Depressions on the Titel loess Plateau: Form – Pattern – Genesis

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Abstract
The Titel loess plateau (Vojvodina, Serbia) is situated in the confluence of the Danube and Tisa rivers, in the southeastern part of the Bačka subregion. Different phases of fluvial erosion have shaped the ellipsoid shape of the plateau which is, characterized by steep slopes on the margins. In the contrast of that, plateau surface provides more sedative morphology with small hypsometric differences. However, the surface of the plateau is entirely covered by a system of depressions. In this study we analysed the morphology of the depressions, and their distributional pattern. A possible genetic origin and time frame of the formation is discussed. Depressions are elongate; their length varies between 50 m and 320 m. Their width rarely exceeds 200 m. The depth of the depressions within aggrandisements reaches up to ca. 4 m. The longitudinal axes of depressions show a preferential orientation. A pattern of both size and orientation is recognised. The formation of the depressions may be explained with a combination of dissolution by seeping waters and an initial aeolian relief predispositions.
Key words: hydrogeochemsitry, loess, depressions, Serbia, and Titel loess plateau

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Introduction

The Titel loess plateau is a unique geomorphologic phenomenon representing the wide diversity of the loess landforms. The Titel plateau is represents of loess island with maximal extension of about 16 km and a maximum width of 7.2 km. Thick loess deposits from 35 to 55 m separated by 5 main pedocomplexes deposited thought the last 5 glacial/interglacial cycles (Marković et al., 2005). Steep loess cliffs include several important loess exposures for understanding of climatic and environmental evolution during the middle and late Pleistocene in this region. (e.g. Pecsi, 1966; Butrym et al., 1991; Bronger, 1976, 2003; Marković et al., in press; Gaudenyi et al., 2007). The paleosol succession presents clear evidence of paleoclimatic transition from humid the middle Pleistocene to drier the late Pleistocene climates (Bronger, 1976, 2003; Butrym, et al., 1991; Marković et al., 2005).

Depressions at the surface of the plateau and many gullies posited on slopes represent the most obvious morphologic features of the Titel loesss plateau. Despite the omni presence of depresions at the plateau surface, data about these landforms were presented only in the frame of general geomorphological studies (Marković-Marjanović, 1950; Bukurov, 1953; Krstić et al., 1983; Krstić, 1992; Marković et al., 2005). Kukin and Miljković (1988) provided a description of the soil morphology of the depressions and state the importance of chemcial erosion for their formation.

In this study we focus on investigations of depressions on the surface of Titel loess plateau, including the morphology, patterns of distribution, orientation and the reconstruction of morphogenetic processes.

Methods

Detailed field investigations were carried out for two relatively deep depressions. The overall structure is similar, therefore only one depression is described in detail.

Investigations of distribution of pattern of depressions were realised using on elevation model based on topographic maps 1:25.000, sheets Zrenjanin 1-3, 1-4, 2-3, 3-1, 3-2, and 4-1. (Vojnogeografski institut, 1993-1995)

Thirteen samples were taken along a transect crossing the whole structure of a depression. Sampling was carried out employing a Pürkhauer core probe.

The solubility of minerals from loess in water was estimated employing the computer program PhreeqC (Parkhurst, Ap-

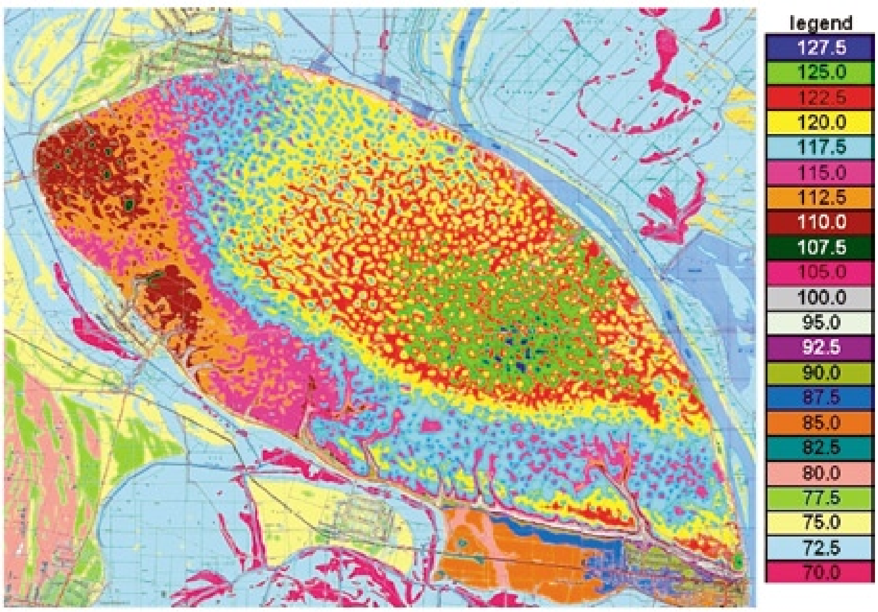

Figure 1 Topography of the Titel-Plateau. Based on data from topographic maps 1:25.000 (Vojnogeografski institut, 1993-1995). Units of the legend are m a.s.l.

pelo, 1999). A saturation of water with dissociated ions from the minerals calcite, dolomite, illite, quartz, kaolinite, chlorite and mica (sensu a saturation index of zero) was aspired. Water is set to an equilibrium with an atmosphere containing $10^{-2,5}$ atm CO_2 and 10^{-1} atm O_2. Reactions were calculated at a temperature of 10°C (the recent mean annual temperature). The exact chemical composition of the loess from the Titel-Plateau area is unknown to the authors. However, calculations done with different loess compositions from nearby sites showed both similar and realistic result. In the following considerations compositional data of loess from Ruma (Marcović et al., 2004) are used. This locality is situated about 45 km south-west of the Titel-Plateau.

Depressions – Patterns of Density and Orientation

The surface of the Titel plateau is characterised by numerous depressions, forming an undulating landscape. Agriculture, in particular the cultivation of corn, results in high erosion on the plateau. The edge is used as feedlot and is partially covered by wood vegetation, as it is too steep for intense agricultural use. Figure 1 presents the topography of the Titel loess plateau, differences in elevation are highlighted by a colour scheme.

The deprecion extension varies, but rarely exceeds a few hundred metres. Maximum depths are ca. 4 m. Depressions are bordered by aggrandisements forming an undulating landscape of shallow slopes. Few level surfaces are observed. First an exemplary depression is described, following the pattern of depressions is outlined.

The results are presented in figure 2. In the central areas of the depressions soil is thickest (exemplary > 2 m). Soil thickness decreases on the slopes, and increases again on aggrandisements.

This pattern is suggested to be the result of erosion. Erosion is highest on slopes, whereas the relatively even surface on top of the aggrandisements experiences less run-off and therefore less erosion. The centres of the depressions represent accumulation areas for the eroded material. During field work heavy rain was observed to displace sediment into the centre of depressions.

Data for the determination of patterns of the depressions were gained from a topographic map. Data were collected in square kilometre plots on the Titel-Plateau. The total number of depressions per km2 was determined. The orientation of depression axes was determined for 12 selected square kilometre plots. Both the number and the extension of depressions were evaluated in the field.

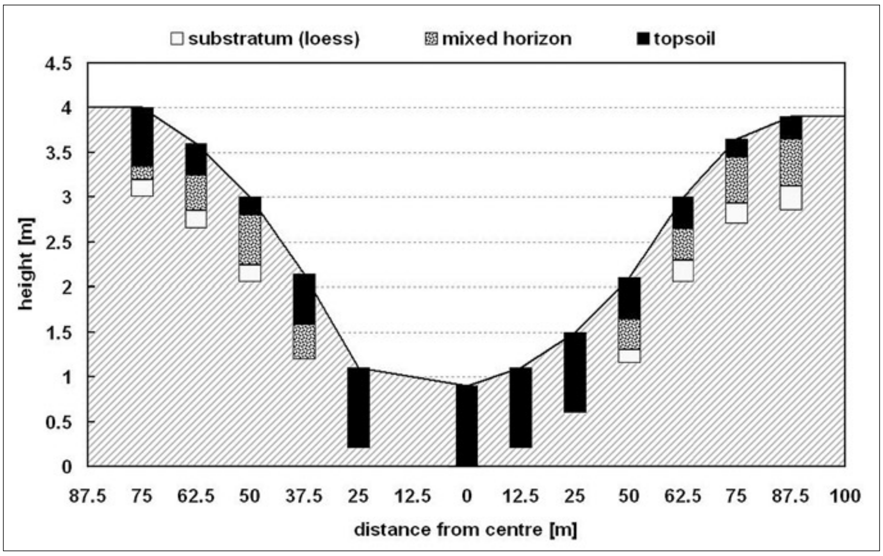

Figure 2 Schematic profile through a depression near Dukatar. Note that topsoils are relative thin on the slopes.

A spatial dataset consisting of 1) number of depressions; 2) length of depressions axis; 3) width of depressions; 4) orientation of depressions axis was produced.

The size (sensu area in m²) of depressions varies, small depressions occur more often than larger ones, as depicted in figure 3.

Depressions show an elongate form. Only 10 out of 190 depressions do not have a clear preferential orientation. A dependency of length and width of depression axis may be observed independently of the size of depressions. Figure 4 shows the relationship of length and width of depressions, the length to width ratio is lower than two for most depressions.

The pattern of depression density is visualised employing a spatial interpolation. Trends of the number of depressions are plotted in figure 5. The density of depressions is highest in the central and north-eastern part of the plateau, and decreases from here on to the edges.

The directions of the longest axes for all depressions are depicted in figure 6. A Northwest-southeast orientation prevails.

Spatial trends for the preferential direction of depressions (mean per square kilometre) are also considered and plotted (figure 7). The orientation of the depressions is relatively west-east bound in the centre of the Titel loess Plateau, reaching an average angle of -34° (clockwise from north). In the northern part near Dukatar and in the south-eastern part of the plateau depressions have a stronger north-south orientation.

Depressions - A Result of Dissolution?

The elongate northwest-southeast alignment of the depressions is similar to the direction of wind influenced gredas within the Pannonic Basin (Roszycki, 1967; Pecsi and Richter, 1996). Therefore this orienta-

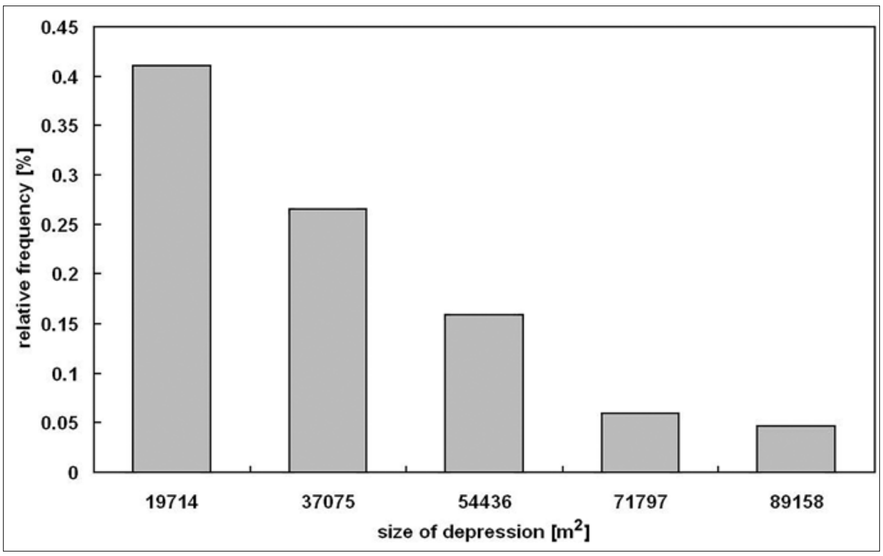

Figure 3 Histogram of the depression size for sampled plots.

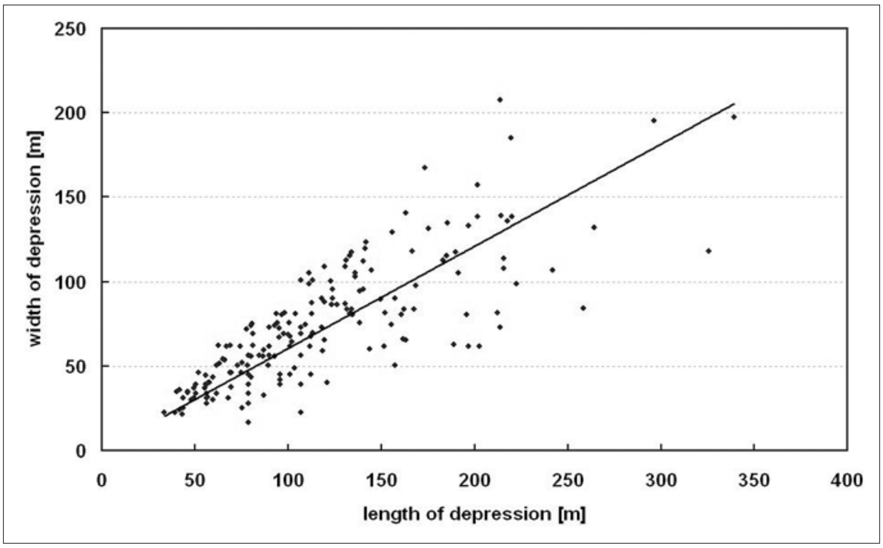

Figure 4 Relation of length and width of depressions for sampled plots.

tion is suggested to be influenced by the main wind direction.

However, the amplitude of the depressions may be generated by preferential dissolution of minerals. Hydrogeochemical calculations are combined with a simplified hydrological model to test this hypothesis.

The origin of the pattern of the depressions is not considered here.

Calculations showed that infiltrating water can dissolve up to ca. 0.50 mmol/l calcite, the ion strength of waters is 1.67 mmol/L. The molar amount of calcite corresponds to ca. 0.05 g/L. Results have to be taken as a guide, and not as absolute values.

As the amplitude of depressions reaches up to ca. 4 m, this difference in elevation is taken as an aspired reference for calculations. In order to dissolve 4 m of loess, ca. 3.82×10^7 mm of precipitation have to drain through the substrate. Because the potential evapotranspiration is higher than the precipitation for every month (Bronger, 1976), a low annual drainage is expected (further 30 % of precipitation are assumed to drain).

Assuming 1) 18 kyr of precipitation (the time span since the last glacial maximum) 2) a drainage (excluding the evapotranspiration) of 30 % of precipitation 3) 10 % of drainage flowing to the centre of depressions (as surface discharge or interflow), 4) 4 m more dissolution of loess in the centre of depressions than on aggrandisements and 5) a ratio of 1 m² centre to ca. 100 m² inclined area (as seen in the field), a mean annual precipitation of ca. 700 mm

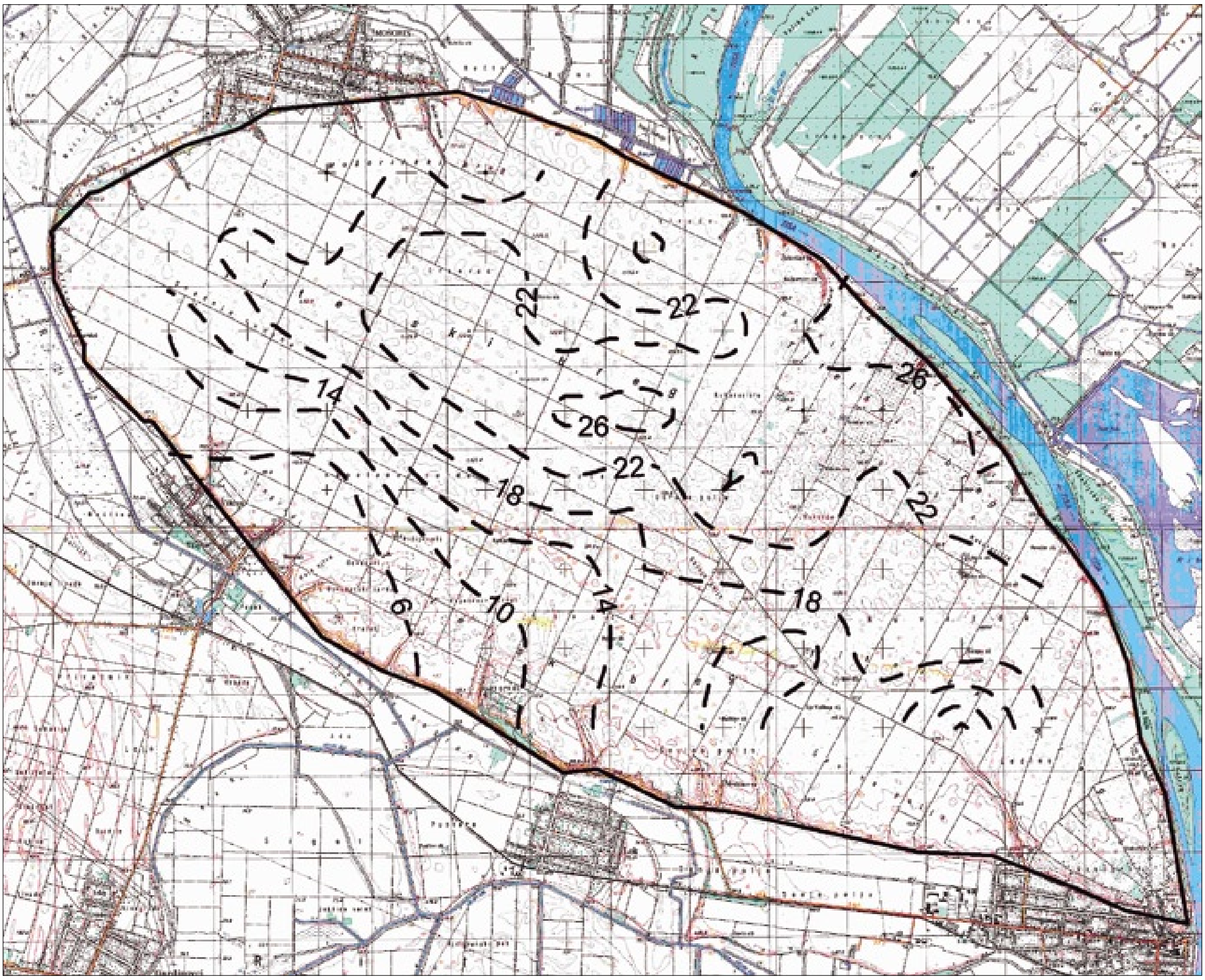

Figure 5 Spatial distribution of the density of depressions on the Titel loess Plateau based on data from topographic maps (Vojnogeografski institut, 1993-1995).. Crosses indicate the centres of sampled square kilometres. Dashed lines are the result of interpolation.

is required to explain the differences in elevation on the Titel-Plateau. Though the actual precipitation is not expected to exceed 500 mm, this result lies within a realistic order of magnitude. Probably a longer time interval is required to achieve the aspired dissolution.

Further aspects as e.g. the accumulation of sediment in the depressions, the influence of an initial relief, and potential errors resulting from mentioned assumptions are not discussed in detail. These factors may lead to different results of the quantification of dissolution. However, the order of magnitude implies that dissolution plays an important role in the formation of the observed depressions.

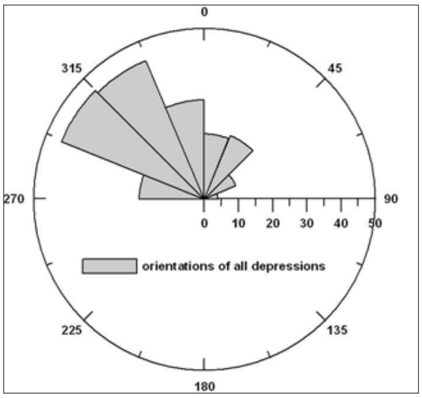

Figure 6 Classes of orientation axes of depressions for sampled plots. The absolute number of depressions per directional class is given by the radial axis.

Conclusions

The morphology of the depressions and their pattern on the Titel Plateau is presented here. The depressions on the Titel-Plateau differ in size and orientation. Depressions on the Titel-Plateau have a preferential northwest-southeast orientation, which is suggested to be influenced by eolian processes. Patterns of both number and orientation of depressions on the Titel-Plateau are identified and presented.

The form of the depressions is influenced by both wind and dissolution. An eolian influence appears the most probable explanation for the preferential alignment. The differences in elevation are suggested to be influenced by dissolution. We suggest a formation driven mainly by dissolution acting upon an eolian initial relief.

Further investigations may improve the understanding of the present surface morphology of the Plateau. Insight into the three-dimensional structure of paleosoils within the Plateau appears inevitable for an understanding of the system of depressions on the Titel-Plateau. The analysis of water within or flowing out of the Titel-Plateau would enable more meaningful hydrogeochemical calculations.

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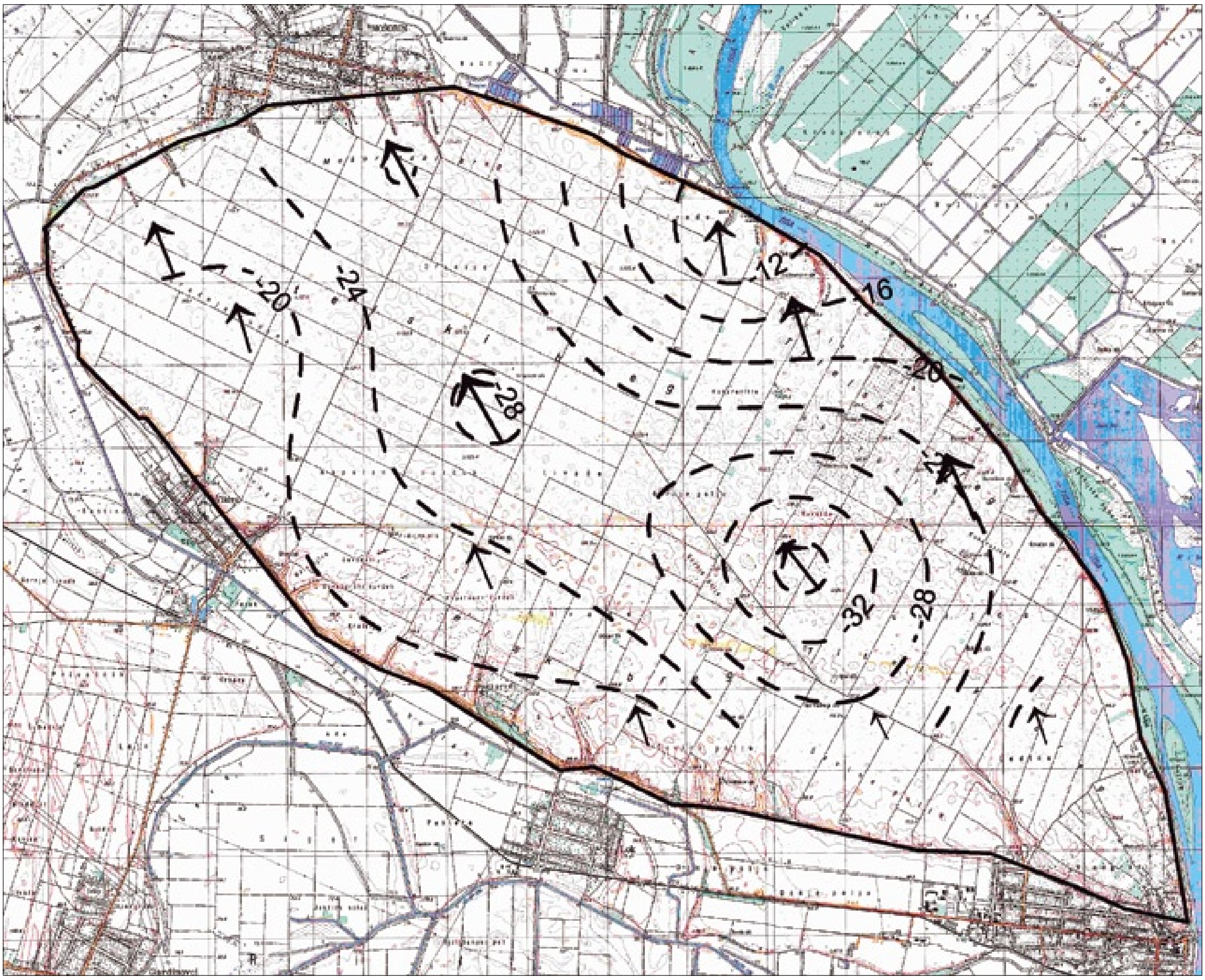

Figure 7 Mean orientation of the depressions axis on the Titel loess Plateau based on data from topographic maps (Vojnogeografski institut, 1993-1995) for sampled plots. Arrows represent mean depression orientations, the length is proportional to the density of depressions. Dashed lines are the result of interpolation. Numbers represent mean orientation angles of depressions.

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