Influence of Geomorphology and Land Use on Soil Formation – Case Study Maksimir (Zagreb, Croatia)

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Summary

Factors of soil formation govern soil processes and determine soil properties. The aim of this study was to asses the influence of geomorphology (soil parent material, soil age, soil landscape position) and land use (vegetation) on soil properties in the southeastern part of the Maksimir district in Zagreb, Croatia. Representative profiles of Eutric Cambisol, Humofluvisol, and Pseudogley soils (soil profiles P-1, P-2, and P-3, respectively) were studied on different parent materials (older Holocene sediments, younger fluvial sediments, and loess derivates, respectively), landscape positions (lowland, lowland next to the stream, and plateau, respectively), and land uses (abandoned plough land, urban park, and forest, respectively). Geomorphology influenced soil morphological properties (horizonation, structure and consistence, redoximorphic features), soil particle size distribution (including the coarse/fine sand ratio and the vertical trends of the silt/clay ratio), and soil chemical properties (pH and ΔpH, $CaCO_3$ content). Land use (vegetation) primarily influenced the topsoils of the investigated profiles (soil structure, abundance of roots, humus content, and soil pH), but also the presence of artefacts in the profile P-1 and the properties of redoximorphic features in the profile P-3. Soil profiles P-1, P-2, and P-3 were classified according to the WRB-2014 system as Eutric Relictigleyic Cambisol (Geoabruptic, Loamic), Calcaric Endogleyic Fluvisol (Loamic), and Dystric Retic Stagnosol (Loamic), respectively. We conclude that both geomorphology and land use had crucial impacts on soil formation in the southeastern Maksimir. Moreover, the recent regulations of the local streams significantly influenced properties of the profiles P-1 and P-2.

Key words

soil parent materials, soil landscape position, soil characterization, WRB-2014 soil classification system

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Received: October 15, 2014 | Accepted: June 21, 2015

Introduction

Soil parent material, time of soil formation, relief, organisms, and climate represent the soil-forming factors (Jenny, 1994). These factors govern soil processes and determine soil properties. At the early stages of pedogenesis, parent material determines soil permeability for water, thus largely setting the rates of soil-forming processes (e.g., Škorić, 1986). Relief-controlled microclimate and soil position in the landscape impact various soil properties (see De Souza et al., 2006 and Griffiths et al., 2009). Organisms affect soil weathering rates (Egli et al., 2008) and many soil characteristics, especially at the beginning of soil formation (e.g., Yaalon, 1975). Along with the soil flora and fauna, humans are often considered as organisms that affect soil formation (e.g., Škorić, 1986; Husnjak, 2014), most notably by various land uses.

The aim of this study was to asses the influence of geomorphic features (soil parent material, soil age, and soil landscape position) and land use (i.e., vegetation) on soil properties in the Maksimir district of the city of Zagreb. We investigated three representative soil profiles (P-1, P-2, and P-3) of three different soil types (Eutric Cambisol, Humofluvisol, and Pseudogley, respectively - soil classification according to Škorić et al., 1985). Eutric Cambisol, Humofluvisol, and Pseudogley comprise 3.1%, 9.9%, and 1.5% of Croatian soil cover, respectively (Husnjak et al., 2011). The three soil profiles were found on different parent materials and landscape positions, and under different vegetation covers and land uses. Hence, we wanted to investigate if the varying environmental settings affected the formation of the studied soils in different manners. We also wanted to correlate the three soil profiles with the new version of the WRB soil classification system (IUSS Working Group WRB, 2014) to determine if significant differences in their systematization would occur.

Each soil profile was, at least partly, characterized by redoximorphic features (RMF), which we often used as indicators of soil formation. RMF form by reduction and subsequent oxidation of Fe and/or Mn (hydr)oxides in response to the soil water regime. According to Vepraskas (1995) and Schoeneberger et al. (2002), RMF include redox concentrations (non-cemented Fe/Mn masses, cemented Fe/Mn concretions and nodules), redox depletions (Fe-depleted and/or clay-depleted soil volume), and reduced matrix (soil volume containing Fe^{2+}-bearing minerals).

Materials and methods

Study area

The study area represents the southeastern part of the Maksimir district of the city of Zagreb, Croatia. Three locations, with one soil profile at each location, were studied in the surroundings of the University of Zagreb Faculty of Agriculture (Fig. 1).

Soil profiles P-1 (Fig. 2) and P-2 (Fig. 3) are found on the level terrain in a lowland (with the profile P-2 immediately next to the Bliznec stream), whereas the soil profile P-3 (Fig. 4) is found at the upper third of about 70 m long slope (1-2% inclination, straight form). Consequently, whereas the first two soil profiles are situated at about 128 m asl, the P-3 profile is elevated to about 133 m asl (according to the map TK25, 1997). Accordingly, whereas the first two soil profiles developed on the Holocene terrace, the P-3 profile developed on the Pleistocene terrace. This Pleistocene terrace is largely formed by the Pleistocene loams, which are considered as non-calcareous loess derivates by Haase et al. (2007) and Rubinić et al. (2014). The above-outlined geomorphic setting is confirmed by the soil map of Kovačević et al. (1969).

In line with the presented geomorphic characteristics, time of soil formation and soil parent materials vary among the

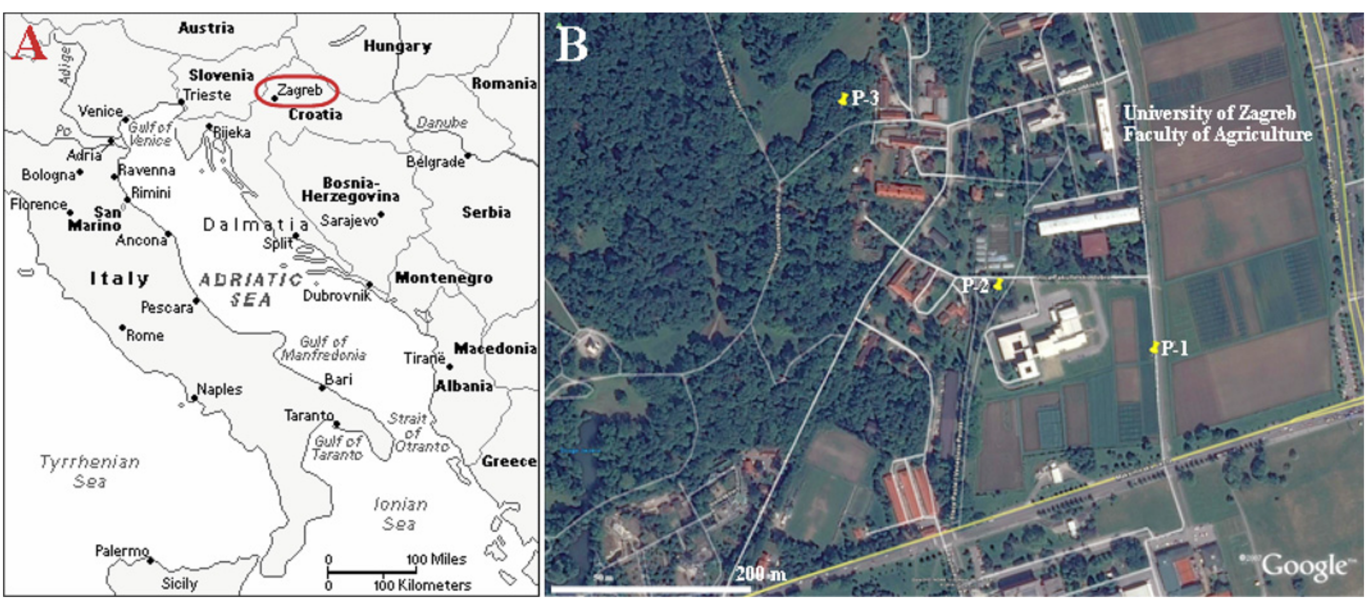

Figure 1. A: Position of the city of Zagreb (Croatia) in Europe. B: Positions of the investigated soil profiles (P-1, P-2, P-3) in the southeastern part of the Maksimir district in the city of Zagreb

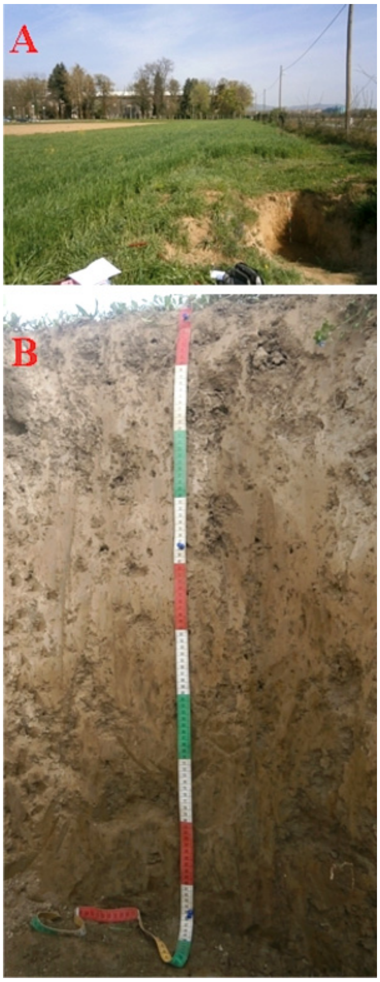

Figure 2. A: Landscape at the site of the soil profile P-1. B: Soil profile P-1

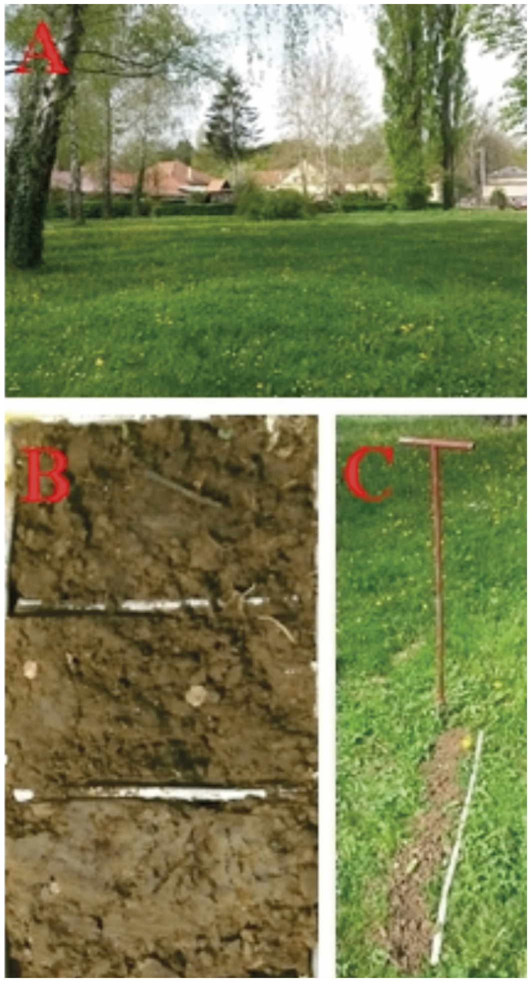

Figure 3. A: Landscape at the site of the soil profile P-2. B: Micro-monolith taken from the soil profile P-2. C: Soil augering at the site of the soil profile P-2

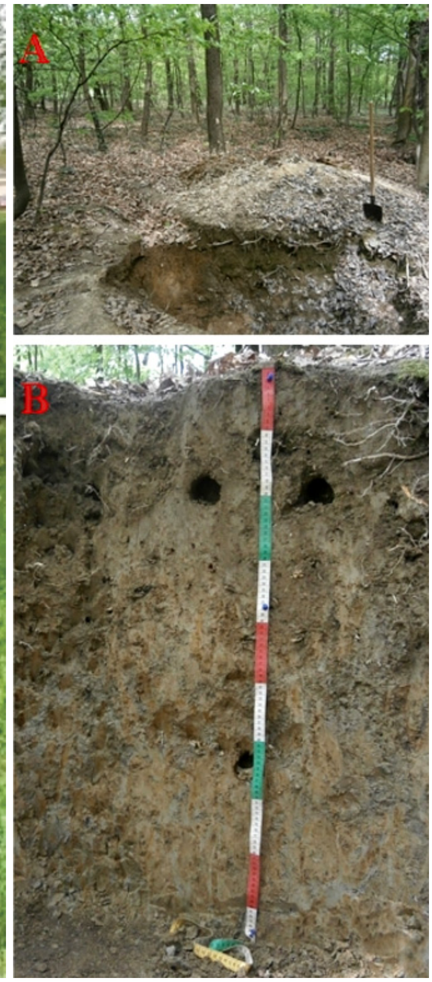

Figure 4. A: Landscape at the site of the soil profile P-3. B: Soil profile P-3

investigated locations. Namely, the age of soils increases from the profile P-2 (formed on recent fluvial sediments), across the profile P-1 (formed on older alluvial-deluvial sediments), to the profile P-3 (formed on the Pleistocene sediments).

According to Zaninović et al. (2008), Maksimir area features a moderate continental climate that can be classified as humid (according to Thornthwaite) and as moderately warm rainy (according to Köppen). Mean annual precipitation and air temperature amount to 840.1 mm and 10.7°C, respectively. Mean values for potential evapotranspiration are 699 and 671 mm, respectively, with draughts usually occurring in the summer.

Vegetation cover and human influence differ among the studied locations. Namely, at the site of the P-1 profile, the experimental field of the Faculty of Agriculture is situated (the soil pit was dug on the grassland not ploughed for the past two decades). At the other hand, the profile P-2 is found in a small urban park along the Bliznec stream, with the vegetation cover largely comprising grassland and ornamental trees, such as European yew (*Taxus baccata*), Black poplar (*Populus nigra*) and Silver birch (*Betula pendula*). The P-3 profile is situated in a well developed forest community of sessile oak and hornbeam (*Epimedio-Carpinetum betuli*), as the typical climax vegetation of the Pleistocene terraces in the continental Croatia (Roglić, 1974; Roglić, 1975).

Field and laboratory analyzes

At the locations of the profiles P-1 and P-3, soil pits were dug to the depth of 1 m (Fig. 2 and Fig. 4). At location of the profile P-2, augering was performed instead (Fig. 3). Soil description and horizon designation were done according to FAO (2006) and Schoeneberger et al. (2002). Soil samples were collected from each soil horizon and put in the plastic bags. In the laboratory, soil samples were air-dried, crushed and sieved through a 2 mm sieve (HRN ISO 11464, 2009).

Soil particle size distribution was determined by pipette-method with wet sieving (sand fractions) and sedimentation (silt and clay fractions) after soil dispersion with sodium-pyrophosphate ($Na_4P_2O_7$, c = 0.4M) and interpreted according to FAO (2006). Soil pH in water and in KCl (c = 1M) was obtained according to HRN ISO 10390 (2005). Content of carbonates was determined according to the modified method HRN ISO 10693 (2004). Humus content was determined by acid potassium-dichromate ($K_2Cr_2O_7$, c = 0.4M) digestion after the Turin method.

Results and discussion

Soil morphology

Even though all soil profiles were silt loams (Table 1), increase in clay content with depth was noted by feel in each profile, especially in the P-3 profile. The P-3 profile had more abundant RMF and more abundant roots, than the remaining two profiles (Table 1). The high abundance of RMF in the P-3 profile is the result of the pronounced downward increase in clay content and decrease in soil permeability for water in that soil profile. The high abundance of roots in the P-3 profile is due to the forest vegetation cover at the site of that soil profile. Largely because of the activity of soil organisms (roots), each soil profile showed downward decrease in organization of soil constituents and increase in hardness of soil consistence (see Gregory, 2006) (Table 1). Nevertheless, given that loess is generally a massive material (e.g., Škorić, 1986), the abovementioned vertical trends were most obvious in the P-3 profile (Table 1).

The profile P-1 consisted of three soil horizons (Table 1). The uppermost was the Ap horizon, formed by ploughing and other agricultural interventions in the soil. Given that for the past two decades the part of the field on which the profile P-1 was investigated has not been ploughed, the Ap horizon does not strikingly differ from the underlying B horizon anymore (Fig. 2). Because the soil pit was dug close to the field fence and the road, some artefacts (mainly fragments of bricks and rubble) were observed in the B horizon of the P-1 profile. The 2Cc horizon of the P-1 profile had distinctly different morphology from the above horizons (based on which it was designated using the prefix “2”) (Table 1). Most notably, the 2Cc horizon featured Fe-Mn concretions and nodules (which is why it was designated using the suffix “c”). In accordance with Stoops and Eswaran (1985) and Vepraskas (2008), Fe-Mn concretions and nodules may be relict signs of gleying, indicating higher groundwater table in the past (possibly until the regulations of the nearby streams Bliznec and Štefanovec during the late 1980s).

The P-2 profile featured a mollic A horizon (Table 1, Fig. 3), formed on the fluvic material labeled as C (Table 1). This profile featured abundant RMF in its bottom horizon (Table 1), but these were largely soft Fe-Mn masses and not hardened concretions/nodules as in the profile P-1. Therefore, it was inferred that the groundwater table, in response to the Bliznec stream, occasionally rises up into the lower 50 cm of the P-2 profile, saturating it for periods long enough for the reducing conditions to occur. Consequently, the suffix “l” was used to designate this horizon as 2Cl (Table 1).

In the P-3 profile, an organic horizon of slightly decomposed litter (Oi) was observed above the mineral soil (Table 1, Fig. 4). Given that the underlying A horizon featured common roots (50-200 roots smaller than 2 mm in diameter per dm^2 of soil, i.e., 5-20 roots larger than 2 mm in diameter per dm^2 of soil), it had a wavy lower boundary due to floral (and partly faunal) soil turbation (Table 1, Fig. 4). The eluvial horizon (Eg) of the P-3 profile was characterized by the depletion of clay and sesquioxides (resulting in the pale soil color), weakly expressed soil structure, and distinct redox concentrations (Table 1, Fig. 4).

Table 1. Morphological features of the soil profiles investigated in Maksimir

Soil profile	Horizon designation *FAO, 2006*	Horizon depth (cm)	Horizon lower boundary[1]	Dry soil color *Munsell Soil Color Chart, 2000*	Structure[2] primary (secondary)	Texture *FAO, 2006*	Dry soil consistence[3]	RMF[4]	RC quantity[5]	Roots abundance[6]
P-1	Ap	0–30	G, S	10YR 6/4	GR	Silt loam	SO	-	F	F
	B	30-55	C, S	7.5YR 6/3	BL		SHA	RC	F	VF
	2Cc	55-97	-	10% 5YR 4/6 90% 10YR 6/3	MA (BL)		HA	RC, RD	M	VF
P-2	A	0-20	-	10YR 5/3	GR	Silt loam	SO	-	-	VF-F
	C	20-50	-	10YR 6/4	BL		SO	RC	F	VF
	2Cl	50-100	-	7.5YR 5/4	BL		HA	RC (RD)	C-M	VF
P-3	Oi	5-0	A, S	-	-	Silt loam	-	-	-	-
	A	0-13	A, W	7.5YR 5/4	GR		SO	RC	F	C
	Eg	13-36	C, I	10YR 7/3	GR		SO	RC	F-C	F
	Btg	36-69	D, S	40-60% 10YR 7/2 10-30% 7.5YR 2.5/1 10-30% 5YR 7/8	MA (BL)		HA	RC, RD	M	VF
	Cg	69-100	-	20-40% 10YR 7/2 40-60% 7YR 3/2 10-20% 5YR 7/8	MA		VHA	RC, RD	M	N-VF

[1] A – abrupt, C – clear, G – gradual, D - diffuse; W – wavy, I – irregular, S – smooth (FAO, 2006); [2] GR – granular, BL – blocky, MA – massive, PR - prismatic (FAO, 2006); [3] LO – loose, SO – soft, SHA – slightly hard, HA – hard, VHA – very hard, EHA – extremely hard (FAO, 2006); [4] RMF - redoximorphic features; RC – redox concentrations (Fe, Fe-Mn and Mn masses/nodules/coatings), RD – redox depletions, RM – reduced matrix (modified according to Schoeneberger et al., 2002); [5] RC – redox concentrations; F - few, C - common, M - many (modified according to Schoeneberger et al., 2002); [6] M – many, C – common, F – few, V – very few, N – none (FAO, 2006)

Table 2. Particle size distribution (%) of the soil profiles investigated in Maksimir

Soil profile	Horizon designation	Horizon depth (cm)	Sand 2-0.063 mm	Coarse/fine sand 0.2 mm limit	Silt 0.063-0.002 mm	Coarse/fine silt 0.02 mm limit	Clay <0.002 mm	Silt/clay
P-1	Ap	0–30	19.2	0.6	72.4	9.1	8.4	8.6
	B	30-55	18.5	0.6	73.5	9.2	8.0	9.2
	2Cc	55-97	19.3	0.3	64.4	8.9	16.3	4.0
P-2	A	0-20	20.9	0.5	66.5	8.8	12.6	5.3
	C	20-50	20.2	0.4	66.8	8.8	13.0	5.1
	2Cl	50-100	13.1	0.5	68.1	7.0	18.8	3.6
P-3	A	0-13	5.3	1.3	81.4	10.0	13.3	6.1
	Eg	13-36	3.7	2.4	82.0	10.1	14.3	5.7
	Btg	36-69	2.1	3.2	72.6	8.9	25.3	2.9
	Cg	69-100	2.7	0.8	70.8	8.2	26.5	2.7

The illuvial horizon (Btg) of the P-3 profile featured distinctly more clay than the Eg horizon and a massive to blocky structure. Thereby, Btg horizon acts as a barrier for the percolation of precipitation water (e.g., Ćirić, 1984 and Resulović et al., 2008), which in turn periodically stagnates on/in this horizon causing the formation of RMF throughout the Btg horizon (Table 1, Fig. 4). In line with the preferential flows of the stagnant soil water and the reduction/oxidation cycles dependent on these flows, redox concentrations in the Btg horizon were mostly inside the peds and redox depletions were mostly on/near the surfaces of the peds. Redox depletions were grayish and silty, at places pervading large portion of the soil volume (Fig. 4). Most authors consider such large zones of clay and Fe depletion to form after the mineralization of dead roots (e.g., Ćirić, 1984; Husnjak, 2014; Resulović et al., 2008; and Vepraskas, 1995).

The Btg horizon of the P-3 profile graded slowly towards the Cg horizon (Fig. 4), which represents a loess derivate that is thoroughly altered by pseudogleization (see Haase et al., 2007; Rubinić et al., 2014; 2015a; 2015b). The Cg horizon had similar morphology as the Btg horizon above it, but with slightly different RMF pattern, less expressed structure, and a very hard consistence (Table 1). Schaetzl and Anderson (2005) stressed that older soils often have thick illuvial horizons that transform to their parent materials very gradually (with illuvial clay frequently leached along the vertical cracks of such parent materials).

Soil particle size distribution

Although within all soil profiles the silt fraction dominated each horizon (Table 2), distinctly different particle size distributions were determined both within and along the profiles. Averaged along profile depth, the profiles P-1 and P-2 had less silt (70.1% and 67.1%, respectively), compared with the profile P-3 (76.7%). The high silt content of the P-3 profile corresponds to its formation from an aeolian parent material. On average, the P-3 profile comprised as much as 3.5% sand, whereas the profiles P-1 and P-2 featured 19.0% and 18.1% sand, respectively. The P-3 profile also showed different coarse/fine sand ratios compared to the profiles P-1 and P-2 (Table 2), confirming the different origin of the P-3 parent material.

The averagely highest clay content of the P-3 profile (19.9%) can be considered the result of intense acidification and weathering in a loess-derived soil (see Janeković, 1960; Rubinić et al., 2014; 2015a; 2015b). Furthermore, in this soil profile a vertical texture contrast was observed. Namely, the two topsoil horizons contained as much as 13.3% and 14.3% clay, whereas the two subsoil horizons contained 25.3% and 26.5% clay (Table 2). Given that the clay content in the Btg horizon was 1.8 times higher than that in the Eg horizon, the Btg horizon of the P-3 profile is considered as *argic horizon* sensu IUSS Working Group WRB (2014). This is in line with Pseudogleys mainly forming by progressive lessivage (see Baize, 1998; Rubinić et al., 2014; ; 2015a; 2015b; Škorić, 1986; and Zaidel`man, 2007).

On the other hand, the abrupt increase in clay content from the B horizon to the 2Cc horizon in the P-1 soil profile is not regarded as the result of clay illuviation but as a geogenetic textural difference. We do not consider this textural change in the P-1 profile to be created by pedogenetic processes because: a) the 2Cc horizon is separated from the B horizon by a discontinuity (see previous chapter); b) the distinct increase in clay content and the decrease in silt/clay ratio was observed only in the lower part of the P-1 profile (Table 2); and c) the neutral pH values (Table 3) keep clay flocculated and inhibit the lessivage process.

Contents of sand and clay (along with the ratios of coarse/fine silt and silt/clay) pointed to *lithic discontinuity* sensu IUSS Working Group WRB (2014) between the C horizon and the 2Cl horizon in the P-2 profile (Table 2). The fact that such discontinuity was noted at depths of about 0.5 m in both the P-1 profile and the P-2 profile (Table 2) resulted from the small distance between the two sites (Fig. 1). Namely, the formation of both the P-1 profile and the P-2 profile took place on the sediments deposited after the withdrawals of local streams and rivers in the past. Even so, one must not ignore the possible additions of deluvial material to the studied soils, although the rate of deluvial sedimentation is most often impossible to estimate in the given geomorphic conditions (Kovačević et al., 1972). Nevertheless, the homogeneous ratios of coarse/fine sand and coarse/fine silt in the profiles P-1 and P-2 point to the similar provenance/age of the sediments, especially of those from which the horizons in the upper 0.5 m developed (Table 2).

Soil chemical properties

Among the three soil profiles, only the profile P-2 was calcareous (Table 3). Accordingly, the P-2 profile featured the highest average pH, both in H_2O (8.0) and KCl (7.4). At the other hand,

Table 3. Basic chemical properties of the soil profiles investigated in Maksimir

Soil profile	Horizon designation	Horizon depth (cm)	$CaCO_3$ (%)	pH H_2O	pH KCl	ΔpH pH(H_2O)-pH(KCl)	Humus (%)
P-1	Ap	0–30	0.0	7.5	6.8	0.7	2.5
	B	30-55	0.0	8.0	7.1	0.9	1.9
	2Cc	55-97	0.0	7.9	6.8	1.1	0.6
P-2	A	0-20	4.2	7.9	7.2	0.7	2.7
	C	20-50	5.0	8.1	7.3	0.8	1.6
	2Cl	50-100	2.7	8.0	7.2	0.8	0.9
P-3	A	0-13	0.0	5.0	3.8	1.2	6.3
	Eg	13-36	0.0	4.5	3.5	1.0	3.3
	Btg	36-69	0.0	4.7	3.4	1.3	0.9
	Cg	69-100	0.0	5.3	3.5	1.8	0.4

the P-3 profile had the distinctly lowest average pH values among the three profiles, both in H_2O (4.9) and KCl (3.6). These results originate from the dependence of soil leaching on the time of soil formation (e.g., Sauer et al., 2009) and on the vertical flows of soil water, both of which largely varied along the investigated locations (see previous chapters). .

In the P-3 profile, pH(H_2O) increased from the Eg horizon towards the Cg horizon (Table 3). Generally, in Croatian Pseudogleys, pH(H_2O) increases with soil depth (see Rubinić et al., 2014; 2015a; 2015b; and Škorić, 1986). The fact that the minimum pH value within the P-3 profile was not determined in the A horizon resulted from the bioclimatic influence in forest soils (e.g., Dahlgren et al, 1997 and Pernar et al, 2009). Namely, in forest soils, basic cations often accumulate in the topsoil due to the decay of abundant litter on the forest floor. In respect to the pH(H_2O), pH(KCl) showed a generally reversed vertical trend in the P-3 profile, resulting in an increase of ΔpH values with depth (Table 3). Similar ΔpH trends were determined in pseudogleyic soils by Khan et al. (2012). According to Škorić (1986), free Al strongly decreases pH(KCl) in Pseudogleys.

Humus content decreased with depth in each soil profile (Table 3). If only the two topsoil horizons of the three profiles are considered, the average humus content in the P-3 profile (4.8%) was distinctly higher than in the profiles P-1 and P-2 (both 2.2%). Such findings agree with vegetation being (along with precipitation) the major factor that determines soil organic matter content (see Alvarez and Lavado, 1998, Griffiths et al., 2009 and Wanhong and Yao, 2006). Namely, the P-3 profile was located within the forest community of sessile oak and hornbeam, and oaks are rich in tannins, as substances that promote SOM formation, i.e., inhibit its decomposition (see Makkar, 2003 and Kraus et al., 2003). Moreover, forest soils typically accumulate high content of humus in their shallow top horizon (Jenny, 1994).

Soil classification

Based on soil morphology, particle size distribution, and chemical properties of the investigated soils (see previous chapters), we classified the three soil profiles according to the WRB soil classification system (IUSS Working Group WRB, 2014). Each soil profile was systematized into a different Reference Soil Group (RSG) and featured different Principal Qualifiers.

Soil profile P-1 is classified as Eutric Relictigleyic Cambisol (Geoabruptic, Loamic). The RSG of Cambisols indicates the presence of a cambic horizon (B horizon) within the soil profile (Table 1). Principal Qualifier Relictigleyic is added to the RSG because the 2Cc horizon featured *gleyic properties* with no signs of *reducing conditions*. Supplementary qualifier Geoabruptic designates an *abrupt textural difference* (very sharp increase in clay content within a limited depth range) that is due to the sedimentation of a coarser-textured material (Ap and B horizons) over a finer-textured material (2Cc horizon) (Table 2).

Soil profile P-2 is a Calcaric Endogleyic Fluvisol (Loamic). It is correlated to Fluvisols because it formed by past fluviatile sedimentation and still shows stratification. The Principal Qualifier Endogleyic refers to *gleyic properties* and *reducing conditions* in the 2Cl horizon.

Soil profile P-3 is classified as a Dystric Retic Stagnosol (Loamic). It is systematized into the RSG of Stagnosols due to the *stagnic properties* accompanied with the occasional *reducing conditions*. *Stagnic properties* imply mottled soil morphology, which is characterized by the oximorphic colors (e.g., black and reddish) inside the peds and the reductimorphic colors (e.g., whitish and grayish) around the root channels and on/near the surfaces of peds. The Principal Qualifier Retic points to *retic properties* (interfingering of coarser-textured and light-colored material into a finer-textured *argic horizon*). Within the soil volume, *retic properties* usually appear as vertical and horizontal whitish intercalations on the faces and edges of soil aggregates.

Conclusion

We investigated the representative profiles of Eutric Cambisol, Humofluvisol, and Pseudogley soils (soil profiles P-1, P-2, and P-3, respectively) in the southeastern part of the Maksimir district of the city of Zagreb. Uneven geomorphic characteristics and land uses along the investigated soil profiles caused distinct differences in soil properties. Geomorphology influenced soil morphological properties (horizonation, structure and consistence, RMF), soil particle size distribution, and soil chemical properties (pH, $CaCO_3$ content). Land use (vegetation) primarily influenced the topsoils of the investigated profiles (roots abundance, soil structure, humus content, and soil pH), but also the presence of artefacts in the profile P-1 and the properties of RMF in the profile

P-3. Given the results obtained, profiles P-1, P-2, and P-3 were classified according the WRB-2014 system as Eutric Relictigleyic Cambisol (Geoabruptic, Loamic), Calcaric Endogleyic Fluvisol (Loamic), and Dystric Retic Stagnosol (Loamic), respectively. We infer that both geomorphology and land use had crucial impacts on soil formation in the southeastern Maksimir. Moreover, the regulations of the local streams (Bliznec and Štefanovec) significantly influenced properties of the soil profiles P-1 and P-2.

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