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The Becoming of a Prehistoric Landscape: Palaeolithic Occupations and Geomorphological Processes at Lojanik (Serbia)

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Abstract: Accomplishing long-term plans to harvest and modify natural resources has been a crucial skill for the survival of our species since early Prehistory. Research on this first step of production mostly focuses on the provenience study of lithic artifacts uncovered at archaeological sites, using petrographic and geochemical analyses to correlate the artifacts with potential geological outcrops. Although fundamental for understanding key aspects of landscape use and mobility, regional raw material economy, and extraction technology, Palaeolithic raw material sources have been less intensively investigated, as they are often difficult to locate and challenging to tackle with traditional archaeological approaches. Lojanik in the Central Balkans is one of the largest Prehistoric quarrying areas known in Europe, showing numerous lithic raw material outcrops exploited from the Middle Palaeolithic to the Chalcolithic periods, over an area of 18 hectares. In this paper, we present the results from our renewed research program in this region. Combining airborne LIDAR mapping, geomorphological and archaeological survey, and techno-typological analysis of lithic artifacts, we were able to reconstruct the geomorphological evolution of the landscape and its use by prehistoric societies.

Keywords: archaeological survey; LiDAR; geomorphology; lithic analysis; Middle Palaeolithic; Upper Palaeolithic; Serbia

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1. Introduction

The capacity of humans to exploit natural resources has been crucial for their survival throughout history. It illustrates their cognitive capacity for long-term planning, selection, predetermination, and resource management. To understand Prehistoric societies, it is important to study the way they acquire and manage their raw materials, especially the lithic component, which represents an important part of the remains recovered from this period.

The study of lithic raw material procurement in Europe is usually focused on petrography in order to identify the type of raw material and possible outcrops. Palaeolithic mines and quarries have seldom been extensively studied for themselves, especially for Lower (ca. 3.3 million years ago–300,000 years ago) and Middle Palaeolithic (ca. 300,000–30,000 years ago). However, they are important assets when trying to understand regional economic systems, as they allow us to study landscape use and mobility, raw material economy, and lithic technology.

Being a corridor for human migrations [1–9], the Balkan peninsula presents a perfect area for the study of the evolution of human interaction with their environment, as we should expect ancient societies to gravitate around and exploit areas rich in lithic raw material—an invaluable resource during prehistoric times. Zones of raw material extraction show evidence of a long-standing relationship between humans and their landscape, and how it changes with different human species or cultural groups. Despite this advantageous position, the archaeological record of this region is not as rich in Palaeolithic sites as one could expect, and the region is often absent from general interpretations. Neanderthal occupation patterns are difficult to theorise due to uneven research, and our understanding of their typo-technological solutions remains limited [10]. A surprising characteristic of the Balkans is the rarity of Middle Palaeolithic elements that can be linked to the Levallois concept of reduction (as defined by [11–13]), which is the most widespread reduction system for this period in Europe and the Near East [14]. Although rare and poorly dated Levallois artefacts have been identified in some sites, most Middle Palaeolithic assemblages in the Balkans are characterised by a more expedient, Discoid-based industry throughout the Danube corridor, as well as Micromousterian and Denticulate Mousterian along coastal areas [15]. These variations are still difficult to explain due to the lack of absolute dates and the fact that vast areas of the Balkan peninsula remain under investigated. In Serbia especially, research was mostly concentrated on cave sites of intermediate mountain landscapes, while it is probable that Palaeolithic populations occupied more densely the valleys and basins.

The Lojanik complex is an open-air locality of west-central Serbia on the right bank of the Ibar river, 200 km south of Belgrade (Figure 1), where numerous lithic raw material outcrops have been identified over an area of twelve hectares [16,17]. The outcrops were exploited during later Prehistory (Neolithic and Chalcolithic, which date in the region from ca. 6500 to 1000 years BC), but some artefacts showed Middle Palaeolithic traits. The recent discovery of clear Levallois elements (cores and preferential products) in some of the different sites of Lojanik confirms that the site was exploited as early as the Middle Palaeolithic era [17]. As we mentioned previously, this Levallois component is a very rare occurrence in the central Balkans, making Lojanik a key raw material industrial complex for the comprehension of raw material extraction strategies and their evolution from the Middle Palaeolithic to Chalcolithic.

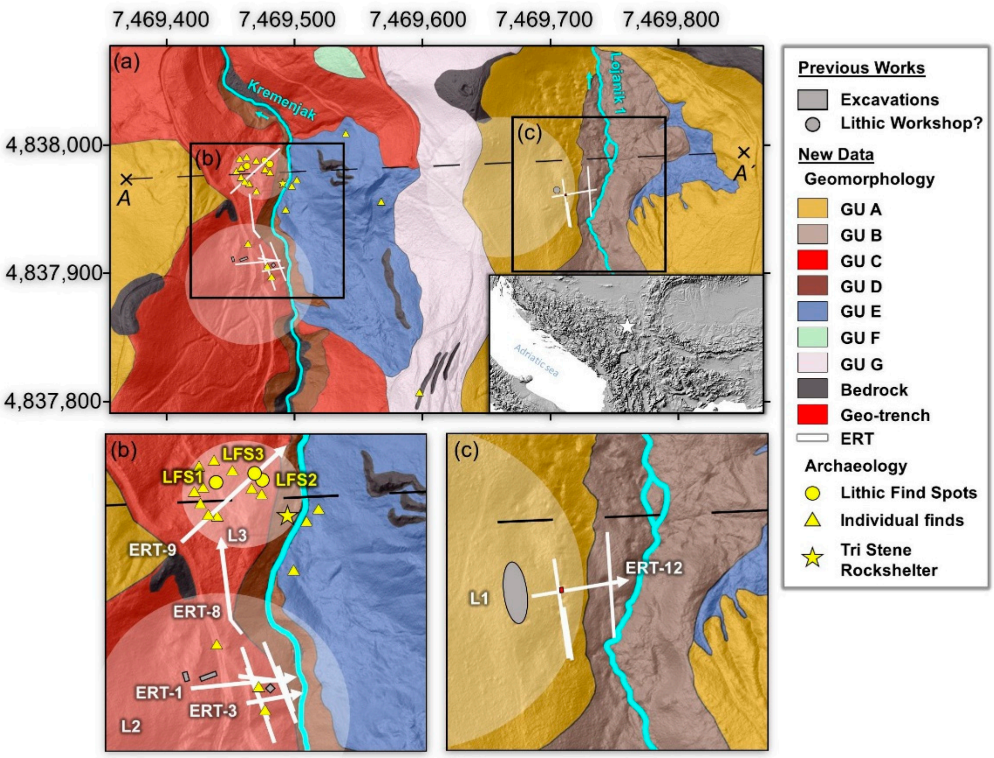


Figure 1. *Cont.*

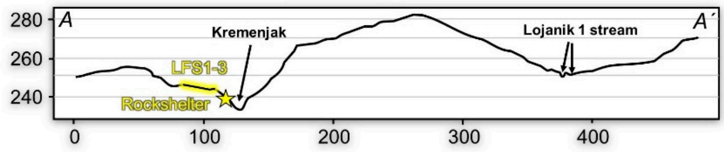


Figure 1. Study region: (**a**) Geomorphological map displaying the main Geological Units (GU) mapped during our survey, based on the LiDAR data. (**b**) Detail from the Kremenjak Valley showing Lojanik 2 (L2), our Lithic Find Spots (LFS) from Lojanik 3 (L3), and the Electrical Resistivity Tomographies (ERT) displayed in Figure "ERT1". (**c**) Detail from the Lojanik 1 Valley displaying Lojanik 1 (L1), our Geotrench, and the ERT data exhibited in Figure "ERT2". A–A′ topographic section across the two valleys, location in detail (**a**).

In this article, we present the results of our 2022 field study, which encompass different field and laboratory methodologies, designed to provide an understanding of prehistoric human behaviour on a regional, micro-regional, and local scale.

2. Materials and Methods

2.1. Study Area

The Lojanik complex is an open-air locality that encompasses hills and valleys, which developed along faults [18] and drain into the Ibar River—an important axis of communication from Prehistory to today, crossing south to north from Montenegro until the West Morava River. Prehistoric societies have been documented in the region, which is regarded as part of important migratory routes for Prehistoric humans [16,19,20].

The geological history of Lojanik is unique, as it was formed by the silicification of an ancient forest by a cataclysmic event during the Miocene [21]. The petrified wood created by these processes has been exploited since prehistorical times until today as sharpening material for knives and agricultural tools, such as scythes [16]. This opalised wood was also a good quality knapping material, and its use by prehistoric humans has been attested in the nearby late-Neolithic site of Divlje Polje, leading to surveys of the Lojanik complex to understand the origin of the material [22,23]. In the frame of research about the Neolithic and Mesolithic occupations of the West Morava Valley, it was demonstrated that Lojanik opal was found in other localities in the surroundings, such as the Early Neolithic settlement of Crkvine, shedding new light onto the interpretation of Neolithic mobility and territories in the region [24]. From 2016 to 2021, Lojanik has been systematically surveyed to understand the raw material exploitation techniques from the Palaeolithic until today [24]. The first area to be surveyed, Lojanik 1, is located on the west flank of a seasonal unnamed stream—that we call "Lojanik 1 stream" (Figure 1)—and is characterised by surface scatters of artefacts which have been surveyed and 3D scanned to understand their organization [25]. From 2017, another locus has been surveyed on the west slope of the Kremenjak Valley (fig.), Lojanik 2, which was tested with three trenches (A, B and C). Recent research has demonstrated that a division of the space had been implemented in some localities, with distinct extraction, workshop, and discard zones [25]. In 2017, the discovery of a Levallois recurrent centripetal core opened new perspectives of interpretation and demonstrated the significance of the Lojanik complex, since Levallois elements are very scarce in the Central Balkans Palaeolithic record [17]. Our 2022 field study was organised to better understand the status of this Levallois component and the earliest Palaeolithic occupations of the site.

2.2. Methods

To locate new archaeological occurrences and establish a correlation between surface finds and geomorphological processes, we combined remote sensing, geomorphological and archaeological surveys, geophysical prospections, as well as geological excavations.

An airborne Light Detection And Ranging (LiDAR) survey [26] was performed on the study region to penetrate the dense forest coverage and obtain high resolution (0.25 m) topographic data of the ground surface. The use of airborne LiDAR has already been attested in numerous sites to define architectural features of later time periods, e.g., [27–29], but its use in the study of prehistoric landscapes is yet to be developed. The data obtained has helped us to produce a targeted pedestrian survey, aimed at reconstructing the geological and depositional environment of the area, as well as defining archaeological features present here.

The LiDAR results were analysed with the software SAGA (SAGA User Group Association, Hamburg, Germany) and QGIS (QGIS.org, %Y. QGIS Geographic Information System. QGIS Association. http://www.qgis.org (accessed on 10 November 2022)) to produce topographic [30], slope/aspect [31–35], and hillshading maps [36], as well as topographic cross-sections of selected features (QGIS Profile Tool). These maps and cross-sections enabled us to locate key, potential landforms, such as breaks-in-slope, gullies, bedrock outcrops, and pits. We expected that these features had high potential to yield archaeological material and could be used to explore the relation between archaeological occurrences and different geomorphological processes. For instance, breaks-in-slope might correspond to bedrock or river terraces and, thus, might preserve intact archaeological deposits (e.g., [37,38]). Gullies' margins provide natural sediment exposure, which can be surveyed to investigate the occurrence of buried archaeology-bearing deposits in the landscape (e.g., [39,40]). Opal outcrops were likely exploited by the Prehistoric people of Lojanik for quarrying [16,25]. Additionally, bedrock outcrops have been commonly used as shelters by Prehistoric humans (e.g., [41,42]), thus locating them was an important step of our study. Lastly, the excavation of pits to extract raw materials has been a well-established practice since at least the Neolithic period [43–46], probably also at Lojanik [16]. Therefore, identifying human-made pits was important to document phases of landscape use and raw material extraction in our study area.

We focused our fieldwork on two areas that appeared more promising from an archaeological point of view, located in the vicinity of the previously surveyed sites of Lojanik 1 and Lojanik 2 (Figure 1). With targeted surveys, we located in the field the potential landforms detected by LiDAR, we cleared the vegetation that was covering them and documented them with photos and occasionally with photogrammetry (using the software Metashape). Within each sediment exposure, we distinguished separate geological layers (GL) based on lithological properties. These included depth, transition to the next lower sediment [47], and amount of coarse (>2 mm) and fine fraction (<2 mm [48]). For the coarse fraction, we described colour, composition, frequency [48], size (ISO 14688-1:2002 standard), shape [49], roundness [50], sorting [51], and orientation. For the fine fraction we reported Munsell colour and texture, which was estimated in the field "by feel", following the protocol published by Vos et al. [52]. For simplicity, when presenting the result of our surface mapping, we grouped the GLs identified in the field into facies, named geological units (GU).

To gain insights about their underground geometry, depth to bedrock, and lithology, we surveyed with geophysical methods a representative group of landforms, such as breaks-in-slope, potential rock outcrops, and potential man-made pits. Electrical Resistivity Tomography (ERT) is a non-invasive geophysical method employed to reconstruct the lithological properties of the subsurface by measuring and modelling its electrical resistivity (e.g., [53,54]). Previous studies have demonstrated the ability of ERT methods to map the bedrock topography (e.g., [55,56]), detect human-made pits and ditches (e.g., [57,58]), as well as provide insights on the landscape evolution of river valleys (e.g., [59,60]). In the field, we collected 14, 2D, freely oriented ERT profiles using a Lippmann 4-point light 10 W resistivity meter connected to a chain of 20 electrodes, which we inserted in the ground along straight lines. ERT data were acquired with electrode spacing of 1 m along the transects ERT-2, 3, 7, and 11, while an electrode spacing of 2 m was used along the remaining survey lines from ERT-1 to ERT-14. ERT-9, which covers a length of 55 m, was acquired following a roll-along protocol. All ERT data were acquired using Dipole–Dipole, Wenner, and Schlumberger arrays. All measurements were evaluated as both separate and joint inversions [61] with the software ResIPy [62]. In this paper we present the results of the jointed inversion, as these have higher data sensitivity.

Due to restrictions in our fieldwork permit, excavation was limited exclusively to the re-opening of one of the many, partly refilled pits, that we identified downslope from the site of Lojanik 1. A small (1 × 0.5 m) geological trench was dug to re-open half of this pit down to its bottom, this allowed us to corroborate our interpretation of the ERT data and investigate formation and geomorphological context of this man-made feature. Its infilling was removed, respecting the morphology of sedimentary contacts, and retrieving all identified archaeological materials. The GLs we distinguished in the field were described following the same protocol used for the natural sediment exposures (see above).

Key geomorphological features were also surveyed for archaeological materials. The LiDAR data allowed us to select places of interest where artefacts could be more visible such as breaks-in-slope or bedrock outcrops. We also closely monitored places where the sediment could have unearthed artefacts by recent movement, such as around tree roots or sediment exposed by either erosion or recent human modifications of the landscape, e.g., roads and hiking trails. When a locus was identified, we intensively surveyed its surroundings. We did not collect the artefacts, but set up a data recording strategy based mainly on the three-dimensional modelling of the diagnostic artefacts directly in the field by structure-from-motion methods using a portable field setup and the software Metashape. The coordinates of each locus were recorded with a Differential GPS (DGPS), with the ReachView 3 survey app.

Three types of loci were distinguished:

- Isolated artefacts;
- Findspots, which are clusters of artefacts scattered on less than 1 square meter;
- Find areas, which are larger scatters, and can include different findspots.

We collected typo-technological data with the E5 program developed by OldStoneAge. We took a peculiar interest in diagnostic artefacts, such as cores or predetermined flakes, that would allow us to precisely attribute the artefact to a specific technocomplex, as this study does not aim to be exhaustive but to draw a first picture of the history of the human occupations in Lojanik.

3. Results

3.1. Geoarchaeological Results

a Geomorphological mapping

From a geomorphological point of view, the Kremenjak Valley, where Lojanik 2 is located, and the unnamed valley where Lojanik 1 is situated (from here on "Lojanik 1 Valley") appear dissimilar. The first valley is narrow ("V" shaped), exhibits steep flanks (up to 40–70°), and shows frequent active and relict erosional features, such as gullies and scarps, likely resulting from the formation of debris flows [63]. The lack of run-out lobes downslope from the scarps indicates that the Kremenjak, while dry in spring and summer, has enough water discharge in fall and winter to remove sediments and possibly even carve the bedrock outcropping from its riverbed. On the other hand, the Lojanik 1 Valley is more open ("U" shaped), is completely dry in spring/summer, and has a shallower bottom (15 m above the Kremenjak stream). This valley also exhibits gentler flanks (up to 20–55°) and rare geogenic erosional landforms. Up to 30 m downslope and 80 m north from the archaeological area Lojanik 1, the western flank of the Lojanik 1 Valley is carved by numerous, subcircular, human-made pits. The size of these features changes along the hillside, with the smaller ones (ca. 3 m in diameter, 40 cm in depth) located in the upper part of the slope and the larger ones (ca. 6 m in diameter, 1.5 m in depth) situated at the valley bottom.

The two valleys appear also different from a sedimentological point of view. GU A (Figure 2a) is the sole lithological unit we documented in both valleys, covering the western hilltop above the Kremenjak and most of the flanks of the Lojanik 1, including the majority of the archaeological area Lojanik 1. This unit is made from frequent, triaxial to equiaxial, subangular to subrounded fossilised wood, serpentinised peridotites, and very rare opal embedded in yellowish brown (10 YR 5/3–5/6) to light olive brown silty clay (2.5 Y 5/3–5/6). This sediment appears from moderately compacted to loose, depending on the density of the vegetation cover. Aside from GU A, the Lojanik 1 Valley is mostly entirely filled with common, fine to medium, triaxial to equiaxial, subangular to subrounded, serpentinised peridotites embedded in poorly compact silty clay, which range in colour from very dark greyish brown (10YR 3/2) to strong brown (7.5 YR 4/3–4/6; Unit B; Figure 2b). This deposit appears laterally eroded and redeposited by the stream. Most of the sediments we observed along the slopes of the Kremenjak Valley correspond to common, fine to medium, fresh to highly weathered, subangular to subrounded fragments of peridotites, fossilised wood, and opal. These gravel-sized components are buried in moderately compact clay-rich matrixes, which show reddish brown (5 YR 4/3–4/4) to yellowish brown (5 YR 4/6) colours (GU C; Figure 2c). Most of the archaeological area of Lojanik 2 and Lojanik 3 (LFS1, LFS2, LFS3) falls within this lithological unit. Sediments with high clay content and moderate sorting similar to those we documented in GU C might have been accumulated by water-driven sedimentary processes. These could be related to fluvial or colluvial processes. The first hypothesis appears to be supported by the occurrence of breaks-in-slope of possible fluvial origin in the areas of Lojanik 2 and Lojanik 3. On the other hand, the hypothesis that at least part of GU C was accumulated by colluvial mud flows [64,65] cannot be ruled out based on our lithological data. The lower slopes of the Kremenjak Valley are covered with loose sediments, made from frequent, subangular, triaxial bedrock fragments embedded in very rare, dark yellowish brown to dark brown (10 YR 4/4–7.5 YR 3/3) silty sand to silty clay (GU D). Active gullies carving into both GU C and GU D are common, as well as opal-rich peridotite outcrops. Through surface mapping we were unable to verify whether all these outcrops corresponded to bedrock or boulders that fell from a large bedrock outcrop located upslope from the area Lojanik 3 (Figure 2f). Slope instability is clearly higher along the eastern flank of the valley, where we observed very loose, dry, locally de-vegetated, yellowish brown to light olive brown (10 YR 5/6–2.5 Y 5/4) scree deposits (GU E; Figure 2d). The higher immaturity of these sediments in comparison with those accumulated along the opposite valley flank (GU C) suggests that these scree deposits might have formed more recently, possibly as result of the extensive modern logging and quarrying activity conducted along this slope. Alternatively, this stark difference in lithology might reflect different moisture availability along the two slopes. Aside from a localised fluvial deposit composed of well-rounded, triaxial to oblate, polished, fine to medium gravel of limestone and sandstone embedded in a red clay (2.5 YR 4/6; GU F; Figure 2e), most of the ridge separating the Kremenjak and Lojanik 1 valleys exhibits outcropping bedrock. This is only locally covered with compact, possibly authigenic, clay (GL G), which appears light olive brown (2.5 Y 5/3) to light yellowish brown in colour (2.5 Y 6/3).

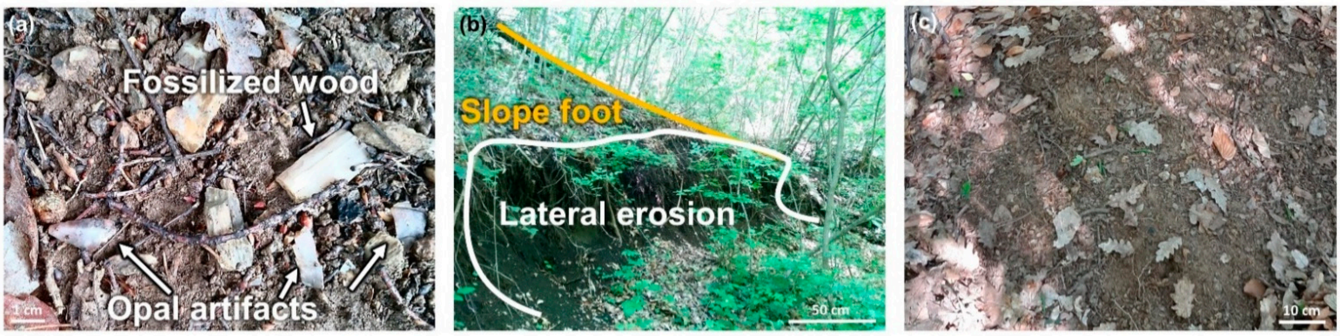
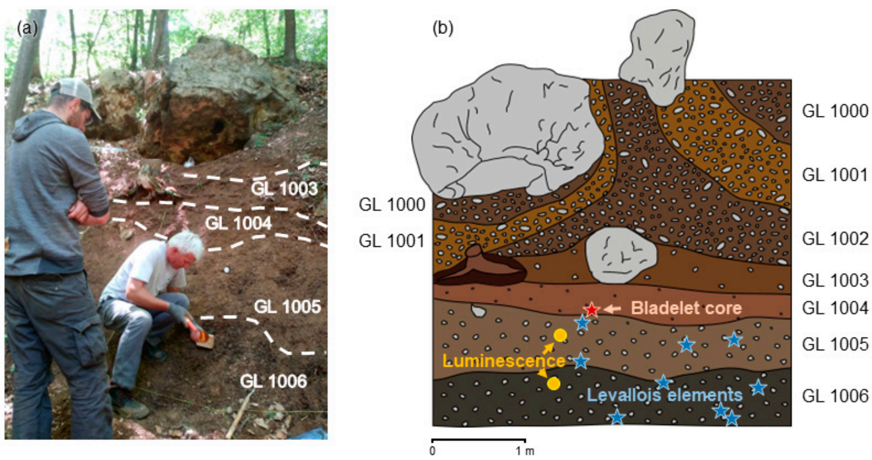


Figure 2. *Cont.*

Figure 2. Geological units detailed in the text: (**a**) Unit A, in the Lojanik 1 area; (**b**) Unit B, at the Lojanik 1 Valley bottom, with an example of stream lateral erosion; (**c**) Unit C, in the Lojanik 3 area, close to LFS1; (**d**) Unit E, on the eastern slope of the Kremenjak Valley; (**e**) Unit F; (**f**) Bedrock outcrop, between Lojanik 2 and 3.

b. Tri Stene Rockshelter

Some 40 m North from the archaeological area Lojanik 2, within the larger GU D, we identified a 2 m high exposure which was likely uncovered by the Kremenjak River through lateral erosion (Figure 3). This sequence, sheltered by opal-rich peridotite rocks, stood out from other sedimentary exposures we observed throughout our survey, as it appeared stratified and contained stone tools. The top of this sequence is made from frequent, subangular to subrounded, triaxial, fine to medium gravel of peridotite and opal (including lithic artifacts) embedded in a loose, extensively bioturbated silty sand. Based on the fine fraction colour, we could distinguish three separate sediments within this larger deposit: a central dark yellowish-brown unit (10 YR 4/4; GL 1001) sandwiched between an upper and lower dark brown layer (7.5 YR 3/3; GL 1000 and GL 1002). These sediments appeared to be the downslope continuation of colluvial lobes descending from the higher portion of the hillside. Below them, underneath a sharp contact, we distinguished rare subrounded peridotite gravel with rare lithic artifacts made from opal, embedded in a compact, strong to dark brown clayey silt (7.5 YR 4/6–3/3; GL 1003). This layer covered (from top to bottom): a very loose brown clayey silt (7.5 YR 4/4; GL 1004) poor in archaeological finds; a compact brown to strong brown (7.5 YR 4/3–5/6) silty clay, with common subangular peridotite and rare lithics (GL 1005); and common, weathered gravel and stone tools embedded in (10 YR 3/3) silty clay (GL 1006). Modern bioturbation appeared intensive in this lowermost layer, likely because of the higher moisture content caused by the water stand oscillations of the Kremenjak River. We plan to determine the chronology of the sequence through luminescence dating. Samples for these analyses have already been collected from layers GL 1005 and GL 1006.



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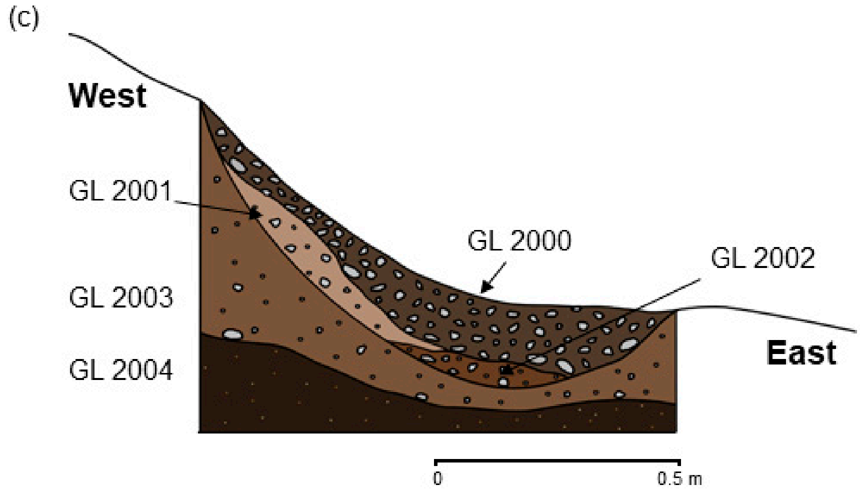

Figure 3. Stratigraphic data: (**a**) Tri Stene Rockshelter during luminescence sampling, analysis underway; (**b**) Schematic drawing of the lithological units and location of key archaeological materials identified at Tri Stene Rockshelter; (**c**) Schematic cross-section drawing from Geo-trench 1.

c. Electrical resistivity tomography

To gain insights into the nature of features detected during our geomorphological mapping (such as breaks-in-slope and potential bedrock outcrops) and collect preliminary data about the formation of Kremenjak and Lojanik 1 valleys, we acquired ERT data along freely oriented lines. Across the western flank of the Kremenjak Valley, we detected a laterally continuous, stratified sequence (Figure 4). From top to bottom, we identified a potential lithological unit exhibiting resistivity between 1.8 and 3 log10 Ωm (ERT-A). This body outcrops at the ground surface and reaches a maximum depth of 3 m. Considering electrical properties [66,67] and location across the slope, ERT-A likely corresponds to the numerous opal rich peridotite rocks we observed during our geomorphological mapping in the archaeological areas Lojanik 2 and 3. Our ERT data demonstrate that these rocks are not bedrock outcrops but rather loose boulders, which likely accumulated during rockfalls. Underneath ERT-A, we documented a resistive unit (1.4 to 1.8 Ωm; ERT-C) sandwiched in between two conductive layers (0.7 to 1.1 Ωm; ERT-B and ERT-D). Based on published reference data [60,68–71], we interpret these potential lithological bodies as boulder/gravel- and clay-rich sediments, respectively. The geometry of these deposits appears to be better resolved in the 1 m spaced tomographies. In particular, in ERT-3, these sediments appear sub-horizontal and truncated by an erosional surface, which was subsequently buried by ERT-A. This suggests that ERT-B, ERT-C and ERT-D might correspond to incised and locally reworked river terraces [59,60,72]. This part of the sequence has a maximum thickness of 10–15 m and rests on top of a unit that exhibits resistivity between 1.5 and 1.8 Ωm (ERT-E). Considering its electrical properties [60,68–71] and its position in the landscape, we hypothesise that ERT-E corresponds to the bedrock that we observed outcropping at the rockshelter and at the valley bottom. Remarkably, ERT-E appears to delimit a laterally continuous depression, which is elongated in the north–south direction and located some 20 to 40 m west from the present course of the Kremenjak. Considering the estimated depth of this feature, it is likely that, prior to the accumulation of ERT-D, the Kremenjak River carved the valley floor either down to or deeper than the current valley bottom.

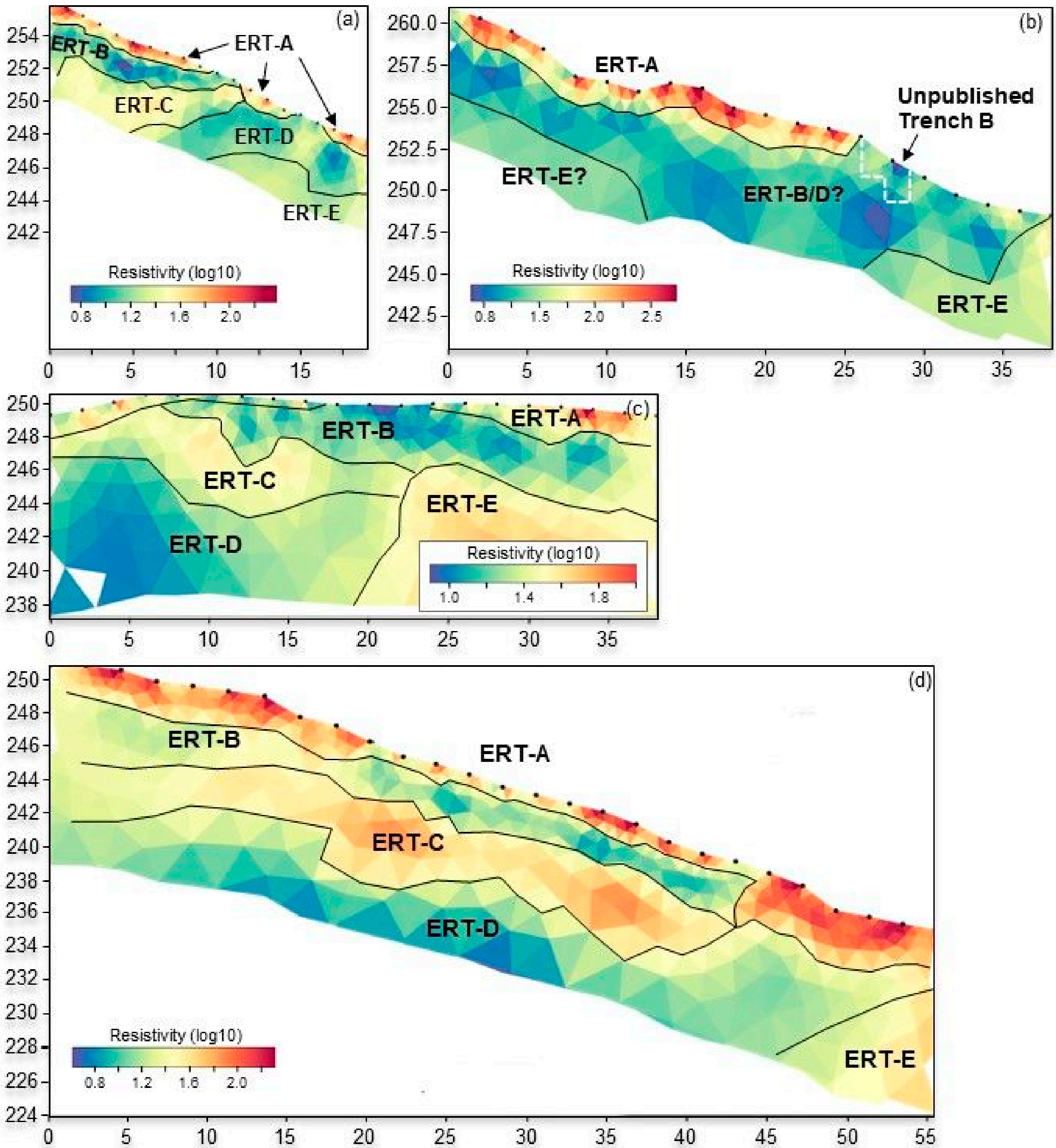

Figure 4. Electrical Resistivity Tomography (ERT) results from the Kremenjak Valley: (**a**) profile ERT-3; (**b**) ERT-1; (**c**) ERT-8; (**d**) ERT-9. All the subpanels display jointed inversions of resistivity measurements acquired with Dipole–Dipole, Wenner, and Schlumberger arrays. The location of these profiles is displayed in Figure 1b.

The potential lithological units we detected along and downslope from the Lojanik 1 area are generally more conductive and less laterally continuous than those identified in the Kremenjak Valley (Figure 5). From top to bottom, we distinguished an uppermost potential lithological body, which outcrops at the ground surface and reaches a maximum depth of 4 m (ERT-F). Based on its resistivity (1.2 to 1.5 Ωm), ERT-F probably corresponds to gravels and boulders deposited along the slope by rockfalls and colluvial processes [60,73,74]. This unit is often laterally discontinuous and alternates with pockets of highly conductive sediments (<1 Ωm; ERT-G), which likely correspond to clay-rich deposits. These features are usually localised within or in proximity of the many man-made pits situated along the slope. Underneath ERT-F and ERT-G, we detected moderately conductive materials (0.7–0.9 Ωm), comparable with silty clay deposits [60,68–70], on top of a more resistive (1–1.2 Ωm) and laterally discontinuous unit (ERT-I), which might have been shaped by river processes.

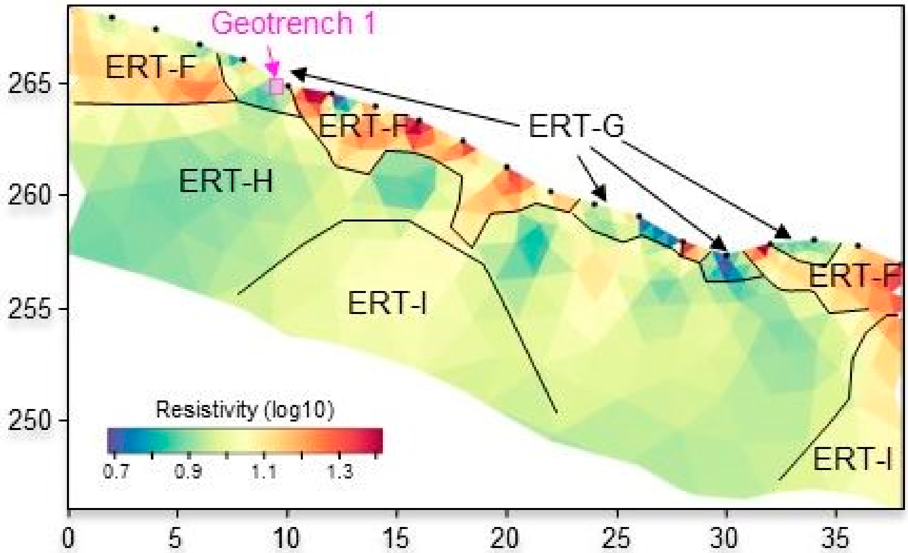

Figure 5. Electrical Resistivity Tomography (ERT) profile ERT-12 from the Lojanik 1 Valley, for the precise location of this transept see Figure 1c. The image displays the jointed inversion of resistivity measurements acquired with dipole–dipole, Wenner, and Schlumberger arrays.

d. Geo-trench 1

In Geo-trench 1, we exposed a 40 cm deep sequence which enabled us to partly re-open one of the numerous pits we identified downslope from the Lojanik 1 area and confirm the interpretation of the ERT we acquired along this slope. During excavation, we distinguished, from top to bottom, an uppermost infilling (GL 2000) made from frequent, subangular to subrounded, triaxial to equiaxial, fine to medium gravel-sized fragments of peridotites and fossilised wood, as well as common lithic artifacts made from opal, which are all embedded in a greyish brown to dark brown (10 YR 5/2–3/2) clayey silt (Figure 3c). Composition, lack of sorting, and geometry (5 cm thick upslope and 25 cm thick downslope) revealed that this sediment likely originated from the erosion of the surface sediments and archaeological materials documented uphill, corresponding to the archaeological area Lojanik 1. High compaction, subangular aggregation, and high frequency of roots suggest that this deposit was overprinted by the development of a modern A horizon. Below GL 2000, localised on the upslope areas of the geo-trench, we unearthed a mostly sterile, loose, light yellowish brown to brownish yellow (10 YR 6/6–6/4) sandy silt, in which only rare subrounded, equiaxial, fine gravel-sized fragments of peridotites and fossilised wood are buried (GL 2001). As discussed for GL 2000, the location and geometry of this deposit suggest that it probably corresponds to a colluvial sediment. Separated by a sharp contact from the above GL 2001, GL 2003 is composed of common, subangular to subrounded, triaxial, fine and medium gravel fragments buried in a dark brown to dark yellowish brown (10 YR 3/3–3/4) silty clay. Only rare potential lithic artifacts were observed in this deposit. Underneath GL 2003, we detected two sediments (GL 2002 covering GL 2004) that appeared laterally continuous across our excavation area and thus might correspond to the original bottom of the pit. Given the limited size of our trench and the much wider diameter of the pits situated at the bottom of the valley, however, we cannot exclude that these as well as the above sediments are the infillings of a larger depression. In any case, while GL 2002 appeared similar to the upper sediments unearthed in the Geo-trench 1, being made from brown to yellowish brown clayey silt (10 YR 4/3–5/4), GL 2004 showed a very different composition. This layer contained common, highly weathered, yellowish red (5 YR 4/6), brownish yellow (10 YR 6/6), and black (10 YR 2/1) peridotite sand-sized fragments embedded in a well-sorted, black (2.5/1 2.5 YR) clay. Remarkably, such deposit is comparable with sediments unearthed in the unpublished trench B situated in the archaeological area Lojanik 2. This field observation might indicate that, below the surface sediments, similar deposits accumulated in both the Lojanik 1 and Lojanik 2/3 areas, which today appear dissimilar due to more intensive (and possibly more recent) aggradation in the Lojanik 1 valley. This working hypothesis remains to be further tested with additional excavation and absolute dating of the deposits in both valleys.

3.2. Evidences of Human Activity

Across the zones that were surveyed, we found scatters of lithic material, of which some could be correlated to the Middle Palaeolithic period, and others to a more recent prehistoric material (Upper Palaeolithic or Neolithic).

a. Lojanik 1

The area of Lojanik 1 had been already extensively researched by previous field missions on its higher elevation and at the hilltop [25]. We focused our interest on the lowest level of the valley, next to the stream, where the LiDAR data allowed us to identify a series of aligned human-made pits that could be attributed as mining shafts. In order to understand the stratigraphy of these pits, we dug a small geological trench, which yielded very few artefacts; the only diagnostic element found in this pit is a large tablet to rejuvenate a blade core (Figure 6c), which was found in GL 2004, and possibly came from below the bottom of the pit. This artifact is specific to volumetric blade productions and mostly associated with the Upper Palaeolithic (ca. 40,000 to 10,000 years ago) or Neolithic periods, although it can also be present in Middle Palaeolithic technocomplexes. However, the pit seemed to be much more recent, and could be linked with modern mining activities for obtaining the petrified wood.

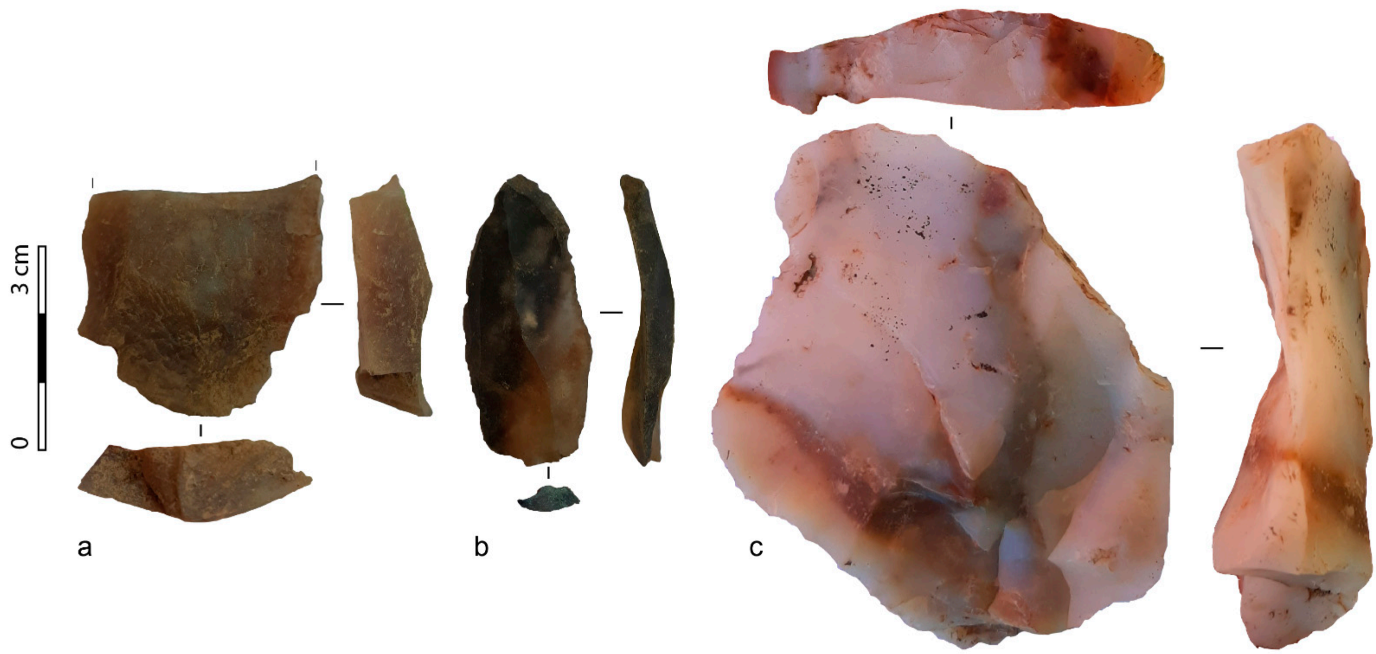

Figure 6. Lojanik 1, lithic artefacts: (**a**) fragment of blade detached with hard hammer; (**b**) potentially Levallois laminar blank; (**c**) core tablet from Geo-trench 1.

A few meters west from the pit, on the middle part of the slope, an important scatter of lithic artefacts had been identified as a workshop during previous surveys. We could not confirm the "workshop" interpretation of this scatter, but we identified Levallois products or production of laminar blanks with a hard hammer (Figure 6a,b). We also found evidence of the production of laminar blanks with a soft hammer, also common in Upper Palaeolithic or more recent Prehistoric assemblages (such as Neolithic or Chalcolithic).

b. Lojanik 2

First documented in 2017, Lojanik 2 is a sloped area on the west bank of the Kremenjak Valley, which was tested with three archaeological trenches (A, B and C) prior to our survey. For this reason, we did not extensively survey this zone, and only identified a small number of artefacts this year, which made us revisit the material uncovered in the previous campaigns.

The artefacts found at Lojanik 2 display a lithic industry characterised by two major components: Levallois and laminar. The features of some of the artefacts, such as the hierarchy of the core faces as well as the organisation of the lateral and distal convexities, fit entirely within the Levallois concept. Looking at the cores, recurrent centripetal and centripetal preferential Levallois production seem to be the preferred method of reduction (Figure 7a), while other methods, such as the unidirectional preferential, seem to only be hinted at [13]. While the number of this kind of artefacts is not vast, the lack of platform preparation is noticeable. This is especially visible in one of the pieces documented during the survey, where the maker decided to keep the natural platform on the core (Figure 7b).

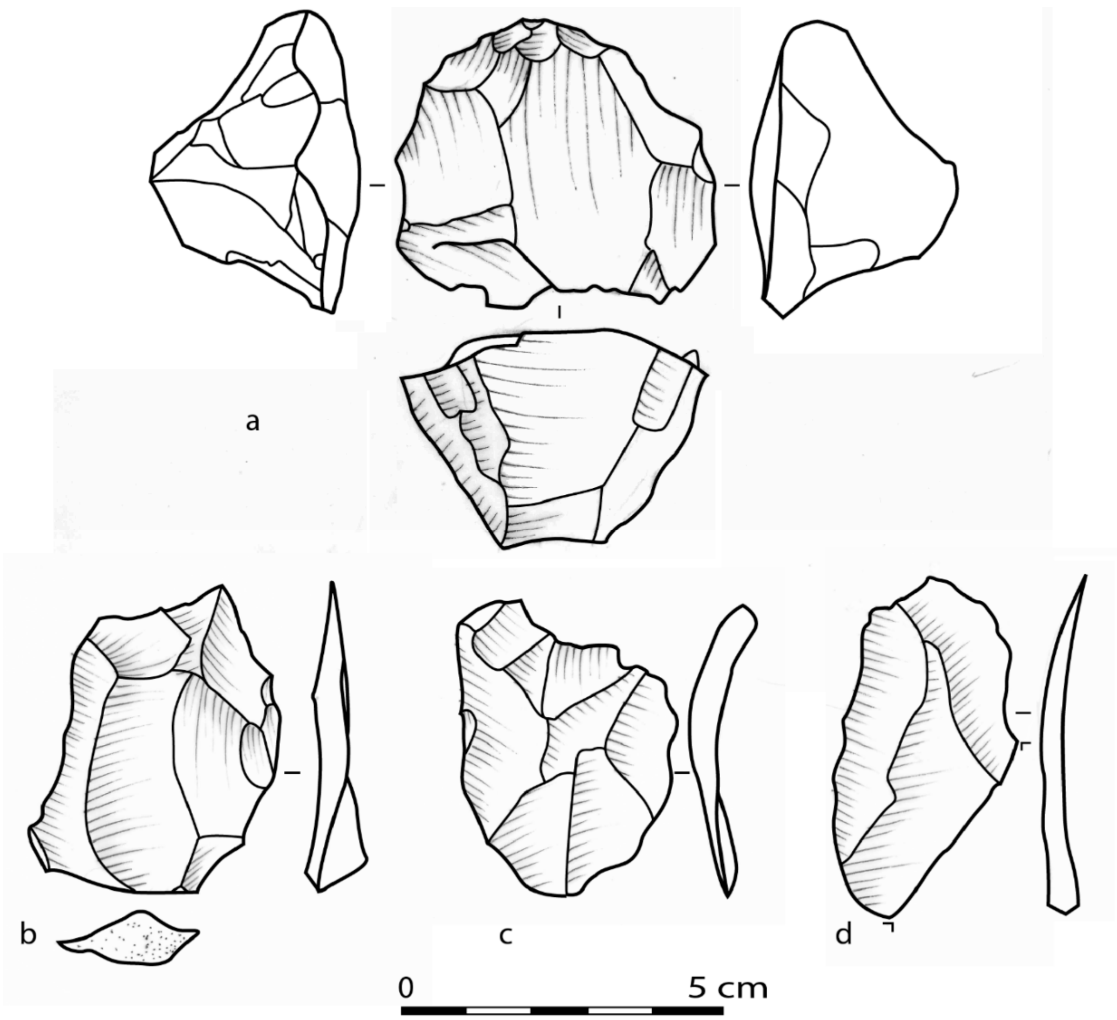

Figure 7. Lojanik 2, Levallois elements: (**a**) Preferential Levallois core (found in 2022); (**b**–**d**) Levallois flakes (from previous surveys).

The reduction of laminar elements seems to be coordinated in a uniform fashion, and the blade core platforms are prepared by faceting, implying they were possibly made by hard hammer percussion. Other traits that we can recognise are bidirectional production of thick laminar blanks or elongated flakes, while some of the pieces display a lateral or posterolateral shaping of the cores (Figure 8a,b and Figure 9c–e). Negatives on the cores, as well as flake morphology, imply a tendency towards pointed blade production (Figures 8 and 9a,d,e), but the artefacts are not numerous enough to back this claim without further research. Apart from the two burin cores, the production of bladelets has not been recognised (Figure 9b,f).

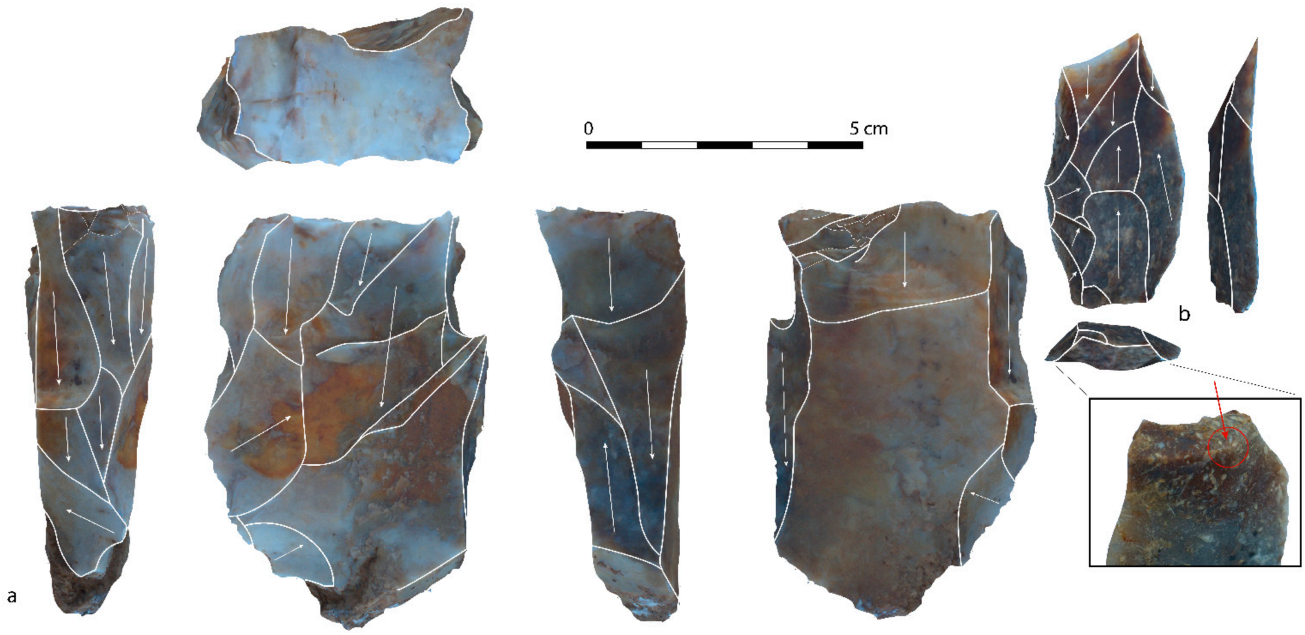

Figure 8. Lojanik 2, lithic artefacts found in 2022: (**a**) narrow-faced blade core; (**b**) blade.

c. Lojanik 3

Lojanik 3 is a find area located on a slope of the Kremenjak valley, north of Lojanik 2. It was identified as a find area due to the concentration of scatters of artefacts (findspots) that we encountered, usually organised as small mounds in various elevations of the slope.

LFS1 (Lojanik FindSpot 1) is a locus which forms a small mound, situated on the edge of a small pedestrian path, next to a boulder. On the findspot we could identify numerous lithic artefacts, of which a majority were small in size compared to the material identified in the other loci. Although most of the artefacts are non-diagnostic flakes, some of them present scars of bladelet production (Figure 10), which occur in Upper Palaeolithic assemblages.

LFS2 and LFS3 are two scatters of artefacts located lower on the slope. LFS2 material is dominated by the production of large artefacts, with a tendency to elongation, which are detached following a direct percussion with a hard hammer (Figure 10). This way of producing large flat flakes and laminar blanks is widely documented in Middle Palaeolithic contexts and is correlated to the Levallois reduction concept. In LFS2, we identified a preform of a volumetric laminar core (Figure 11), which could be associated either with Middle or Upper Palaeolithic.

The rockshelter exposure described above ("Tri Stene Rockshelter") is also part of Lojanik 3, on the southern part of the find area. It has yielded over 70 well-preserved artefacts. The artefacts are in their great majority obtained through direct percussion with a hard hammer. Most of the products display scars that are related to a unipolar reduction, but multipolar, bipolar, and centripetal reduction are also well represented. Nine of these artefacts show characteristics that fits in the Levallois *chaîne opératoire* of reduction, such as a visible organisation of the convexities for the production of predetermined flakes, hard hammer percussion following a fracture plane parallel to the plane of intersection, and for one flake a very typical *chapeau de gendarme* facetted platform (Figure 12b). Elongated products are highly represented in this locus, with more than 10 blades and laminar blanks. This corresponds to what we have seen in other loci, such as LFS2 and LFS3, as well as Lojanik 2.

On the top of the sequence, one artefact displayed unique characteristics compared to the rest of the rockshelter assemblage. This small flake shows scars of bladelet production on its distal side and could be described as a carinated endscraper (Figure 12a) which would be typically found during the Upper Palaeolithic period.

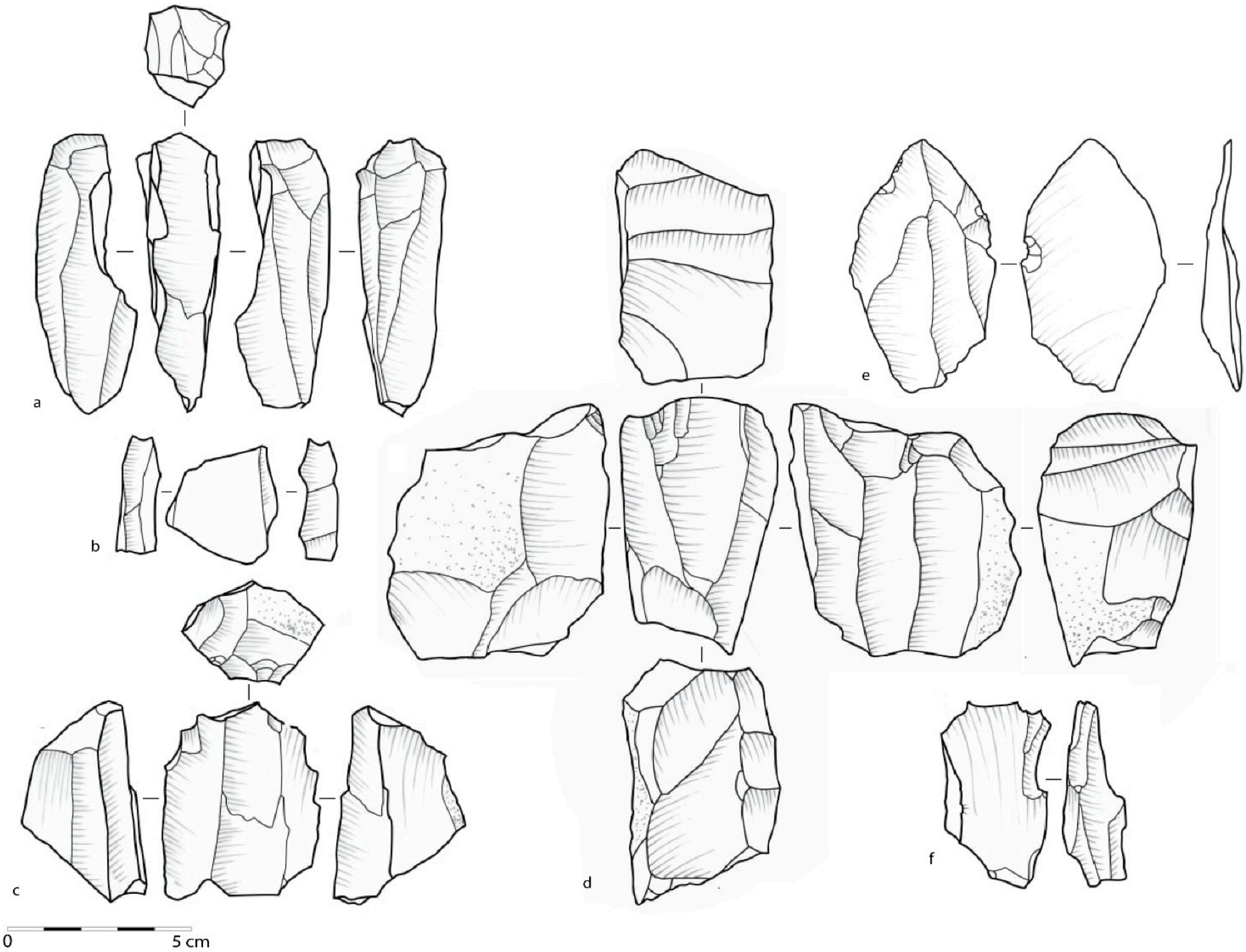

Figure 9. Lojanik 2, lithic artefacts from previous surveys: (**a**,**c**,**d**) blade cores; (**b**,**f**) burin cores; (**e**) laminar flake.

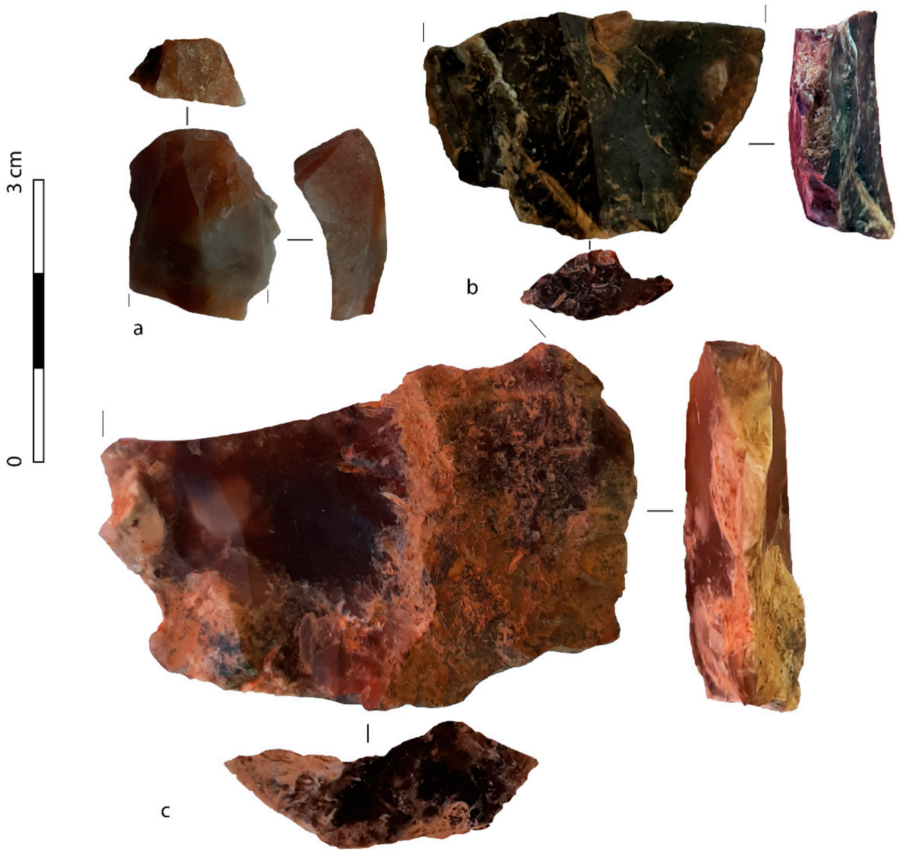

Figure 10. Lojanik 3, lithic artefacts: (**a**) bladelet core from LFS1; (**b**,**c**) fragmented large laminar blanks from LFS2.

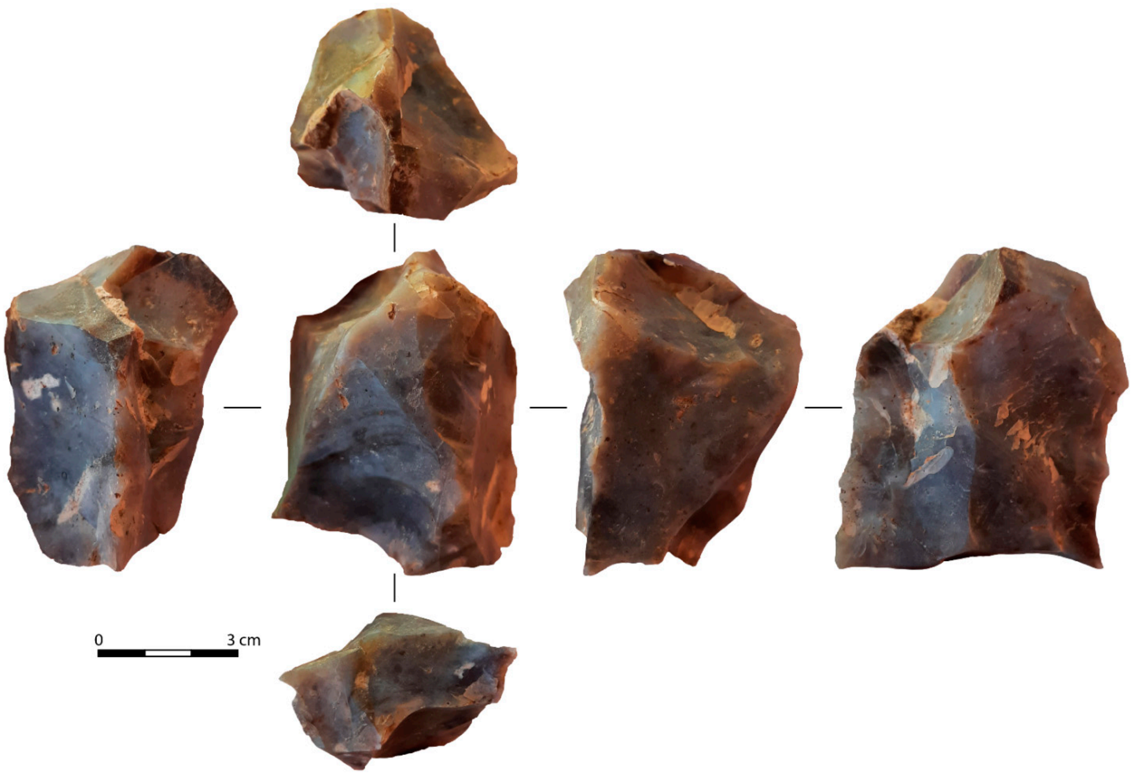

Figure 11. Lojanik 3, preform of blade core from LFS2.

Figure 12. Lojanik 3, lithic artefacts from the Tri Stene Rockshelter: (**a**) carinated endscraper; (**b**) Levallois flake with facetted platform; (**c**) laminar blank.

4. Discussion

The results from the 2022 survey at Lojanik are quite promising for the study of prehistoric occupation in the central Balkans. This study has its limitations, as most of the material comes from the ground surface of a region that has been affected by intensive human modifications, such as modern quarrying and forestry, and the landscape is scarred by erosional landforms (e.g., gullies and scarps). Despite these constraints, we were able to formulate hypotheses about the geomorphological evolution of this landscape and its use by prehistoric societies.

4.1. Phases of Landscape Evolution

Here, we summarise the key phases of landscape evolution we hypothesised based on the geoarchaeological data presented in this paper.

a. The Kremenjak Valley

i. Bedrock incision (Mio-Pleistocene?)

Our ERT data suggest that the bedrock at the bottom of the Kremenjak Valley was carved by river erosion nearly down to the elevation of the current riverbed (see depression on top of ERT-E in Figure 4). Based on the chronology of river terraces in the Ibar Valley [18,75], this deepening of the base level of the Kremenjak River possibly occurred between the end of the Miocene and the early Pleistocene and might have been triggered by tectonic activity [18].

ii. *Aggradation, formation of river terraces, and accumulation of Palaeolithic stone tools (Pleistocene)*

The bedrock incision was filled with sub-horizontal and alternating fine and coarse sediments (ERT-B to ERT-D in Figure 4), which were subsequently truncated and partly moved downslope by erosional processes. The geometry and elevation of one of these beds (ERT-C, 20 m above today valley bottom in Figure 4a) are compatible with a terrace of the Ibar River in the area of Mataruška spa, which was dated to the Pleistocene [75]. The materials unearthed in the unpublished Trench B of Lojanik 2 as well as the lithic artifacts collected during our survey in this archaeological locality and in the areas of Lojanik 3 probably come from this river terrace, or from deposits formed after its erosion and reworking. Therefore, it is possible that foragers producing Middle and Upper Palaeolithic stone tools exploited this landform. This hypothesis remains to be further tested with detailed archaeological, geoarchaeological, and geochronological analyses of Trench B, as well as coring and excavations in Lojanik 3.

iii. *River valley incision, slope erosion, rockfall, and river lateral erosion (late Pleistocene to modern)*

As mentioned above, the potential river terrace that formed in the area of Lojanik 2 and 3 was subsequently truncated during at least two separate erosional phases. The first was followed by rockfall(s), during which gravel-sized up to boulder-sized opal-rich peridotite rocks were deposited along the slope (corresponding to ERT-A in Figure 4), while the second is still ongoing and led to the configuration of today's slope topography. The shift from slope aggradation to erosion was probably triggered by a phase of river valley incision. Causes and timing of these processes remain to be investigated. Slope erosion also led to the accumulation of the upper sediments we observed at the rockshelter (GL 1000 to GL 1004), while we cannot exclude that the lower part of the sequence (GL 1005 and 1006) was accumulated during the previous phase of landscape evolution.

Our geomorphological mapping revealed that today the slopes of the Kremenjak Valley are actively eroded by gullying and debris flows, which are more active on the eastern valley flank likely due to more intensive human activity. On the other hand, at the valley bottom, lateral erosion is probably more intensive than incision, leading to the formation of natural exposures, such as the one visible at the rockshelter.

b. The Lojanik 1 Valley

i. *Bedrock Incision (Mio-Pleistocene?)*

Our ERT data seem to indicate the occurrence of a bedrock depression at the bottom of the Lojanik 1 Valley (top of ERT-I in Figure 5). This landform is some 20 m higher in elevation than the one we observed at the bottom of the Kremenjak Valley (top of ERT-E inFigure 4) and up to 6 m higher than the potential river terrace ERT-C (Figure 4a). This difference in elevation might indicate that the lowermost incision of the Lojanik 1 Valley did not form during the genesis of either landform of the Kremenjak Valley, or, alternatively, that river landforms across this region were vertically displaced due to tectonic activity. Geochronological research is necessary to clarify this point.

ii. *River valley aggradation and accumulation of Palaeolithic stone tools (Pleistocene)?*

Lithological and archaeological data from the bottom of our Geo-trench 1 (GL 2004) seem to indicate that the depression carved in ERT-I was filled with sediments and archaeological materials similar to those reported from the unpublished Trench B in Lojanik 2, which intercepted deposits corresponding to ERT-B/D (Figure 4). Therefore, it is possible that hunter-gatherers producing Middle and Upper Palaeolithic stone tools visited Lojanik 1, 2, and 3 when these exhibited similar environments (possibly low energy river terraces). This hypothesis remains to be tested with further research.

iii. *Slope erosion followed by rockfall, and further accumulation of stone tools (late Pleistocene to Holocene?)*

Based on our ERT data, the archaeology bearing clay-rich deposits accumulated in the Lojanik 1 area were eroded and covered with highly resistive sediments (ERT-F in Figure 5). For the most part, these correspond to gravel-rich sediments that outcrop at the ground surface and exhibit Middle or early Upper Palaeolithic stone tools. Colluviation and human visit to the (upper areas) of the slope might have lasted until the Late Neolithic, as suggested by previous lithic studies [25].

iv. *Human-made pitting triggering slope erosion and further river valley aggradation (Holocene to modern times)*

These coarse deposits were partly excavated in historical to modern times during quarrying activity searching for sediments and bedrock formations rich in silicified wood (reconstruction based on interview with Mr. Dragotinović, who was a worker during these activities until the 1980s). Such intensive destruction of the landscape destabilised the slopes, locally triggering debris flows and causing the erosion of archaeological materials. This process, in combination with the mostly dry stream at the foot of the slope, led to the (ongoing) infilling of the valley.

4.2. Phases of Human Occupation

The results of the survey, as well as the lithic analysis, have demonstrated three possible chronological chapters of human occupation at Lojanik, while other periods did not yield as many pieces of evidence, occurring only occasionally. The earliest evidence of occupation can be correlated to the Middle Palaeolithic, perceived from the abundance of Levallois-like artefacts on the surface of at least two of the defined areas—Lojanik 2 and Lojanik 3. These two areas also yielded a few significant Upper Palaeolithic artefacts, such as bladelet cores, but these are unfortunately not diagnostic and not numerous enough to be able to correlate them with a specific Upper Palaeolithic tradition. Finally, the third chapter of human exploitation is illustrated by the modern mining, visible in the possible mining shafts in Lojanik 1 Valley, as well as quarrying on the eastern slope of the Kremenjak Valley.

a. Lojanik 1

Previous studies on the Lojanik 1 valley have indicated that the site was exploited following a planned organization, with a division of activities between zones of acquisition of raw material, upslope, workshop areas, downslope, and discard zones [25]. The chronological range is very wide, from the Middle or early Upper Palaeolithic to the late Neolithic. The artefacts that can be linked to the earliest occupation seem to be located downslope, around the workshop zone (Figure 1), while Neolithic artefacts have been identified upslope and on top of the hill.

b. Lojanik 2

In Lojanik 2, the discovery of Levallois cores and artefacts during previous studies has indicated that this area was occupied since the Middle Palaeolithic era [17]. However, artefacts identified in 2022, such as a bidirectional narrow-faced blade core (Figure 8), in combination with previously unearthed material from past studies, such as burins and bidirectional blade cores (Figure 9), caused us to question this attribution. Indeed, they are presenting the defining features of Initial Upper Palaeolithic [76–78]: bidirectional production of laminar elements and platforms prepared by faceting, as well as the production of burin cores, by direct percussion with a hard hammer. This notion could actually be strengthened by the presence of Levallois artefacts, which is considered another defining feature of this phenomenon. For this reason, the provenience of Levallois artefacts found on the surface cannot be decided with certainty, as it is considered common for both Middle Palaeolithic and the Initial Upper Palaeolithic. The context of the finds greatly limits our ability to attribute these artefacts to a specific time period with certainty, as it is currently impossible to discriminate between two possible interpretations of occupation for Lojanik 2:

- Either a first Middle Palaeolithic occupation, when the Levallois elements were abandoned at the site, followed by an Initial Upper Palaeolithic occupation, characterised by burins and blade cores.
- Or, only an Initial Upper Palaeolithic occupation, with the combination of Levallois, blade cores and burins.

c. Lojanik 3

In Lojanik 3, the assemblage is dominated by Levallois elements, with a tendency towards elongation. No typical Initial Upper Palaeolithic artefact has been identified during this preliminary study, but some elements indicated the presence of at least one Upper Palaeolithic occupation (e.g., Figures 10 and 12). We can note that LFS1, upslope, yielded typical Upper Paleolithic artefacts (e.g., Figure 10) and small-scale artefacts, while LFS 2 and 3, downslope, yielded large artefacts that can be linked with Levallois and hard hammer volumetric blade reduction. This could be due to modern modifications of the slope, pulling the larger artefacts downslope towards the Kremenjak River, or could illustrate a chronological sequence, with a first occupation downslope during the Middle Palaeolithic, when the valley was lower, then a period of sedimentation, and then a later, Upper Palaeolithic occupation on top of the new deposits.

In the Tri Stene Rockshelter, the upper layers, GL 1000 to GL1002, did not yield noticeable archaeological material, and are probably colluvial lobes that stretch across the lower part of the slope, as mentioned earlier. GL 1003 and downwards seem to be less disturbed, and show an alternation of archaeological and sterile layers, which could indicate an intact sequence. The artefacts positions could also confirm this, with the presence of the more recent artefact, the bladelet core, on the top of the archaeological sequence, while the Levallois elements are more concentrated at the bottom of the exposure. If this is the case, it would mean that the valley was already carved down to the bedrock while the first Levallois-making groups occupied the area.

Thus, the Lojanik 3 assemblage as a whole seems to indicate at least two periods of occupation:

- First, Levallois-making hunter-gatherers occupied the valley near the stream, probably taking advantage from the exposed bedrock to easily exploit the raw material;
- Then, Upper Palaeolithic groups came to occupy the site; at this time the bedrock would not be as exposed and thus not as easily accessible. However, they could have exploited bedrock outcrops that are located higher on the slope, such as the one we identified during our survey (Figure 2f), or boulders that have been detached from the same outcrop and rolled down the slope.

d. Techno-typological summary of the Kremenjak Valley assemblages

Lojanik 2 and Lojanik 3 show a similar pattern of techno-typological features observed on the artefacts. Both of them have a high proportion of both Levallois artefacts and laminar production. Due to the nature of the context of these artefacts as well as their uniqueness on the regional level, their chronological and cultural interpretation is limited. However, due to the presence of some very diagnostic elements, we can make strong assumptions about their cultural attribution. While these assumptions could potentially be of great significance, we should remain conservative on our interpretation. Having this in mind, the presence of Levallois or Levallois-like elements is unambiguous, making Lojanik a clear outlier in the Central Balkans at this point. The nature of the laminar production is less obvious since its ambiguity presents a challenge for interpretation.

4.3. Landscape Use in the Kremenjak Valley

The information gathered from Lojanik 2 and 3 indicate a repeated occupation in the Kremenjak area, possibly with different human species returning to the site over a long period of time. The lack of evidence for other periods could be a product of active geological processes as well as different behaviours concerning raw material economy during later prehistory. Each side of the valley of Kremenjak seems to show a different depositional environment, which is in corelation with the distribution of artefacts. The eastern slope (Figure 1, GU E) displays a greater instability and artefacts are only seldom found in this area. The western slope, on the other hand, presents a more stable depositional environment, and even with the recent human activities, erosion, and reworking, shows a much better preservation of artefacts.

The major difference between Lojanik 2 and Lojanik 3 is seen in the context of the finds. Lojanik 3 seems to have suffered recent modifications due to the levelling of terrain and clearing of smaller forest paths, which have in fact made the artefacts more visible. While we recognise that a lot of them are in a secondary context, the artefacts do not seem to be displaced over great distances, as the piles created by these activities do not require long distance transportation of the sediment. In addition, the artefacts seem to be well preserved, with sharp edges and few post-depositional alterations [79]. The exception in this area is the Tri Stene Rockshelter, which does not seem to be affected by recent human activities but has still been modified by the movement of the Kremenjak stream.

Both areas are located downslope of a large outcrop of good-quality opal, from which boulders have been detached and rolled down, where the raw material is accessible. Upslope from this outcrop, surface finds are extremely rare, and good quality raw material sources decrease sharply. It is thus possible that, although reworked, Lojanik 2 and Lojanik 3 reflect more intensive forager visits in a portion of the landscape where good-quality lithic raw material was readily accessible.

5. Conclusions

The Lojanik complex is a crucial site for the understanding of lithic raw material procurement and landscape use in the Prehistory of the Balkans. Despite the recent modifications of the landscape, due to modern mining, we were able to reconstruct patterns of human occupation in relation with the geomorphological processes affecting the valleys. The promising results of the 2022 survey demonstrate how LiDAR data can be used in the context of Prehistoric archaeology to locate sites and areas of interest even in the absence of large-scale modifications of the ground—such as buildings or enclosures for later periods. Our work represents a step forward for the research on Prehistoric occupations in the Balkans, notably with the identification of Levallois elements, an exceptionally rare occurrence in the region. Future investigations will include archaeological excavations and geoarchaeological and chronological analyses, in hopes of portraying a comprehensive picture of human settlement patterns and cultural behaviours in the central Balkans Prehistory.

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Data Availability Statement: The results of the archaeological survey are currently archived by C. Lesage and A. Barbieri at ICArEHB (Portugal), as well as V. Bogosavljević Petrović at the National Museum of Belgrade (Serbia). These include GPS data points, digital mapping, and LiDAR data, fieldnotes, lithic database, field and material pictures, and ERT database. Artifact collections are the property of the National Museum Kraljevo (Serbia).

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