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Micromorphological soil assessment in abandoned quarry dumps of the Central Caucasus, Russia

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Abstract

This study compared the micromorphological and agrochemical metrics in soils from the quarry dumps and zonal soils, the Central Caucasus. Soil micromorphological investigations are important tool for evaluation of soil dynamics after anthropogenic impacts on terrestrial ecosystems. The results showed that the carbon content in the primary soil of the sand and gravel quarries was lower than that in the reference soil. The differences detected were statistically significant for both the Urvan plot soils ($t = 11.95$; $p = 0.000$) and the Progress plot soils ($t = 18.73$; $p = 0.000$). In contrast, in the quarry with clay bottom substrate (Gerpegezh), no significant difference was found between the reference and postmine soils. The reference soil around the sand and gravel quarries was slightly more acidic than the primary soil. In the clay quarry, the primary soil was more acidic with a strong acidic value, while the reference soil was neutral. The difference of nutrients (P, K, NH_4^+, NO_3^-) between the primary and reference soils were negligible. The only exception was the NO_3^- content in the reference soil of Progress settlement, where it was significantly higher ($t = 4.19$; $p = 0.002$) than in the original soil of the site. No difference was observed for the mineral component of the primary soil. Investigation of key zonal soils of the region. Zonal Caucasus soils: Phaeozem Gleiyc, Phaeozem and Umbric Retisol are different in terms of micro texture. Thus, Phaeozem Gleiyc characterizes by microstructure composed by primary angular mineral forms. Phaeozem and Retisol demonstrated formation of biogenic structure with alteration of mineral particles. Data obtained show that rapid self revegetation of the quarries results in initialization of primary soil formation and transformation of the soil microstructure and organization on the micro level.

Keywords: Central Caucasus, primary soil, soil micromorphological feature, quarry dumps, zonal soil.

Introduction

Land degradation is a major global ecological problems (Gregory et al., 2015; Bagarello et al., 2018). The key factor of terrestrial ecosystems changes is various mineral deposits exploitation with use of mining technologies. Minerals are extracted by mining, open-pit, and combined methods. Open-pit (quarry) extraction is the dominant method for mining due to its low-cost (Abakumov and Gagarina, 2006). However, this method can have a great damage on the landforms (GRLD, 1976). For example, open-pit mining in forest areas is associated with deforestation, draining, and changing of hydrological regime. Negative changes occur not only at the extraction sites but also in the adjacent areas. Previous studies showed that the areas affected by open-pit mining are much larger than the mine itself (Bekarevich and Masyuk, 1969; Melnikov, 1977).

Numerous degraded soil areas have been reported in the Central Caucasus regions, including 3400 ha and 1007 ha of degraded soil in Stavropol Krai and Kabardino-Balkarian Republic, respectively (SRLS, 2019). These regions are dominated by the extraction of common minerals such as boulder-sand-gravel mixes,

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construction sand, and building stone. There are 171 quarries in Stavropol Krai and 53 quarries in Kabardino-Balkaria. These quarries include sand-and-gravel, sandpits, stone pits, brick-and-tile pits, and deposits of keramzite clays, brick loam quarries, volcanic ash and pumice, deposits of tuff, limestone, granite, argillite clay, technical waste, gypsum, sand, and bentonite. The minerals extracted in the Central Caucasus are mostly used for construction (SRLS, 2019; Khamarova, 2019).

Agrochemical and biological soil properties have been used to study artificially-disturbed lands (Gavrilenko et al., 2011; Murugan et al., 2014; Gorobtsova et al., 2016a; Kazeev et al., 2020). However, micromorphological properties were not used for investigation of soils of this region. Despite the fact that micromorphological methods are not often used, they are an important tool for studying soil changes under anthropogenic influences (Stoops and Eswaran, 1986; Lebedeva et al., 2016; Zgangurov et al., 2018). Thus, works on the effects of toxic metals on soil fauna activities and hence on the ecological functions of soils (Acosta et al., 2011) and the effects of the combined addition of organic and industrial waste on stimulating soil formation in degraded landscapes left by extensive mining activities (Arocena et al., 2012) show that soils are best evaluated by knowing the distribution of metals and organics in solid soil phases using micromorphological methods. Micromorphological methods allow the assessment of general physicochemical and biological indicators of soil quality by determining the mineral composition, porosity, quality and quantity of organic matter (Lebedeva-Verba and Gerasimova, 2009; Gerasimova and Lebedeva-Verba, 2010). The conventional soil micromorphology approaches can provide the information about the soil evolution at the micro-level (Stoops and Eswaran 1986, Gerasimova et al., 1992). Micromorphological studies can help identify various physical properties of soils, the nature of minerals, and their relationships with organic matter (van Mourik, 1999; Srivastava et al., 2009; Francis and Poch, 2019; Ageeb et al., 2019). Micromorphological methods have also been used to study degraded landscapes formed after mining (Arocena et al., 2010; Doroshkevich et al., 2020) and their reclamation (Abakumov et al., 2005; Arocena et al., 2012). In the Central Caucasus there are large areas of degraded land, formed as a result of open-cast mining. But there are no works devoted to the assessment of these lands with the use of micromorphological and agrochemical methods of research. On this basis, the aim of the present study was a comparative analysis of micromorphological and agrochemical indicators of soils formed on the waste dumps of open-pit complexes, compared with undisturbed benchmark soils of adjacent landscapes on the example of the Central Caucasus (Stavropol Territory and Kabardino-Balkar Republic).

Material and Methods

Study area

The study area was located in the Central Caucasus, Stavropol Krai and the Kabardino-Balkarian Republic. The surveyed sites are categorized (Sokolov and Tembotov, 1989) as steppes (200-400 m asl), the broad-leaved forest belt (600-1700 m asl) of the Elbrus zonality, and the meadow steppes belt (400-800 m asl) of the Terek zonality for the Central Caucasus. This area has a moderately humid climate with warm summers and cold winters. The average annual precipitation reaches 750-800 mm, and the average annual air temperature varies from 8.5 to 10.0 °C. The steppe zone is characterized by an arid climate with the precipitation is 400-500 mm/year. The climate is more humid in the meadow steppes belt with the average annual rainfall ranges from 600 to 700 mm/year, while the precipitation in the broad-leaved forest area is about 900 mm/year (Sokolov and Tembotov, 1989).

We studied abandoned quarries at three sites in the Central Caucasus at their revegetation stage. Two sites were in Kabardino-Balkaria and one site was in Stavropol Krai (Figure 1). A total of 5 quarries and 3 soil sections each site with different soil types were investigated. The soils were analyzed and classified under the World Reference Base for Soil Resources (WRB, 2015).

The parent materials of the study areas are represented by Quaternary deposits: yellow-brown and brown-brown carbonate loams and clays, as well as loess-like loams (Molchanov, 1984; Gorobtsova et al., 2021).

The first site is located in the steppe zone of the Terek zonality in the Central Caucasus next to Urvan settlement, Urvan District, Kabardino-Balkarian Republic where two sand-and-gravel quarries (Quarry No. 1 and No. 2) were studied there. The quarries are located on both banks of the Urvan River. The soils at the sample points are Phaeozem Gleic. The second site is in the meadow steppes of the Central Caucasus close to Progress settlement, Kirovsky District, Stavropol Krai. The area narrowly extends into the territory of Kabardino-Balkaria where two sand-and-gravel quarries (quarry No. 3 and No. 4) were investigated. The soils at the sample points are Phaeozems. The third site is located in the wide-leaved belt zone in the Central Caucasus next to Gerpegezh settlement, Cherek District, Kabardino-Balkarian Republic where one clay quarry (quarry No. 5) was studied. The soil at the sample point is Umbric Retisol.

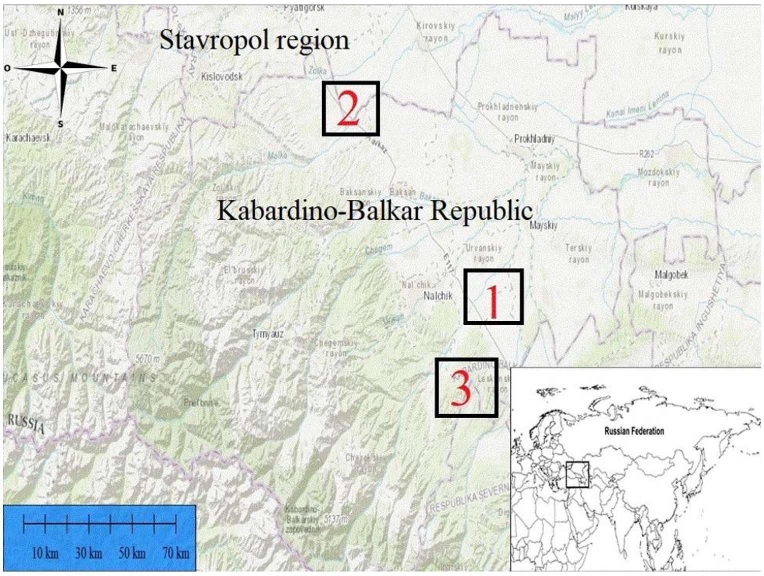

Figure 1. Studied sites. Quarries 1: sand and gravel pit (Urvan); Quarries 2: sand and gravel pit (Progress); Quarries 3: clay pit (Gerpegezh).

Two types of samples were collected in the field. Totally 42 samples were collected. The first type was a 150 g soil sample for lab analysis. The second type was a 2×2×1 cm (H×L×T) micro monoliths. Two to four samples were taken at each site for micromorphology (micromonnolith) and agrochemical analysis (150 g) (Arinushkina, 2013). The samples were taken from the surface layer because they are the most sensitive to various changes. The sample point properties for each site are listed in Table 1.

Soil Chemical Analysis

The carbon content in shallow soils was measured by direct combustion with an elemental analyzer (Euro-EA3028-HT). The pH values of soil solution were measured by the using a pH-meter-millivoltmeter pH-150MA ("Antech", Belarus). Soil solution was prepared in the ratio of 1:2.5 with water. The content of available forms of ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^- -N) were determined using potassium chloride solution (ISO/TS 14256-1, 2003). The content of mobile potassium and phosphorus was determined by the Kirsanov method (Sparks et al., 1996; GOST, 2011). The method is based on the extraction of mobile compounds of phosphorus and potassium from the soil with a solution of 0.2 M hydrochoric acid (HCl). The results were statistically processed in Statistica 10.0 and Excel software. The statistical processing included using the *t*-test to measure the statistical significance of the difference between the variables. Spearman's correlation coefficients were also estimated. The significance level for this study was $p \leq 0.05$.

Micromorphological Studies

The objects of the study were micro monoliths of primary soil samples from the quarries and of the reference soils (usually sampled in pairs). The micromorphological studies followed the guidelines by Parfenova and Yarilova (1977), and the manual by Gagarina (2004). The sections were examined and photographed with a Leica MC 170 HD polarization microscope. The microphoto images (Figure 2-10) show transmitted light photos (parallel nicoles) on the left, and photos with the analyzer actuated (crossed nicoles) on the right.

Results

Soil agrochemical characterization

Table 2 lists the chemical properties of the soil surface layer. The studied soils were neutral and slightly alkaline, except for the Leptosol in the Gerpegezh settlement quarry due to the chemical composition of the mineral waste. The primary soils of the site showed a strongly acidic reaction, while the reference soil is neutral, and the differences are statistically significant (t = 7.11; $p < 0.02$).

The organic carbon content in the studied primary soils was low. Despite this, the primary soils formed in the sand-and-gravel quarries contained less carbon than that in the reference soils. The differences were statistically significant both for the Urvan settlement soils (t = 11.95; $p = 0.000$) and the Progress settlement soils (t = 18.73; $p = 0.000$). In contrast, the organic carbon content in the primary soils sampled in the clay quarry near Gerpegezh settlement was higher than in the reference soil (t = 3.51; $p = 0.02$). This can be explained that the reference samples with Umbric Retisol at this site was taken in a beech-horn-dead forest.

Table 1. Research object properties.

Site No.	Horizon	Depth(cm)	Soil	Coordinates
Fig. 2. Overgrowing bottom of quarry No.1, near Urvan settlement, Urvan, right bank of the Urvan River				
N1-1	A	0-3	Leptosol/Sand	N 43.505832° E 43.775770°
N1-2	A	0-2	Leptosol/Sand	N 43.505926° E 43.775748°
N1-3	A	0-3	Leptosol/Sand	N 43.505818° E 43.775559°
N1-4	A	0-3	Leptosol/Sand	N 43.505832° E 43.775770°
Fig. 3. Overgrowing bottom of quarry No.2, near Urvan settlement, left bank of the Urvan River				
N3-1	A	0-2	Leptosol Umbric Calcaric Gleyic/Sand	N 43.511371° E 43.772516°
N3-2	A	0-4	Leptosol Umbric Calcaric Gleyic/Sand	N 43.511371° E 43.772516°
N3-3	A	0-3	Leptosol Umbric Calcaric Gleyic/Sand	N 43.511371° E 43.772516°
Fig. 4. Reference soil, near Urvan settlement, above the wall of quarry No.1 MATURE				
N2-1	A	0-12	Leptosol Umbric Calcaric Gleyic/Sand	N 43.504599° E 43.775571°
N2-1	B	12-20	Leptosol Umbric Calcaric Gleyic/Sand	
N2-1	C	20-28	Leptosol Umbric Calcaric Gleyic/Sand	
Fig. 5. Bottom of quarry No. 3, grassy vegetation area, near Progress settlement				
N5-1	A	0-4	Leptosol Umbric Petrocalcic Gleyic/Sand	N 43.822996° E 43.331634°
N5-2	A	0-5	Leptosol Umbric Petrocalcic Gleyic	N 43.823000° E 43.331664°
N5-3	A	0-4	Leptosol Umbric Petrocalcic Gleyic	N 43.822671° E 43.332096°
Fig. 6. Bottom of quarry No. 4, a plot given for pasture, vicinity of the settlement. Progress				
N6-1	AU	0-6	Leptosol Umbric Calcaric /Sand	N 43.831616° E 43.347615°
N6-2	AU	6-12	Leptosol Umbric Calcaric /Sand	N 43.831616° E 43.347615°
N6-3	AU	12-30	Leptosol Umbric Calcaric /Sand	N 43.831788° E 43.347126°
Fig. 7. Bottom of quarry No. 4, area with new hillside dumps, near Progress settlement				
N7-1	A	0-10	Leptosol Umbric Calcaric Nudilithic/Sand	N 43.829922° E 43.350023°
N7-2	A	0-12	Leptosol Umbric Calcaric Nudilithic/Sand	N 43.829818° E 43.349988°
N7-3	A	0-10	Leptosol Umbric Calcaric Nudilithic/Sand	N 43.829650° E 43.350224°
Fig. 8. Reference soil, near Progress settlement, above the wall of quarry No. 3 MATURE				
N4-1	AU	0-25	Phaeozem / Loam	N 43.823767° E 43.332439°
N4-1	AUe	25-50	Phaeozem / Loam	
N4-1	BI	50-70	Phaeozem / Loam	
N4-1	C	70-90	Phaeozem / Loam	
Fig. 9. Overgrown bottom of quarry No. 5, near Gerpegezh settlement				
N9-1	A	0-3	Leptosol/Loam	N 43.371111° E 43.623391°
N9-1	C	3-20	Leptosol/Loam	
N9-2	A	0-2	Leptosol/Loam	N 43.370927° E 43.623366°
N9-2	C	2-25	Leptosol/Loam	
N9-3	A	0-23	Leptosol/Loam	N 43.371198° E 43.623161°
N9-3	B	23-35	Leptosol/Loam	
N9-3	C	35-50	Leptosol/Loam	
Fig. 10. Reference soil, near Gerpegezh settlement, above the wall of quarry No. 5 MATURE				
N8-1	A	0-12	Retisol Folic Inclinic/Loam	N 43.371051° E 43.622333°
N8-1	B	12-20	Retisol Folic Inclinic/Loam	
N8-1	C	20-35	Retisol Folic Inclinic/Loam	
N8-2	A	0-15	Retisol Folic Inclinic/Loam	N 43.371000° E 43.622275°
N8-2	B	15-25	Retisol Folic Inclinic/Loam	
N8-2	C	25-34	Retisol Folic Inclinic/Loam	
N8-3	O	0-2	Retisol Folic Inclinic/Loam	N 43.370858° E 43.622207°
N8-3	A	2-18	Retisol Folic Inclinic/Loam	
N8-3	B	18-27	Retisol Folic Inclinic/Loam	
N8-3	C	27-35	Retisol Folic Inclinic/Loam	

For all the other studied chemical properties, there was no difference between the primary and reference soils. The only exception was the NO_3 content. It was significantly higher ($t = 4.19$; $p = 0.002$) in the reference Phaeozem soil of Progress settlement than in the primary soil of the site.

The Spearman correlation coefficient (Table 3) indicated a strong negative relationship between the content of ammonium and nitrate nitrogen compositions. The exchangeable phosphorus content positively correlated with the content of ammonium nitrogen compositions and negatively correlates with the nitrates content. No strong correlations were found for the other chemical composition properties.

Table 2. Soil chemical composition.

Point	Soil skeleton (%)	C_{org} (%)	pH of salt extract	$P\text{-}P_2O_5$ (mg/kg)	$K\text{-}K_2O$ (mg/kg)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)
Primary soils, Urvan settlement							
N1-1	15	0.29	7.7	34.4	259.7	44.96	0.10
N1-2	20	0.56	7.4	69.9	360.8	79.93	0.10
N1-3	17	0.34	7.4	43.0	274.2	54.46	0.10
N1-4	28	0.45	8.0	35.2	303.0	38.50	0.10
M ± σ	20±5.72	0.41±0.12	7.63±0.29	45.63±16.64	299.43±44.70	54.46±18.20	0.10±0.00
N3-1	18	0.41	8.0	16.1	173.2	23.76	0.10
N3-2	17	0.36	7.9	30.9	303.0	36.55	0.10
N3-3	18	0.41	7.7	44.1	346.3	38.14	0.10
M ± σ	17.67±0.58	0.39±0.03	7.87±0.15	30.37±14.01	274.17±90.08	32.82±7.88	0.10±0.00
Reference soil, Urvan settlement							
N2-1	12	1.89	7.6	17.7	173.2	15.84	5.20
N2-2	11	2.71	7.5	40.1	389.6	37.34	0.10
N2-3	13	2.69	7.6	32.3	288.6	25.59	0.10
M ± σ	12±1	2.43±0.47	7.57±0.06	30.03±11.37	283.8±108.3	26.26±10.77	1.8±2.95
Primary soil, Progress settlement							
N5-1	32	0.78	7.5	12.4	331.9	4.75	8.47
N5-2	21	0.63	7.5	15.1	404.0	6.46	7.80
N5-3	27	0.65	7.6	14.0	317.5	5.30	13.49
M ± σ	26.67±50.51	0.69±0.08	7.53±0.06	13.83±1.36	351.13±46.35	5.50±0.87	9.92±3.11
N6-1	15	0.78	7.5	41.9	692.6	29.91	0.10
N6-2	16	0.79	7.5	42.8	678.2	32.04	0.10
N6-3	15	0.74	7.5	43.0	793.7	30.16	1.15
M ± σ	15.33±0.58	0.77±0.03	7.5±0.00	42.57±0.59	721.50±62.94	30.70±1.16	0.45±0.61
N7-1	25	0.87	7.3	25.5	606.1	12.67	5.20
N7-2	24	0.81	7.4	80.9	894.7	29.18	0.56
N7-3	27	0.82	7.2	21.2	606.1	18.40	0.33
M ± σ	25.33±1.53	0.83±0.03	7.3±0.1	42.53±33.30	702.3±166.62	20.08±8.38	2.03±2.75
Reference soil, Progress settlement							
N4-1	25	2.56	7.1	14.0	404.0	13.83	15.60
N4-2	23	2.21	6.9	14.5	389.6	12.37	33.32
M ± σ	24±1.41	2.39±0.25	7±0.14	14.25±0.35	396.8±10.18	13.1±1.03	24.46±12.53
Primary soil, Gerpegezh settlement							
N8-1	15	1.12	4.9	19.1	375.2	15.90	0.10
N8-2	14	0.75	5.2	19.6	490.6	22.05	0.10
N8-3	21	0.63	5.7	25.3	505.1	58.00	0.10
M ± σ	16.67±3.79	0.83±0.26	5.27±0.40	21.33±3.44	456.97±71.18	31.98±22.74	0.10±0.00
Reference soil, Gerpegezh settlement							
N9-1	23	0.34	7.2	10.8	966.8	10.84	0.11
N9-2	27	0.31	7.3	56.5	1125.5	51.54	0.37
N9-3	30	0.09	6.9	13.7	562.8	27.90	0.10
M ± σ	26.67±3.51	0.25±0.14	7.13±0.21	27±25.59	885.03±290.1	30.09±20.44	0.19±0.15

Table 3. Spearman rank-order correlation coefficients.

Variable	Spearman Rank Order Correlations - Marked correlations are significant at $p < 0.05$						
	Soil skeleton	C_{org}	pH of salt extract	$P\text{-}P_2O_5$, mg/kg	$K\text{-}K_2O$, mg/kg	NH_4^+, mg/kg	NO_3^-, mg/kg
Soil skeleton	1.00						
Corg	-0.27	1.00					
pH of salt extract	-0.19	-0.19	1.00				
$P\text{-}P_2O_5$ (mg/kg)	-0.31	-0.09	0.23	1.00			
$K\text{-}K_2O$ (mg/kg)	0.25	0.04	-0.57	0.14	1.00		
NH_4^+ (mg/kg)	-0.25	-0.41	0.17	0.78	-0.05	1.00	
NO_3^- (mg/kg)	0.44	0.34	-0.16	-0.41	0.20	-0.69	1.00

Soil microstructure

The primary soils of the quarries near Urvan settlement (Figure 2 and 3) had a conventional sandy microstructure without any signs of plasma formation. The sand grains were angular fragments of quartz, mica, feldspars, and pyroclastic material (the presence of the latter is associated with the ancient volcanic activity in the North Caucasus). The average fragment size was 100-500 μm. There is no evidence of rounded mineral grains, indicating the autochthonous origin of the mineral grains in the soils. The second quarry soil features finer mineral grains, and poorly decomposed plant remains. The microstructure is characterized by a high share of porous space. The reference Leptosol between the quarries did not differ from the primary soils (Figure 4). Its mineral grain fragments were less angular, suggesting a greater transformation of the mineral content in the soil.

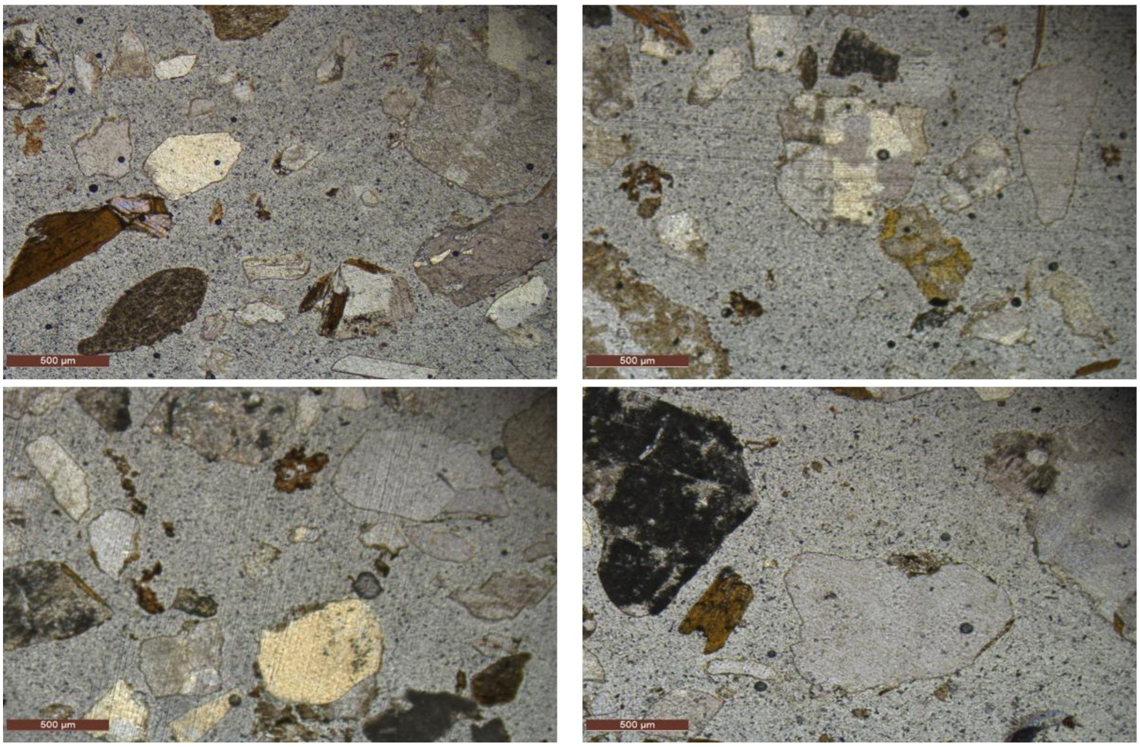

Figure 2. Overgrowing bottom of quarry No.1, near Urvan settlement, Urvan, right bank of the Urvan River.

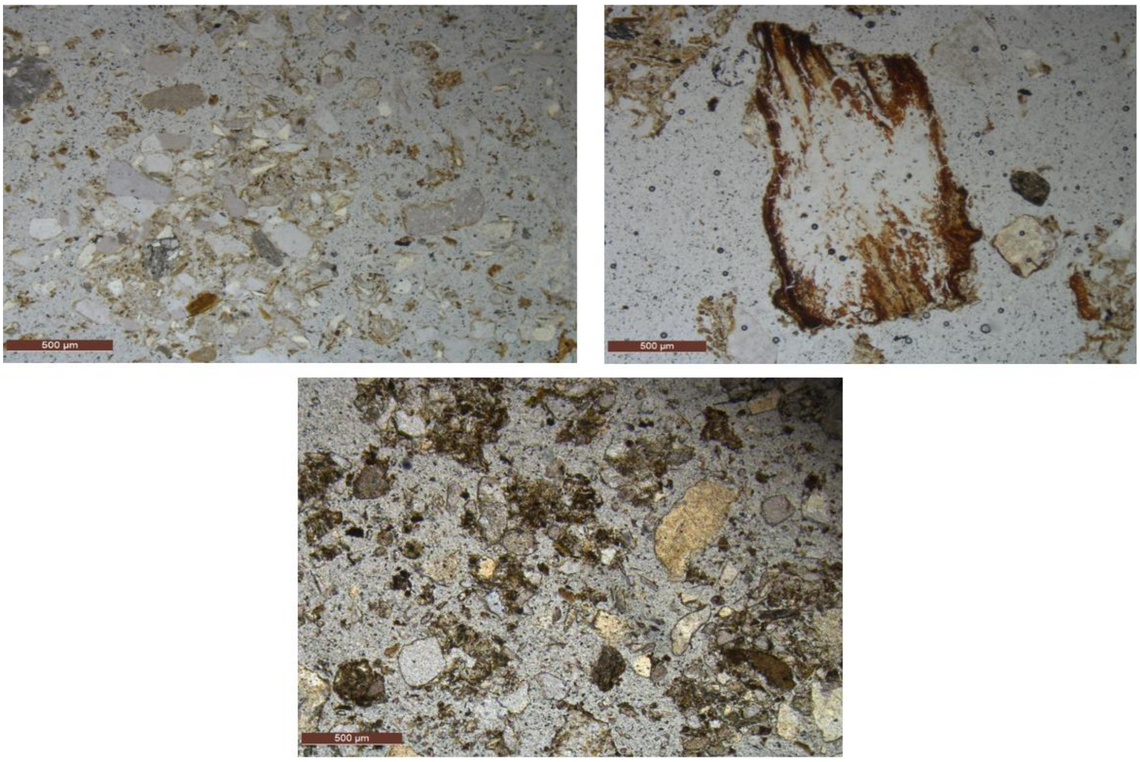

Figure 3. Overgrowing bottom of quarry No.2, near Urvan settlement, left bank of the Urvan River.

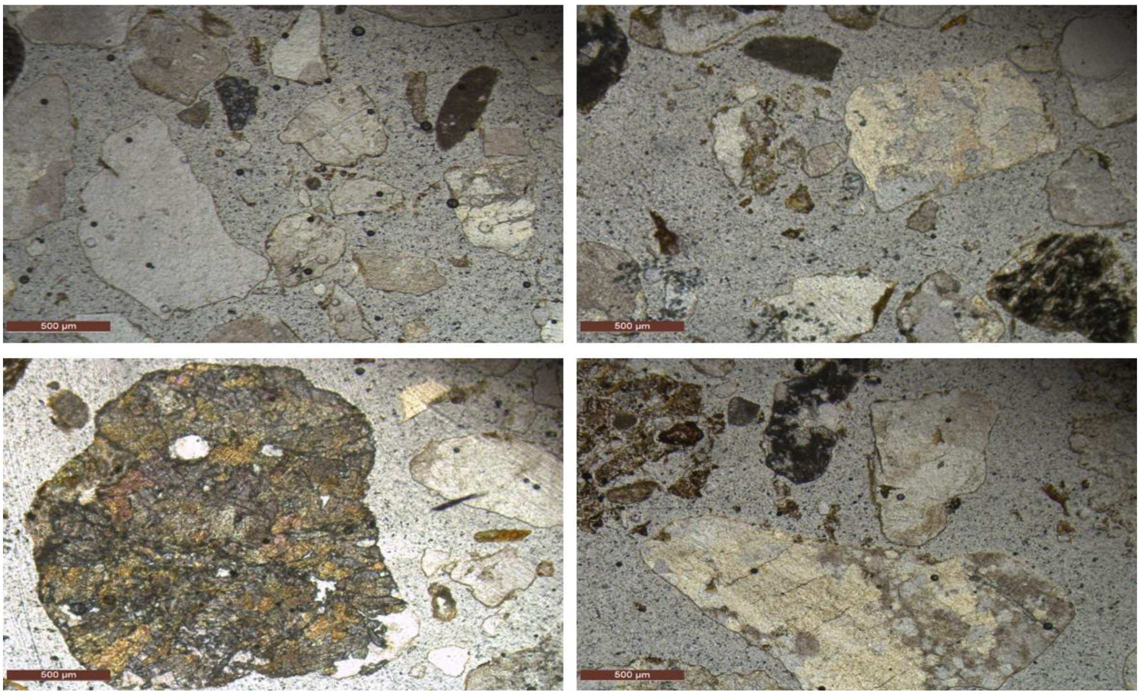

Figure 4. Reference soil, near Urvan settlement, above the wall of quarry No.1 MATURE

The primary soils in the quarry near Progress settlement were similar in that organic-mineral rounded and oval shape aggregates with irregular faces are formed in the upper horizons of these Leptosols (Figure 5,6 and 7). This was observed in all the three studied soils sampled from the quarry. The mineral grains that are not part of the aggregates are represented by angular diamond-shaped quartz grains, in which the porous spaces are extensive. In the benchmark Phaeozem soils (Figure 8) in vicinities of Progress settlement formation of aggregates is evident which is typical for this type of soils everywhere. The clay extraction quarry bottom in Gerpegezh is an underdeveloped lithosol. With a large number of roots, they are formed with rounded-cubic aggregates having a diameter exceeding 2,500 μm (Figure 9). It also contained small weakly decomposed plant residues. In the reference Umbric Retisol (Figure 10), the formation of rounded aggregates, accumulation of poorly decomposed plant residues, and loessivage of fine-grained soil in the humus-alluvial horizon were also observed.

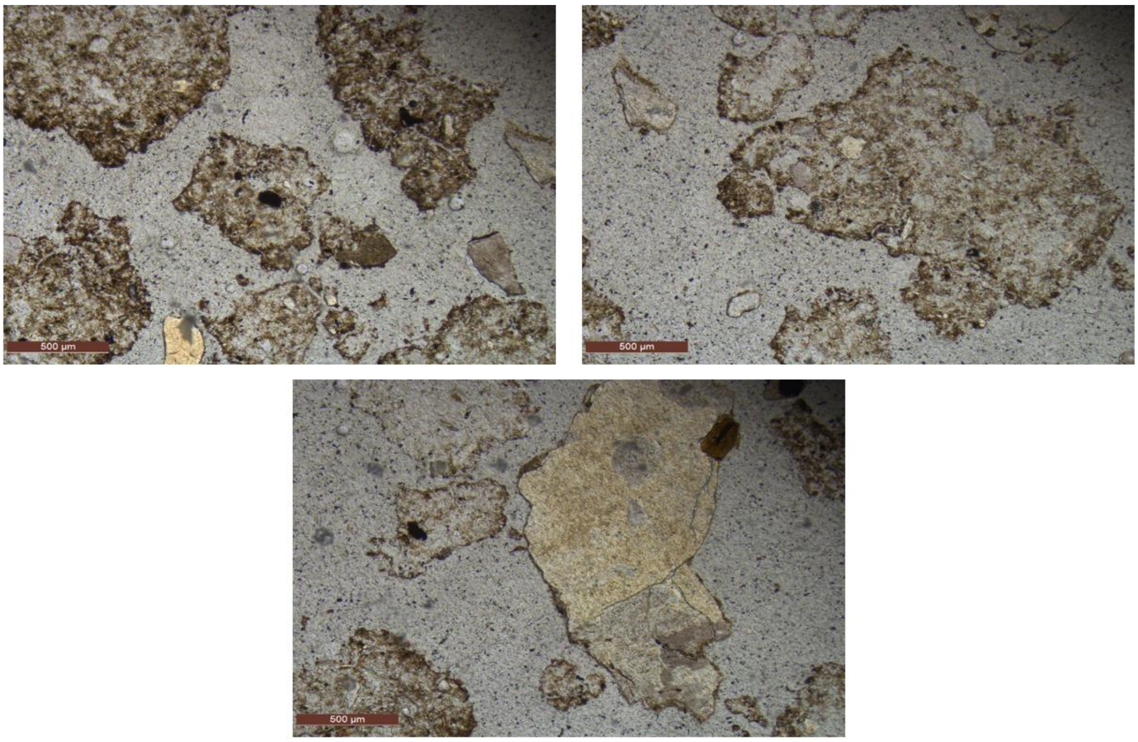

Figure 5. Bottom of quarry No. 3, grassy vegetation area, near Progress settlement.

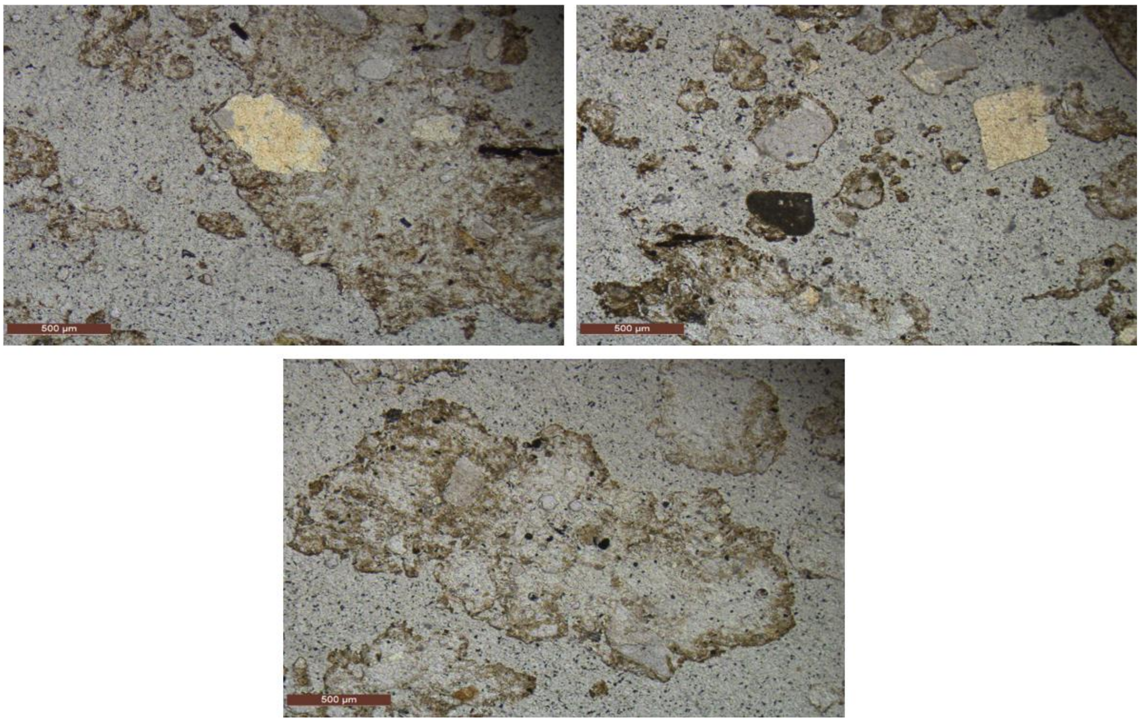

Figure 6. Bottom of quarry No. 4, the pasture area, near Progress settlement

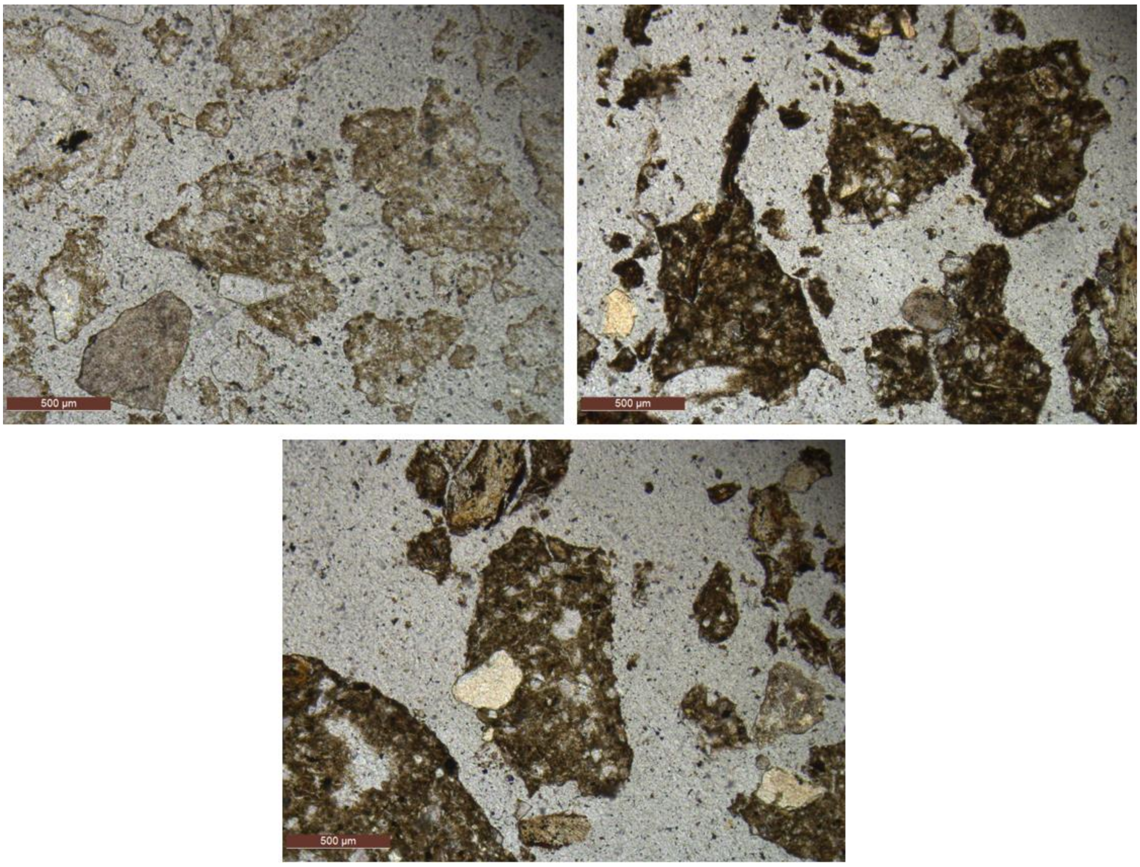

Figure 7. Bottom of quarry No. 4, area with new hillside dumps, near Progress settlement

The key factor for the primary soil formation in the quarry dumps of the studied region is the biogenic growth on the substrate, expressed primarily as the formation of rounded aggregates and the accumulation of weakly decomposed plant residues. There was almost no change in the mineral components of the primary soil. The micromorphological structure of the key local zonal soils (Phaeozems Gleic, Phaeozems and Umbric Retisols) showed that the microstructure associated with the accumulation of clastic grains of primary minerals prevails in the humus Gleysol while the microstructure of the Phaeozem and Retisol soils was controlled by biogenic transformation.

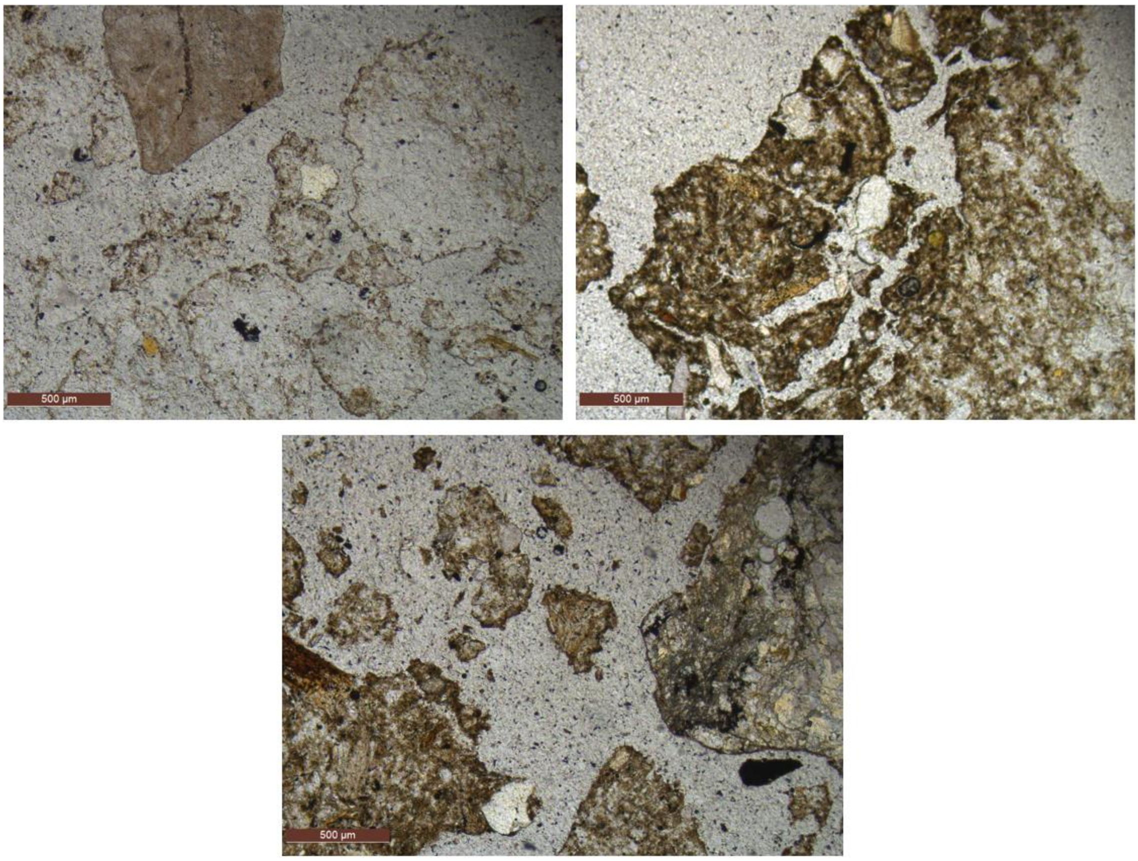

Figure 8. Reference soil, near Progress settlement, above the wall of quarry No. 3 MATURE

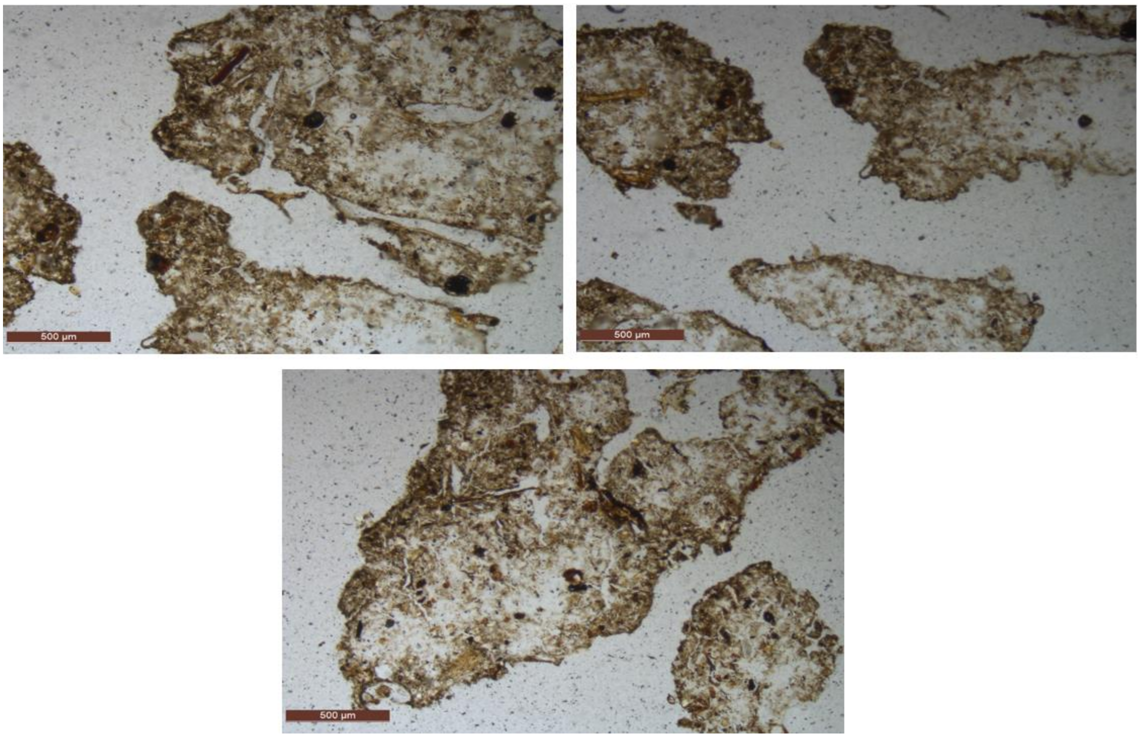

Figure 9. Overgrown bottom of quarry No. 5, near Gerpegezh settlement

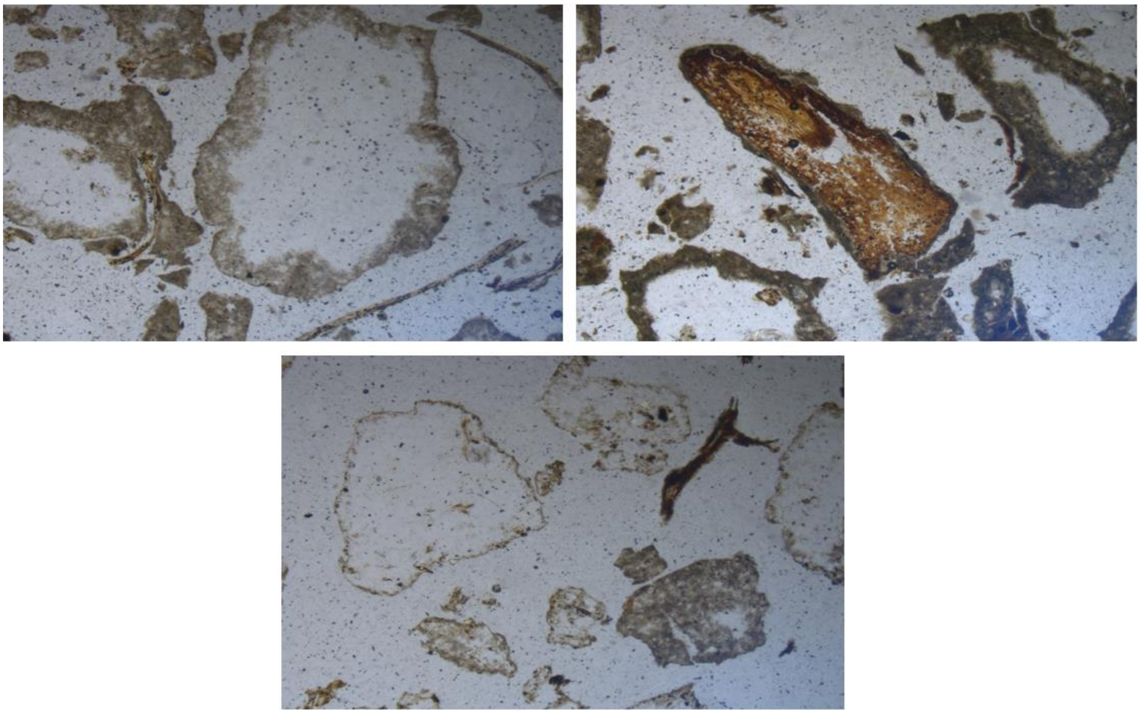

Figure 10. Reference soil, near Gerpegezh settlement, above the wall of quarry No. 5 MATURE

Discussion

Study of agrochemical properties of soils

The current study shows that the content of most measured agrochemical indicators (nutrients), was low at all sample sites. The exception was the content of K_2O, which is very high in many points, which agrees with the literature data showing that soils of the Caucasus, including the Central Caucasus, have a medium to high supply rate of mobile potassium, while in the presence of nitrogen and phosphorus they have weak and very weak supply (Novruzova, 2019; Pinskoy, 2022). The level of acidity of the background and primary soils corresponds to the genetic features of the studied soils (Gorobtsova et al., 2016b, 2017, 2021) and has a slightly alkaline and neutral reaction. The organic carbon content of the studied primary soils is characterized by relatively low values. The background soils are also characterized by a low content of organic carbon, which is typical for the soils of this region (Gorobtsova et al., 2017, 2021). The low content of organic matter in the Phaeozems sampled in Progress settlement is explained both by their genetic features and by the fact that the content of organic matter decreases in soils during their reclamation, with which other authors agree (Gedgafova et al., 2015; Liu et al., 2016). It was found that in the primary soils sampled in the clay quarry, the content of organic carbon is higher than in the background soil. This is due to the fact that the background sample, represented by Umbric Retisol, at this site was sampled under a beech-horn-horn-beech forest, under which, according to Gorobtsova et al. (2021), the humus content is low. In the primary soil, all the newly formed humus is concentrated in the superficial horizon which result in apparenly increased concentration.

The background soil in Progress settlement was the only one for which high levels of NO_3 were found and there was a predominance of NO_3 over NH_4, which is common in some agricultural soils (Cui and Song, 2007). This can be explained that clay particles and organic matter of acid soils called also as colloidal materials include positive ions due to variable charges and NO3 ions include negative charge so acid soils have high NO3 level. This may be due to soil acidity, nitrate leaching, or the application of crop residues after harvesting has ceased (Dejoux et al., 2000; Miller and Kramer, 2004). Soil agrochemical analyses have shown, that soil restoration is not limited by nutrient content, at least the nutrient content is not a critical factor for self-overgrowing pits and soil regeneration.

Study of micromorphological properties of soils

Previous micromorphological studies of soils in the Caucasus have focused on issues such as the study of deep soil processes in ancient mounds (Alexandrovskiy et al., 2014), organic matter distribution processes (Kovda et al., 2010), and the study of the micromorphology of cryoconite, which showed the presence of a silty fraction with a predominance of grains with smooth edges (Zawierucha et al., 2019). They found that local geomorphology and features of geology are more important than regional climate in shaping soil micromorphology. Our work was the first to investigate the micromorphological organization of the main zonal soils of the Central Caucasus - Phaeozem Gleic. Phaeozems and Umbric retisol and primary soils of quarry-dump complexes. The formation of a humus-clay plasma was revealed in the Phaeozem soil, which is characteristic of zonal soils of the accumulative-humus series (Gerasimova et al., 1992). Our study has shown that in Phaoeozem Gleyic soils, microstructure dominates, associated with the accumulation of angular grains of primary minerals, while in Phaeozem and Retisol, microstructure is caused mainly by biogenic processes of structure transformation.

The received data have shown that the main factor of initiation of primary soil formation on dumping pits of Central Caucasus is biogenic alteration of a substrate, expressed, first of all, in formation of rounded aggregates and accumulation of weakly decomposed vegetative residues. It is revealed that the change in the mineral part of the soils in the primary soils is practically not observed, indicating that the biogenic-abiogenic interactions in the soils are at the very initial stage. This is typical feature of microstructure of primary soils of dry region if one compare they with initial soils of boreal environments (Abakumov and Gagarina, 2006). Thus in norther soils weathering rate and degree of mineral part alteration is higher due to higher water saturation rate and accumulation of organic acids, derived from organic remnants of coniferous forests. Thus, self regeneration of soil could evaluates as slower process in quarries steppe region if one compare with boreal ones.

While Figures 2-10 shows photos of soils in transmitted light, which allows us to analyze the shape of grains and structure, Fig. 11 shows photos in transmitted light and crossed nicols (Stoops, 1986) which is important for analyses of mineralogical soil features. Fists pair of photo demonstrates oligomineral grains with dominance of quarts, which changes color from white-grayish in transmitted light to blue in crossed nicols. This and angular form of grains is typical for primary soils and indicates that weathering is only on very initial stages (Abakumov et al., 2005). Another feature is that mica presented on surfaces of grains, mica is unstable for weathering and its being in soils indicates very initial alterations stages of soil materials transformation (Abakumov et al., 2022). Thus, the soil of Urvan quarry demonstrates very initial stage of mineral part alteration. Leptosol of the bottom of Progress quarry demonstrate very intensive aggregation of soil matter – sandy particles are glued by clay and humus, which indicates intensive biogenic-abiogenic interaction (Figure 11). Nevertheless, the reference Phaeozem demonstrates higher intensity of aggregate formation and larger diameter of structural units (Figure 11), which is typical for zonal Chernozems of Caucasus region.

Conclusion

The soils from the quarries of the Central Caucasus were compared with the reference soils from the adjacent territories. The significant differences in the organic carbon content of the primary and reference soils for the areas near Urvan and Progress settlements. In contrast, the Gerpegezh site showed no differences for organic carbon content but acid and alkaline properties. For all other studied chemical properties, no significant differences between the primary and reference soils in the areas studied were found. The results indicates that the primary soil formation in the surveyed areas is close to zonal formation in terms of chemical properties. The micromorphological data shows that the soils of Progress and Gerpegezh settlements contain biogenic round-cubic aggregates and some humus-clay plasma components. In general, non-toxic waste rocks in the studied areas are subjected to fairly rapid overgrowth, which leads to the manifestation of biogenic accumulative processes and the formation of primary soils with attributes (including micromorphological properties) close to that of the Leptosols in the primary soils. Low intensity of in situ soil weathering and appearance of few micro feautres of biogenic-abiogenic interaction in primary soils in spite of good nutrient state indicates that climate is key limiting factor of initial soil development.

For the first time in the Central Caucasus, a micromorphological and agrochemical study of the soils of abandoned quarries was carried out, in comparison with reference soils. In this work, abandoned clay, sand and gravel quarries were examined, although there are also other quarries in the Central Caucasus - stone, brick and tile quarries, loam, volcanic ash and pumice, tuff, limestone, granite, gypsum, sand and bentonite deposits, where no such studies have been conducted so far. All of the above, makes the continuation of the study of morphological. micromorphological and agrochemical properties of abandoned quarries in the Central Caucasus especially relevant.

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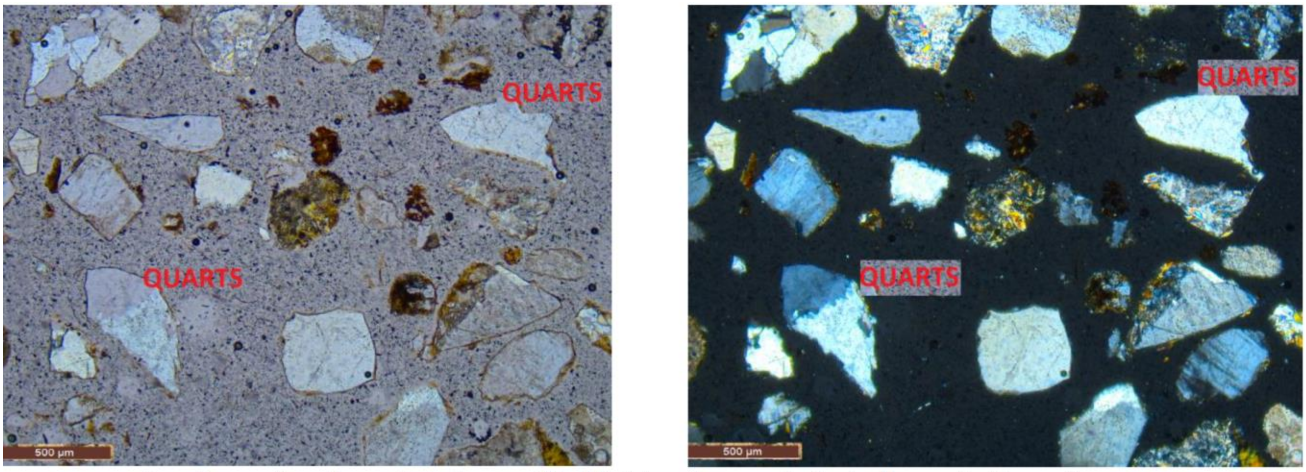
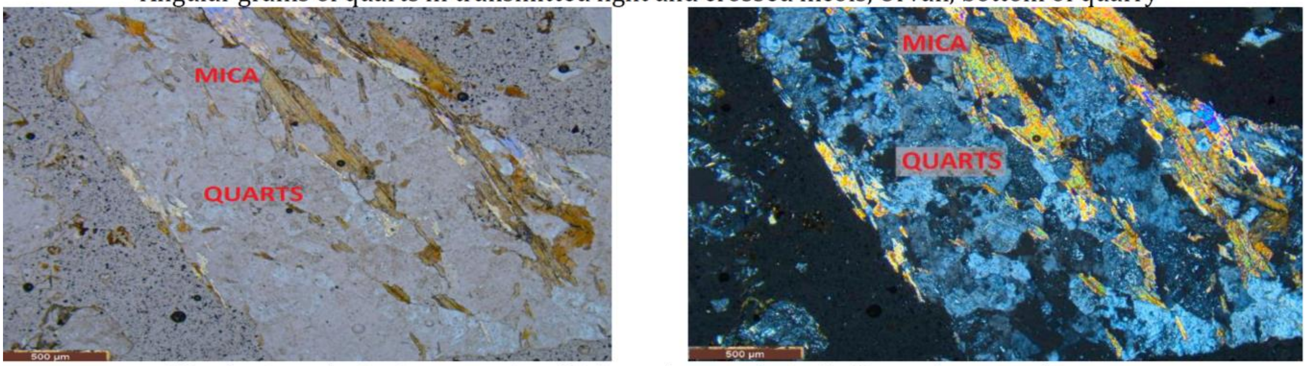
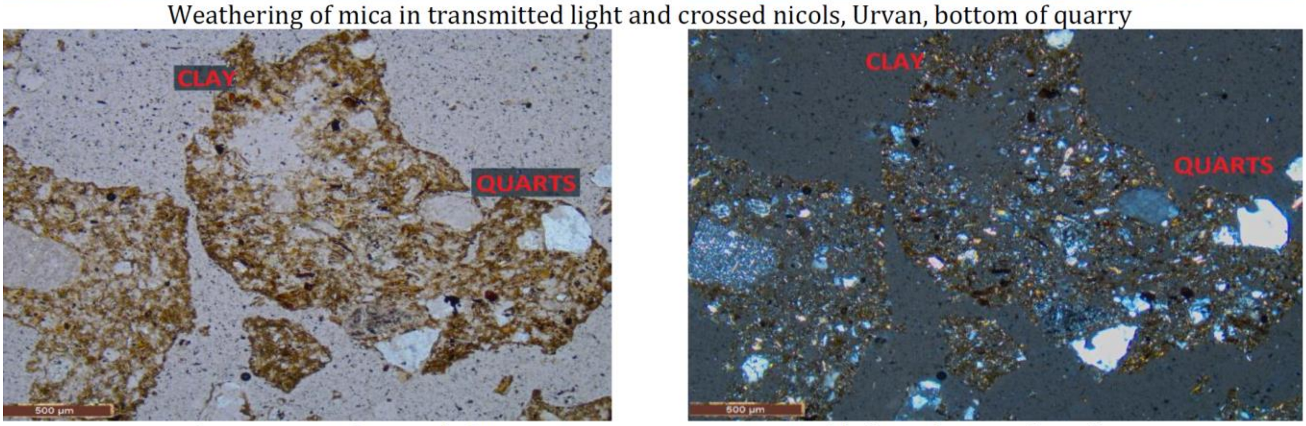


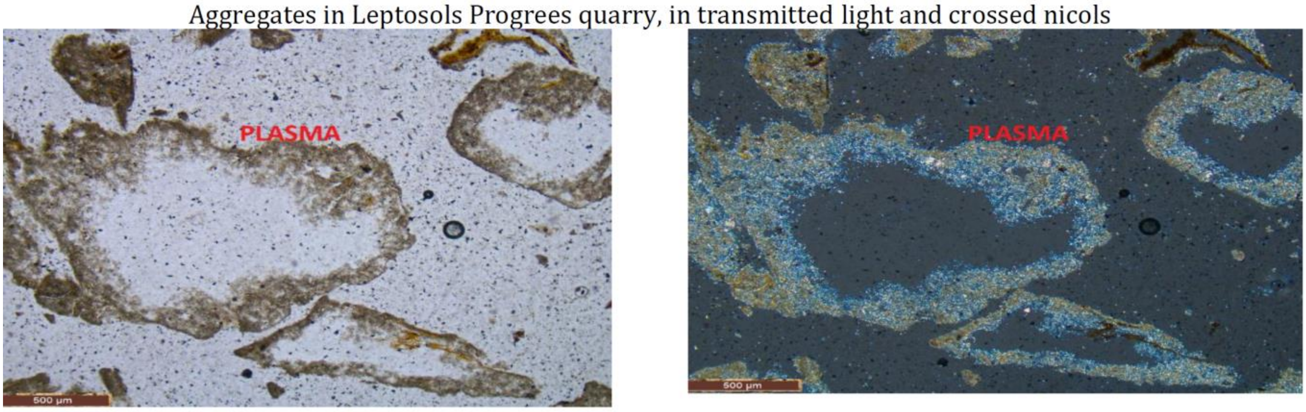
Angular grains of quarts in transmitted light and crossed nicols, Urvan, bottom of quarry



Weathering of mica in transmitted light and crossed nicols, Urvan, bottom of quarry



Aggregates in Leptosols Progrees quarry, in transmitted light and crossed nicols



Aggregates in superficial Phaeozem layer, in transmitted light and crossed nicols

Figure 11. Soil sections in transmitted light (left) and in crossed nicols (right)

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