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# Classification and spatial distribution of soils in the foot and toe slopes of mountain Vukan, East-Central Serbia

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A B S T R A C T

This study describes and classifies the soils of the foot and toe slopes of the Vukan Mountain, Central Serbia, the contact point of two distinct geomorphological units, with a focus on their spatial distribution and their main soil-forming processes. The Vukan Mountain is formed of Jurassic limestones and dolomites, whereas the foot and toe slopes are of fluviatile-colluvial origin. A total of 42 soil profiles were examined. Soil profile locations were determined with respect to elevation differences, accounting for a set of six profiles for every 5-m elevation increase between 175 and 210 m a.s.l. The area is characterized by the dominance of chernic and mollic topsoil horizons and the major part of the area is covered with Phaeozems. Five Reference Soil Groups were found in a very small area. Eleven soil profiles are Chernic Phaeozems, five are Cambic Phaeozems, and twelve are Rendzic Phaeozems. The central part of the study area is characterized by the accumulation of secondary carbonates and Chernozems were identified. The northern part of the study area is covered with Fluvisols, Calcisols, and Leptic Rendzic Phaeozems, whereas Chernic and Cambic Phaeozems and Eutric Cambisols cover the western part of the study area. The differences in the $CaCO_3$ content in the gravels, the differences in the gravel content, and the different lateral and vertical distribution of $CaCO_3$ are strong evidence of surface processes that occurred in the past. The presence of different geological layers and buried horizons suggests fluviatile processes. The spatial distribution of soils is related mainly to parent material occurrence, and colluvial and alluvial processes that occurred in the past. The soil map created in GIS has Reference Soil Group as central unit following Rule 1 for map legend creation, except in the case of Phaeozems, which are present as Phaeozems (Leptic) and Phaeozems (other) following Rule 5. This soil survey with approximately one soil profile per 4 ha has indicated considerable soil heterogeneity in the study area. Detailed surveys are therefore recommended for areas with pronounced heterogeneity of soil-forming factors.

## 1. Introduction

Soils can be explained as a function of four environmental-landscape factors: climate, organisms, relief, and parent material, which together act over time. Much of the variation in the soil cover is a function of relief (Schaetzl and Anderson, 2005), and this factor can have a stronger impact than the other soil-forming factors. Though a passive factor, relief provides potential and kinetic energy to the soil system. Spatial interrelations between soils and topography are best explored by studying soils along a slope (Sommer and Schlichting, 1997). A sequence of soils from the crest to the valley floor changes in accordance to geomorphic and hydrological conditions. Footslopes are the most concave parts of the slopes and are thus sediment- and water-receiving positions. Toeslopes are extensions of footslopes where sediment accumulates not only from higher elevations but also from flooding streams. Compared with other positions on the slope, sediments that accumulate on foot and toe slopes tend to have finer texture (Nizeyimana and Bicki, 1992), the topsoil tends to be thicker (Walker and Ruhe, 1968; Gregorich and Anderson, 1985), while the indicators of wetness are stronger and more prominent. Nevertheless, variability of parent material, age of land surface, water distribution, amount and intensity of rainfall, plant heterogeneity, and human impact on land cover could cause large spatial variability of soils along the transect between two geomorphological units (Key et al., 1984; Wierenga et al., 1987; Shmida and Burgess, 1988).

Colluvial Soils are defined in the ex-Yugoslav classification system (Skoric et al., 1985) as weakly developed soils formed by colluvial processes (as erosional deposits) at the bottom of hills, characterized by

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low humus accumulation and weak soil structural development, and often having buried horizons or layers. The authors of the classification system describe an intensive deposition of materials that causes this soil type to remain consistently in the initial stages of formation. However, this theory is correct only when referring to the erosion of unconsolidated rocks and therefore cannot be accurately applied to the erosion of well-developed soils. Coarse fragments are present in these soils and they usually have angular shapes. The transport of soil material may occur through water movement, land mass movement, or forces of gravity, all of which enable transportation of very fine soil particles to coarse fragments, or even rocks. Colluvial Soils and Colluvial–Alluvial Associations cover > 139,000 ha in Serbia. Colluvial Soils and colluvial processes are present in world soil classification systems under different hierarchical levels. In the German (Beyer et al., 1999), French (Baize and Girard, 1995), Czech (Němeček et al., 2001) and Slovak (VUPOP, 2000), Polish (Polskie Towarzystwo Gleboznawcze, 1989), and Russian systems (Sisov et al., 2000) they are present at a high hierarchical level, whereas the US Soil Taxonomy (USDA, 1999) and the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2015) consider them at lower hierarchical levels as parent materials and Colluvic Regosols, respectively.

This study aimed to analyze soils in the foot and toe slopes of Mountain Vukan, Central Serbia mapped in the late 1950s as Colluvial Soils and Brownized Fluvisols according to the ex-Yugoslav classification system (Skoric et al., 1985). Vukan Mountain is mainly formed of Jurassic limestone and dolomites, while the toeslope presents an old terrace of the River Mlava. The area known as the Great Field is located at the contact of these two geomorphological units. The objectives of this paper were to (1) assess the main diagnostic horizons, properties, and materials in the Great Field area with consideration of pedogenic factors and processes, (2) classify soils in the Great Field area using the WRB, and (3) determine the spatial dependence between Reference Soil Groups (RSGs).

## 2. Materials and methods

### 2.1. Study area description

This study was conducted in east-central Serbia, near the sporadically flooded valley of River Mlava (Fig. 1). The study area, the Great Field (44°18′N, 21°29′E), is located at the elevation between 175 and 210 m a.s.l., and at elevations around 30 m higher than the River Mlava bed. The area has a temperate climate, with a mean annual air temperature of around 11.4 °C, and mean annual precipitation of around 645 mm. The area is within the foot and toe slopes of the Vukan Mountain (987 m a.s.l.), formed of Jurassic Limestone-Dolomite rocks with 90–95% $CaCO_3$ content (Dimitrijevic et al., 1970) and impregnation with Cherts. The slopes of the mountain are exceptionally steep, at > 45% in some parts; however, the foot and toe slopes are uniform at 2–5% throughout the Great Field. The study area is geomorphologically simple and nearly flat with a surface area of around 170 ha. The north border of the study area consists of the Reskovacka River bed (mainly not filled with water), while the other borders are artificially surfaced roads and an old railroad. Arable production is more common in the western part of the area, while the eastern parts are used mainly for grazing. The arable soils are under crop rotation using conventional plowing to a depth of 20–25 cm as a means of primary tillage, and disking as a means of secondary tillage. Cropping systems include winter wheat (*Triticum aestivum L.*), maize (*Zea mays L.*) and alfalfa (*Medicago sativa L.*). The natural grassland vegetation is dominated by grass species including common soapwort (*Saponaria officinalis L.*), mullein (*Verbascum phlomoides L.*), and yellow sweet clover (*Melilotus officinalis L.*) and has been used over the last 100 years for hay production without tillage.

Early soil mapping (Tanasijevic et al., 1959) described the soil cover of the mountain as Skeletal Soils, which is a broad term that could roughly correspond to Nudilithic and Lithic Leptosols, Hyperskeletic Leptosols or to several other RSGs with the Skeletic qualifier. Foot and toe slope soils were characterized as Colluvial Soils, and moving towards the old terrace of the River Mlava to Non-calcareous Brownized Fluvisols according to the national classification system (Skoric et al., 1985). The elevation of the old terrace of the River Mlava is almost 30 m higher than the current stream and the automorphic genesis of these soils is now dominant.

### 2.2. Methods

A total of 42 soil profiles were excavated at different elevations within the study area, forming a specific sampling design with six profiles excavated at each 5-m elevation increase between 175 and 210 m a.s.l. The locations of the soil profiles are presented in Fig. 1. The sampling was conducted over a 2-year period (2013–2014). Soils were investigated according to the FAO Guidelines for Soil Description (FAO, 2006). The profiles were excavated up to the depth of consolidated rock, or up to 100–120 cm depth in the case of unconsolidated rock. Disturbed soil samples were collected from all soil horizons, while soil cores were not taken from subsurface horizons with a high gravel content. If soil horizons identified in the field were thicker than 30 cm, disturbed soil samples were taken at 20 cm increments within that horizon. All profiles were excavated using a mini-backhoe, which was able to reach the depth of consolidated rock, and the width of profiles was wider than usual, so the correct depth of rock was observed in the field. The use of a backhoe rather than a spade facilitates and improves removal of material in the deeper part of profile where a large amount of stones and boulders are present. A total of 161 soil samples were collected from the Great Field area, with a total mass of ~4000 g taken for each horizon. In order to determine water holding characteristics and permeability, five soil cores per horizon were collected using a 100 $cm^3$ cylindrical steel sampler.

In the laboratory, the samples were carefully broken up by hand along natural planes of weakness into aggregates of 20–25 mm. After visible plant materials were removed, all soil samples were air-dried and pestled to pass a 2-mm sieve. The particle-size distribution of the soils was determined by combining sieving and the pipette methods (Rowell, 1997). Soil pH values were measured potentiometrically in a 1:2.5 soil–water suspension (Rowell, 1997). The cation exchange capacity and exchangeable bases were determined by 1 M $NH_4OAc$ (pH 7) (van Reeuwijk, 2002). The soil organic carbon was determined using the dichromate method (Rowell, 1997). Total carbonate content was measured volumetrically with a calcimeter, after treatment with 6 N HCl (Nelson, 1982). Soil color was determined on peds and crushed samples in dry and moist conditions using a Munsell color chart (Munsell, 1975). Soil profiles were classified according to the WRB (IUSS, 2015). All the maps were created using ArcMap 10.1 and the inverse distance weighting deterministic interpolation technique (Shepard, 1968). The soil profile data, including photographs of their *endo-* and ectomorphology, are provided with the manuscript as supplementary .kmz files. These files are part of a self-contained project created in Google Earth and, once downloaded, can be opened without internet access.

## 3. Results and discussion

### 3.1. Pedogenic considerations

Soils of the study area are affected by different processes. The main geogenic processes in the Great Field area are fluvial and colluvial deposition, whereas the main pedogenic processes include accumulation of organic matter (melanization), weathering of primary minerals, formation of secondary carbonates, and leaching of base cations. All of these processes affect the soils of the Great Field at different intensities according to the biomass production, landscape position, distance from