

Introducing the Loess Pyramid – an Unusual Landform in the Thick Loess Deposits of Vojvodina, Serbia

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Abstract

In this paper we introduce the term “loess pyramid” for an unusual form of relief in thick loess deposits. From a distance, the loess pyramid resembles a haystack; this is why it is known as “the haystack” by the local residents. Its erosional origin is conditional, occurring only where loess deposits are thick and gully erosion changes direction significantly. We describe a loess pyramid on a thick loess section near the Tisa (Tisza) River in Titel province, Serbia. The pyramid has a maximum altitude of 111.6 m, a width of 82 m and a length of 52 m. It is framed by two smaller gullies that belong to one hydrological system, but each has different morphological properties. The gullies output directly to the floodplain of the Tisa River, which cut the escarpment that the pyramid is set within. Given the relatively small number of references from the international and geomorphological literature on such landforms, this study represents an interesting contribution to the geomorphology of loess landscapes.

Key words: loess, pyramid, geomorphology, erosion, Titel

Introduction

The morphology of loess relief depends on many factors, the most important one is often the thickness of the loess itself. In thin loess deposits, the terrain often follows the underlying terrain contours. When loess deposits are thick, however, new and unique landforms may develop, as modified by the unique erosional properties of the loess (Zhu, et al., 2002). Properties of the wind and loess accumulation processes also have significant impacts on modifying the relief in loess-based terrain (Leger, 1990).

Loess has several features that render it susceptible to the effects of erosion. High levels of porosity (30-50%) lead to excellent permeability, moisture retention and even sapping along locally less permeable zones. In calcareous loess, the large contents of carbonates or clay as a bonding agent affect its cohesiveness, facilitating the formation of various shapes by water and wind erosion. Since running water can be

very effective at entraining and transporting loess, the dimensions and shapes of loess landforms can change over short periods of time. Additionally, because loess soils are favorable for agriculture, human activities can also have a significant influence on erosion (Leger, 1990; Lavrusevich, Skapintsev, 2013).

Relief microforms formed by erosion in loess sediments of the Vojvodina region (northern Serbia) have been little studied. The earliest study was conducted by Milojević (1949), based on erosion microforms of sandstones and loess plateaus.

Historically, studies of loess landforms have focused on regional-scale issues (e.g. Zeremski, 1955; Bukurov, 1975; 1982; Krstić, et al., 1983; Kukin, Miljković 1988). Most of the recent studies (Marković, 1998; 2007) of loess geomorphology have focused on micro-relief forms on the Srem loess plateau. Included in this listing is the work of Marković et al. (2005), who explored the general characteristics of loess relief

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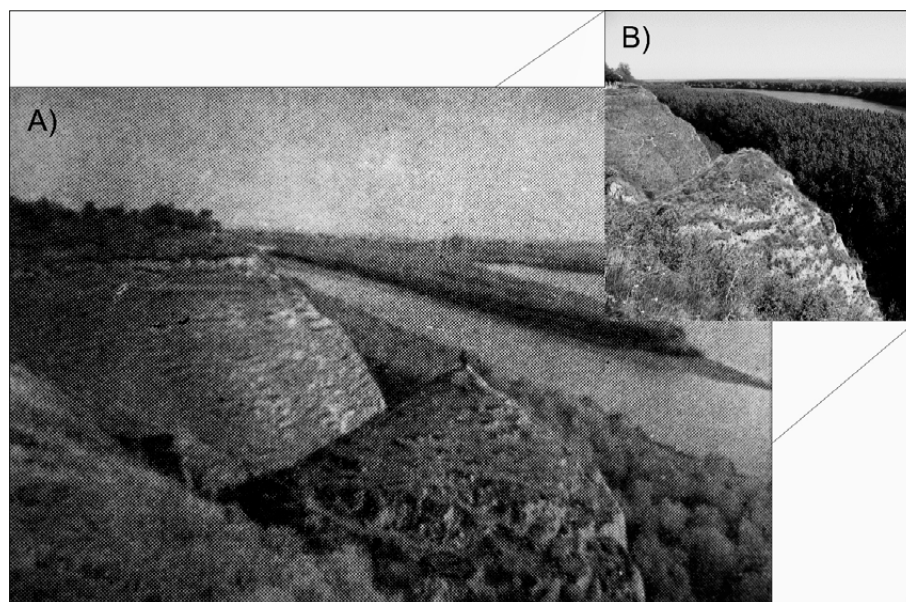


Figure 1. A comparison of photos of the Titel loess pyramid in 1953 (A – Photo: Branislav Bukurov) and 2007 (B – Photo: Slobodan B. Marković)

on Titelski breg (Titel Hill). Zeeden et al. (2007) provided data on the number, morphology and genesis of depressions (loess sinkholes) on Titelski breg. Lukić et al. (2009) examined the morphometric characteristics of the loess cave near the village of Surduk, and Halliday (2007) studied the pseudo-karst forms of relief, and including forms developed on loess.

The contributions of the aforementioned researchers in the field of morphological forms of relief in Vojvodina have focused on erosional landforms in loess. None of these studies have mentioned the existence or genesis of pyramidal structure in thick loess. The only foreign author who has devoted attention to these unusual loess forms is Fuller (1922), who developed a nomenclature for loess deposits in China. Fuller's divisions include morphological forms such as (1) Natural loess bridges, (2) Loess dams or walls, (3) Loess pointed towers or peaks, and (4) Loess wells. The loess pyramid on Titelski breg corresponds morphologically to Fuller's (1922) category of loess towers or tops, and also fits within a subgroup of conical peaks, based on its morphological characteristics. According to Fuller (1922), conical peaks are sharp slopes and mostly rounded peaks with heights up to twice the diameter of the base peak. They are the result of erosion, in some cases aided by human activities (Fuller, 1922).

The loess pyramid on Titelski breg (the Titel loess plateau) was first mentioned by Bukurov (1953) and described as a relief microform with a conical shape which had subsequently been undermined and halved by the Tisa (Tisza) River, turning it into a three-sided pyramid (Figure 1A). From a distance, it resembles a haystack, explaining why it is known as a "haystack" by local residents. The purpose of this study is to de-

scribe and characterize the loess pyramid, and to use these data to better understand its genesis.

Study area, methods and data

Titelski breg is a loess plateau situated in the Vojvodina province of Serbia (Figure 2). It is located in southeastern Bačka sub-region, between the town of Titel in the south, the villages of Lok, Vilovo and Šajkaš in the southwest, the village of Mošorin in the north, and the Tisa River to the east. The plateau landform itself is 18 km long and 7.5 km wide (Figure 2). The pyramid has a local relief height of approximately between 100 and 128 m, with an average height of 120 m (Bukurov, 1953; Jovanović, Zvizdić, 2009).

The Titel plateau abruptly ends at the valley of the Tisa River, where it falls as cliffs toward the surrounding alluvial plains on the south and west side of the plateau. The eastern and northeastern plateau cliffs are almost vertical. Such isolation is directly related to fluvial erosion and denudation (Marković, et al., 2005; Jovanovic, Zvizdić, 2009).

The loess pyramid "haystack" is located on the southeastern margin of the Titel loess plateau, at the geographical coordinates of $\lambda=45^{\circ}12'38.84''$ and $\phi=20^{\circ}18'38.13''$ in the northeastern part of the city of Titel (Figure 2). Not far from the loess pyramid is an archaeological site and profile Kalvarijska, with a vertical section of about 30 m high. Both the pyramid and the archaeological site are in the first zone of highly protected at the Titelski breg nature reserve (Marković, et al., 2005; Jovanovic, Zvizdić, 2009).

Morphological characteristics of the pyramid were obtained by precise measurements of the site and by

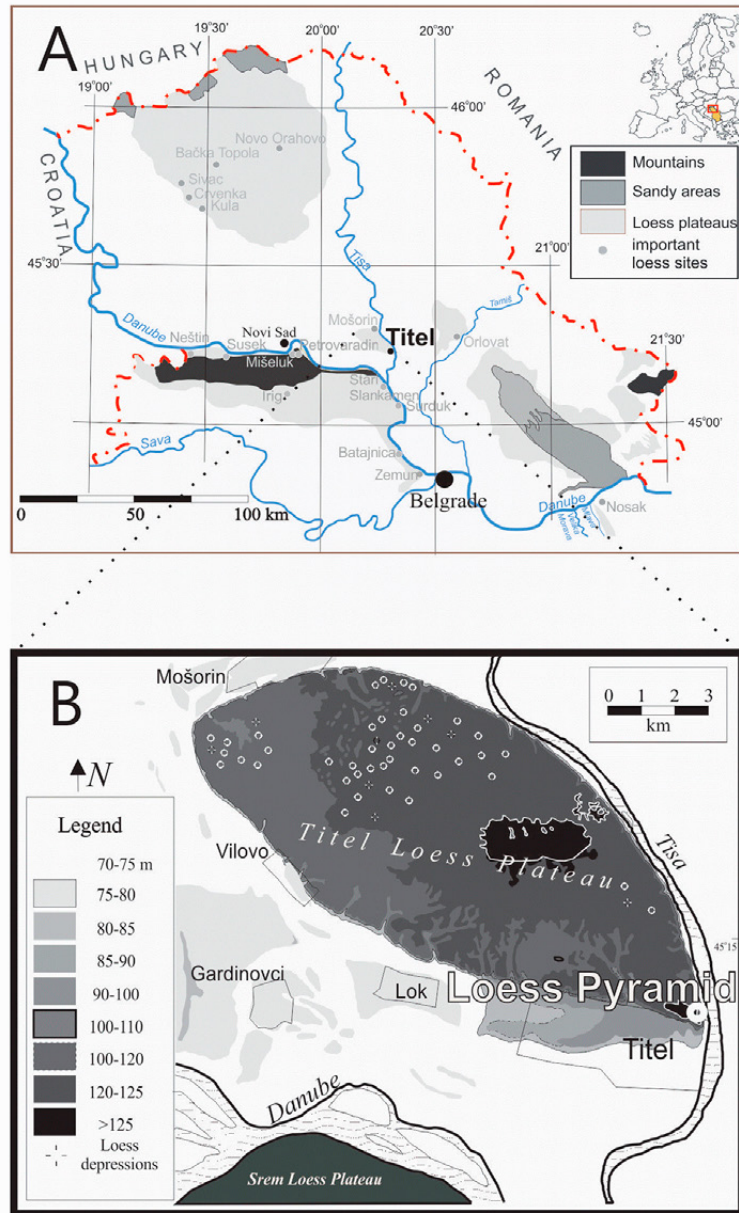


Figure 2. (A) Map of the loess distribution in the Vojvodina and adjacent regions, showing the location of the investigated section and other main loess sites (modified from Marković, et al., 2012); and (B) Map of the area surrounding the Titel loess plateau, showing the location of the loess pyramid (modified from Marković, et al., 2005)

analyzing both Digital Elevation Model (DEM) and high-resolution aerial photographs. We recorded the locations and altitudes at 72 sites across the landform, using a Global Navigation Satellite System antenna with Real Time Kinematic correction.

Results and Discussion

Table 1 shows the morphometric characteristics of the loess pyramid. Its maximum width is 82 m, and the horizontal cross section of the base (length) is 52 m. The length of the northern branch of the pyramid is

77 m, while the southern branch is 54 m. The basal area of the loess pyramid is approximately 2,000 m². The summit of the pyramid has an elevation of 111.6 m above sea level. Because the pyramid has formed due to the undercutting of the escarpment by the Tisa River and subsequent erosion by running water, the base of the pyramid lies on the alluvial plain of the river, at 77 m. Thus, the overall height of the pyramid is 35 m, increasing in the west-east direction.

Two small, ephemeral watercourses flow in gullies on either side of the pyramid. They effectively frame the loess pyramid, and thus are important for the in-

Table 1. Morphometric characteristic of loess pyramid and its drainage basin

Morphometric characteristics of loess pyramid	
Summit elevation	111.6 m
Maximum width	82 m
Maximum length	52 m
Length of the northern branch	77 m
Length of the southern branch	54 m
Thickness of eroded sediments (average)	88 m
Basal area	≈ 2,000 m ²
Morphometric characteristics of periodical watercourses	
Length of the waterway above the point of bifurcation	182 m
Length of the northern watercourse	70 m
Length of the southern watercourse	58 m
Area of drainage basin	≈ 20,000 m ²

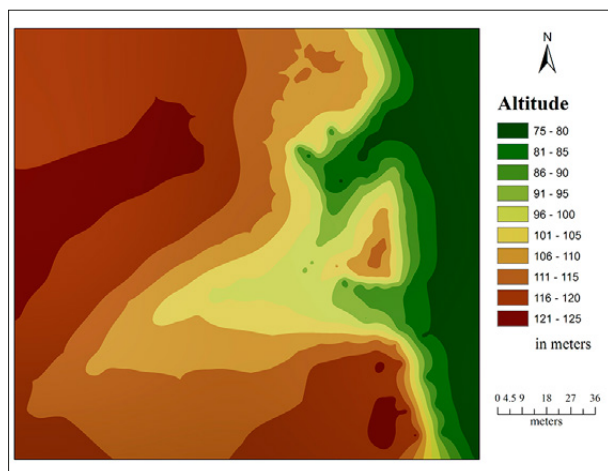


Figure 3. DEM of the landscape near the loess pyramid and the alluvial plain

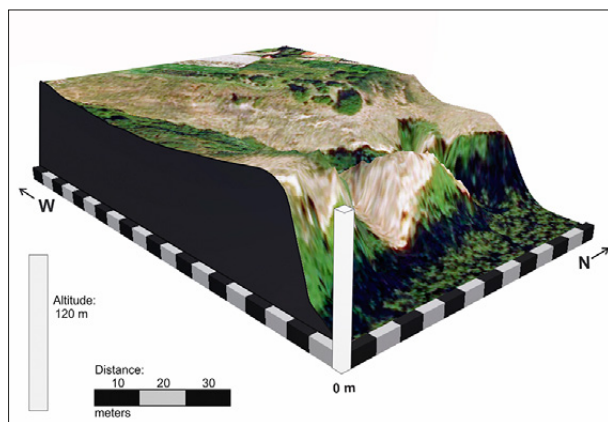


Figure 4. Three-dimensional model of the Titelski breg upland, its escarpment, and the loess pyramid at the margin of the Titel Loess plateau

terpretation of its genesis. The total length of the waterway, up to the moment of its bifurcation into the two branches is 182 m (Table 1). The length of the northern watercourse is 70.48 m and south watercourse amounts 58 m. The total basin area approximately 20,000 m².

The pyramid stands at the edge of the Titelski breg, formed between two large gullies that “hang” above the alluvial plain of the River Tisa (Figure 5). The total length of the northern gully from the spring to alluvial plain is 252 m. The section of the gully which intersects the loess pyramid is 70 m. The longitudinal profile (x-y) of the gully declines continuously, with two distinct steps (Figure 6), one of which occurs as the gully incises below the contact between the loess and the underlying sediment. The other step is in the middle of the waterway, along the pyramid’s northern face. A spring occurs at the end of this gully, at an elevation of 118 m.

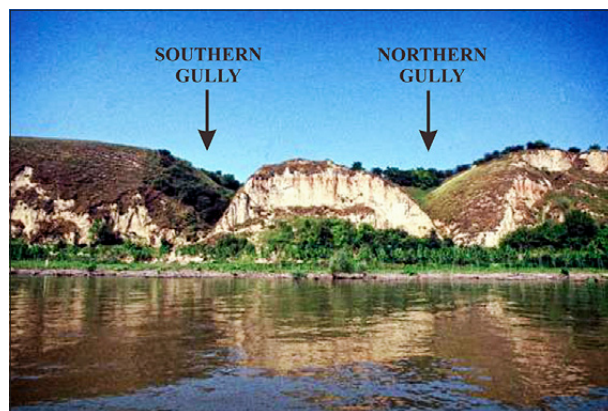


Figure 5. Photograph showing a cross section of the loess pyramid, as photographed from Tisa River, showing both the northern and the southern gullies (Photo: Nedeljko Kovačev)

In the narrow part of the northern gully, on its north side, is a good example of two secondary, steep gullies formed along initial vertical cracks in the thick loess (Figure 6). It is possible that enhanced erosion focused at these cracks led to the steps in the longitudinal profile of gully. The less morphologically expressed and less incised southern gully is 58 m in length (Figure 6). The altitude of the springing part is 97 m, while the lower end of the gully is at 83 m. The sides of the gully are steep and overgrown with vegetation. It is noteworthy that a man-made trail passes through the gully.

The summit of the loess pyramid is 111.6 m in elevation (Table 1), whereas its base, on the alluvial plain, is at 76.6 m. Both of the pyramid’s sides descend steeply into the gullies, whereas its profile on the side that faces the Tisa River plain is less steep. The average height of the the sediments eroded and accumulated on the Tisa

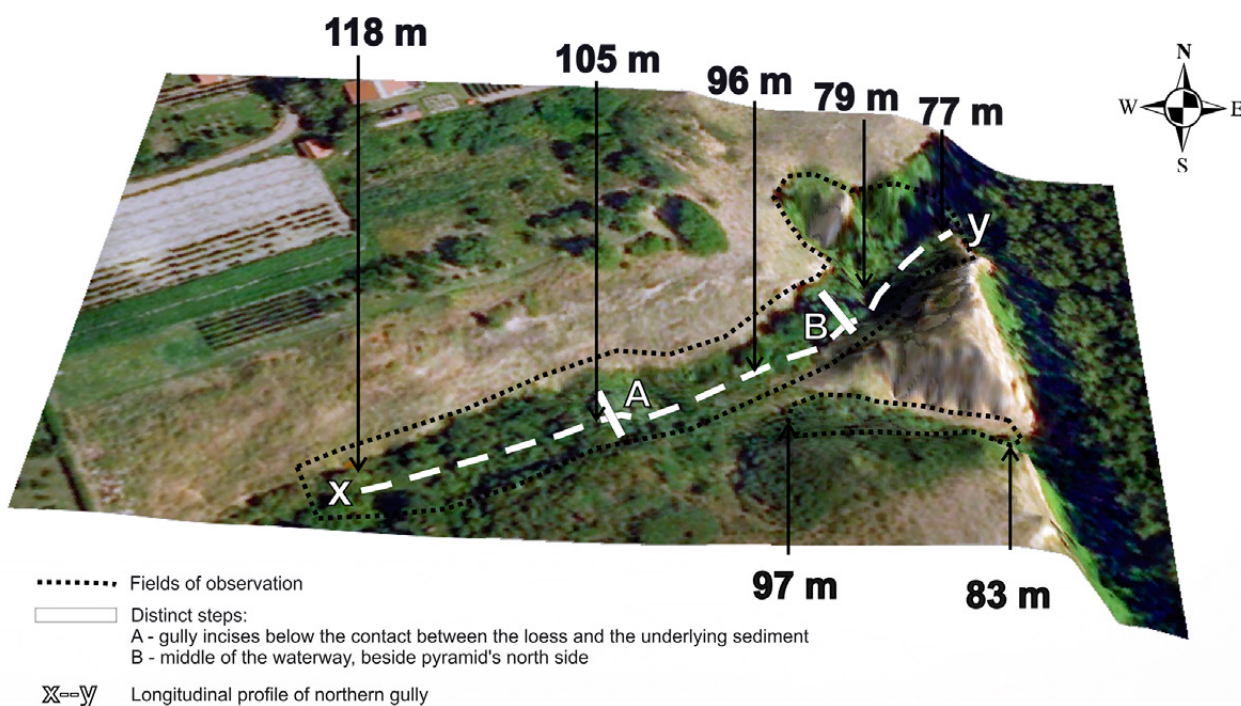


Figure 6. Three-dimensional display of area around the northern gully, showing spot-elevation values, two distinct steps and the route of its longitudinal profile (A and B)

plain is approximately 88 m. Beside these main features, micro-depressions, resembling miniature loess sinkholes, occur on the north side of the pyramid. The total area of the site is approximately 2,000 m².

The morphological characteristics of the loess pyramid help to explain its evolution. The northern valley, due to intensive vertical erosion has deepened rapidly (Figure 7). The over deepening has been affected by paleosol S1 and S2 in the loess, which stand out as steps in the valley's longitudinal profile (Figure 7), and likely accelerated by the erosion of porous loess units L2 and L3 below (Marković, et al., 2008; 2015).

The most likely morphogenesis of loess pyramid involves gully erosion, as controlled by the Tisa River and its undercutting of the escarpment along the

loess plateau. Figure 8 show the main groups of gullies on the Titel loess plateau, classified by orientation and length. Our study area is located in a transitional zone between long, older gullies, oriented toward a large, terraced, Titel alluvial fan, and short, younger gullies developed at recent loess cliffs on the southeastern margin of the loess plateau. The first phase in development of loess pyramid was related to formation of a proto gully, as indicated with dashed red line with arrow in Figure 8, orientated to the larger Titel alluvial fan, with the same orientation as the surrounding big gullies in the vicinity of Titel, as indicated with a normal line with arrow in Figure 8. The second erosional phase is associated with intensive fluvial erosion by the Tisa River, focused at the east-

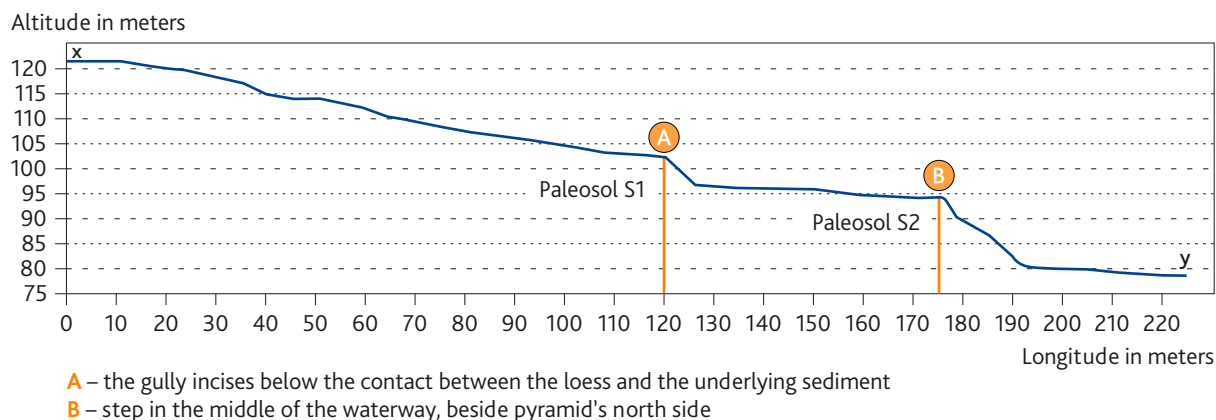


Figure 7. Longitudinal profile of northern gully with two distinct steps
(See Figure 6 for a three-dimensional view of this gully)



Figure 8. Spatial distribution of morphological groups and gullies at Titelski breg

ern margin of the Titel loess plateau. This erosion destroyed the most of this proto gully and initiated a change in drainage, from south to east. It also initiated the formation of two, closely spaced gullies with steep longitudinal profiles, similar to the short gullies located to the north of the loess pyramid. These two gullies are likely relicts of tributaries of the proto gully, because all other gullies with similar size located north of the loess pyramid are spaced at least several hundred meters apart. The final phase of morphogenesis of this feature involves the latest Tisa River erosion event, which allowed the two large, hanging gullies that currently exist there to incise into the loess. The pyramid then formed as an erosional remnant between these two gullies.

Conclusion

The loess pyramid at the margin of the Titel loess plateau is a young landform formed by different generations of gully erosion along a retreating loess escarpment. The overall retreat of the escarpment may be controlled by the current Tisa River. The nature of the dynamic erosional processes on steep cliffs like this one, formed in porous, erodible loess, points to a very limited lifetime for such landforms. The loess cliffs on the Tisa River bank between Titel and Mošorin not only preserve a unique archive of Pleistocene climatic and environmental changes, but also exhibit diverse and short-lived landforms associated with rapid erosion of the loess deposits. These landforms preserve

information on the processes of loess and soil erosion that could help in future attempts to limit the loss of such material through conservation programs, such as the present-day initiative to protect Titelski breg as a geopark (Marković et al., 2005; Vasiljević et al., 2009; Lukić et al., 2009; Boškov et al., 2015). Thus there are aesthetic, cultural, conservation and paleo-environmental research reasons for developing an effective and sustainable geoconservation procedure and plan to protect these landforms, by introducing their significance to a wider audience.

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