 BP
- Post-construction human activity: ~4th century CE

Discussion

The results of this study contribute significantly to the growing body of interdisciplinary research on the Bosnian Valley of the Pyramids by establishing a layered and testable chronological framework. Through the combined application of radiocarbon and uranium-thorium dating, supported by soil profile analysis and stratigraphic observations, a compelling temporal sequence emerges that challenges conventional interpretations of the site's age and complexity [9].

Chronological implications for construction and use

The radiocarbon dates obtained from organic material embedded between concrete-like blocks on the Bosnian Pyramid of the Sun especially the calibrated age of ~33,800 BP suggest a construction phase that predates the Neolithic by tens of thousands of years. This places the pyramid well into the Late Upper Paleolithic, an era for which there is limited documentation of monumental construction on a global scale. The soil development analysis conducted by the Federal Institute for Agropedology supports this conclusion, dating the overlying soil to a minimum of 12,000-15,000 years old, thereby establishing a relative terminus ante quem for the pyramid's surface features [10].

The Pyramid of the Moon, while younger in construction, reveals continuous use or modification across millennia, with radiocarbon dates clustering around 10,000–6,500 BP. The consistency of its terrace formations and their integration into astronomical alignments further support the interpretation of intentional design. Observations of solstitial and equinoctial shadow interactions between the Sun and Moon pyramids imply a high level of planning and astronomical knowledge.

Ravne tunnel system: Age, function, and reuse

The extensive network of Ravne and Ravne 3 tunnels presents a complex palimpsest of activity. The U-Th and radiocarbon dating of stalagmites, calcite deposits, and embedded wood indicate that many sections were open or accessible as early as 30,000-34,000 years BP. These results are bolstered by the presence of megalithic blocks beneath stratified conglomerate layers, suggesting tunnel formation prior to sediment infill and natural sealing. Notably, more recent human interaction with the tunnels is confirmed by charcoal samples dated to the 4th century CE, likely reflecting reuse or ritual visitation rather than original construction. This pattern of initial Paleolithic construction followed by millennia of silence and eventual rediscovery is consistent with other ancient megalithic sites globally [11].

Methodological reliability and interdisciplinary integrity

While early debates surrounding the Bosnian Pyramids focused heavily on their classification as natural or artificial, this study emphasizes the value of verifiable scientific methods to bypass that dichotomy. The chronological data presented herein are independently verifiable, laboratory-validated, and sourced from internationally accredited institutions. The potential presence of "dead carbon" in speleothems and sediment-bound samples was accounted for through methodological triangulation combining U-Th and C-14 dating with geochemical context to assess contamination risks. Calibration curves (IntCal13 and IntCal20) were consistently applied, and sample integrity was maintained through careful stratigraphic documentation and international submission protocols.

Context within southeastern European prehistory

The findings of this study suggest the Bosnian Valley of the Pyramids may represent one of the earliest examples of megalithic activity in Southeastern Europe, potentially predating known Mesolithic and Neolithic cultures in the region. While this interpretation remains provisional, pending further excavation and interdisciplinary review, the currently available evidence necessitates the reconsideration of cultural capacities in the Late Pleistocene Balkans [12].

Future research directions

The results presented in this study underscore the need for continued, multidisciplinary investigation of the Bosnian Valley of the Pyramids. The unexpectedly early radiometric dates, particularly those related to the Bosnian Pyramid of the Sun and the Ravne tunnel system, invite further scrutiny not only to refine current chronologies but also to explore the broader cultural and environmental implications of the findings.

Expanded radiometric sampling

Future work should prioritize broader radiocarbon and U-Th sampling across stratified contexts and a wider variety of materials. This includes:

- Additional dating of stalagmites and calcite crusts in the less-disturbed sectors of Ravne 3;
- Targeted radiocarbon analysis of organic residues found beneath megalithic terraces on the Pyramid of the Moon;
- Testing of sedimentary carbonates within sealed segments of the Ravne tunnels, especially where construction-like dry walls intersect flowstone deposits.

Ensuring redundant testing across multiple laboratories will further strengthen chronological confidence and mitigate concerns over localized contamination.

Geoarchaeological correlation

Improved correlation between radiometric dates and geomorphological processes such as sediment transport, percolation pathways, and pedogenic changes will help differentiate between construction-related events and natural depositional sequences. Detailed soil micromorphology, isotope geochemistry, and mineral composition studies could offer further insights into anthropogenic versus natural layering [13].

Non-Invasive subsurface imaging

Geophysical techniques such as Ground-Penetrating Radar (GPR), Electrical Resistivity Tomography (ERT), and muon tomography should be deployed more extensively to detect potential internal structures within the pyramidal formations and to trace the full extent of subsurface voids or tunnel branches. Integration with existing LiDAR and photogrammetric models will aid in predictive excavation planning.

Cultural and astronomical integration

As astronomical alignments continue to emerge as a significant

architectural feature, systematic archaeoastronomical surveys—including simulations of celestial movements in prehistoric epochs should be undertaken. Ethnographic analogs and regional mytho-historical records may also yield context for intentional site orientation and landscape symbolism.

Open Data and Peer Collaboration

To facilitate broader academic engagement, future research should prioritize transparent, peer-accessible publication of datasets, including all laboratory reports, field logs, and calibration files. The promotion of open scientific dialogue across disciplines—archaeology, geology, physics, and archaeoastronomy is essential to assess the site's significance with both rigor and neutrality [14].

Conclusion

The Bosnian Valley of the Pyramids presents a unique and complex archaeological landscape whose features warrant serious scientific attention. Through the application of radiocarbon dating, uranium-thorium series analysis, and soil chronology, this study provides a coherent multi-method framework for establishing the temporal depth of key structures within the valley—including the Bosnian Pyramids of the Sun and Moon and the Ravne tunnel systems.

The evidence consistently points toward phases of construction or accessibility that significantly predate the Neolithic period, with calibrated radiocarbon dates as early as 33,800 years BP for the Pyramid of the Sun and 30,600–34,000 years BP for embedded organic material in the Ravne tunnels. Meanwhile, the Pyramid of the Moon demonstrates layered human interaction over thousands of years, supported by its integration into astronomical alignments and extensive megalithic terraces. The discovery of Late Antiquity charcoal within Ravne 3 indicates later, secondary human engagement with the site, reaffirming its long-term cultural relevance.

These findings challenge prevailing assumptions about prehistoric activity in the Balkans and highlight the need for continued, transparent, and interdisciplinary research. While questions remain regarding the origin, function, and cultural context of these structures, the robust chronological data establish a factual baseline from which further archaeological, geological, and archaeoastronomical inquiry can proceed.

Acknowledgment

The author expresses sincere gratitude to the Federal Institute for Agropedology (Sarajevo) and its late director Prof. Husnija Resulović for foundational research on pedogenetic soil dating on the Bosnian Pyramid of the Sun. The author also acknowledges the editor of the ICBP Proceedings, the late Professor Muris Osmanagić, for his early support in promoting interdisciplinary scientific dialogue related to the Bosnian Valley of the Pyramids.

Special thanks are extended to the following laboratories for conducting radiocarbon and uranium-thorium dating with methodological precision and professionalism:

- Silesian University of Technology, Gliwice, Poland
- Leibniz Laboratory for Radiometric Dating, Kiel, Germany
- Uppsala University, Sweden
- TÜBİTAK MRC AMS Laboratory, Turkey
- Beta Analytic Radiocarbon Dating Laboratory, USA
- Institute of Geological Sciences, Polish Academy of Sciences, Warsaw
- Institute of Geology, Czech Academy of Sciences, Prague

The author further acknowledges the contributions of professional archaeologists who led and supervised field excavations during various seasons: Ricardo Brett, Nicolo Bisconti, and Sarra Acconci (Italy); Tim Moon (New Zealand); and Andrew Lawler (United Kingdom), whose detailed trench documentation and stratigraphic interpretation strengthened the archaeological integrity of the site.

Appreciation is also extended to the Cantonal Ministry of Culture (Zenica-Doboj Canton) for its continued support in authorizing excavation permits and facilitating long-term heritage preservation.

Finally, the author expresses heartfelt thanks to the local community of Visoko and the thousands of international volunteers who have contributed their time, energy, and goodwill to this ongoing research effort since 2005.

Funding statement

This research was independently funded by the author, Dr. Sam Osmanagich, and conducted under the auspices of the Archaeological Park: Bosnian Pyramid of the Sun Foundation. No external grants were received for the design, data collection, analysis, or publication of this study.

Competing interests

The author declares no competing financial or non-financial interests relevant to the content of this article.

Author contributions

Dr. Sam Osmanagich was solely responsible for the conception, fieldwork coordination, sample collection, literature review, data interpretation, manuscript writing, and submission process.

Ethics approval and permissions

All archaeological investigations were conducted with formal approval from the Cantonal Ministry of Culture (Zenica-Doboj Canton) and were carried out in compliance with local cultural heritage protection laws. No human or animal subjects were involved in this study.

Data availability

All laboratory reports, dating certificates, and field documentation cited in this study are available from the corresponding author upon reasonable request. Select documents are publicly accessible via the Foundation's official archive (http://www.piramidasunca.ba, www.icbp.ba) and booksbydrsam.com.

References

1. Radiocarbon Dating Certificate – Sample Beta-388849. Miami, FL: Beta Analytic Inc. Beta Analytic. 2024.
2. Dalan RA (2014) A Refined Approach to Calibration of Radiocarbon Data.
3. Radiocarbon 56 (2): 737–752.
4. Doğan M, Demirel Y, Yücel N, Tetik K, Yavuz, M (2023) Radiocarbon Analysis and Status Report from Türkiye: 1 MV National AMS Laboratory (TÜBİTAK-AMS). Radiocarbon.
5. Lawler A (2008) AMS Radiocarbon Dating of a Wood Sample from Tunnel Ravne: Methods, Results and Implications for Further Research. Int Rep Archaeol Park Foundation.
6. Leibniz Laboratory (2008) Radiometric Dating Report for Wood Sample, Kiel University. Christian-Albrechts-Universität zu Kiel, Germany.
7. Osmanagich S (2014) Pyramids Around the World & Lost Pyramids of Bosnia. Sarajevo: Archaeological Park: Bosnian Pyramid of the Sun Foundation.
8. Osmanagich S(2023) Bosnian Pyramids – My Story. Visoko: Archaeological Park: Bosnian Pyramid of the Sun Foundation. ISBN 978-9958-674-10-5.

9. Osmanagich S, Hoyle R, Agic A, Delibašić H (2023) Ravne 3. Visoko. Archaeological Park: Bosnian Pyramid of the Sun Foundation.

10. Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, et al (2020) The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP) Radiocarbon 62 (4): 725–757.

11. Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, et al (2013) IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55(4):1869-87.

12. Resulović H, Čustović, H (2008) Pedomemory as a Source of Information on Soil.

13. Development, Processes and Age in the Function of Archaeological Investigations. In ICBP Proceedings: First International Scientific Conference. Bosnian Valley of the Pyramids 495–500.

14. TÜBİTAK MRC AMS Laboratory (2024) Radiocarbon Dating Report, Sample S001. Gebze: TÜBİTAK Marmara Research Center.