
DEGRADATION, REHABILITATION, AND CONSERVATION OF SOILS

Technogenic Surface Formations in the Areas of Placer Gold Mining (the Bureya Upland, Far East)

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Abstract—Technogenic surface formations in the areas of placer gold mining in the Far East of Russia (the Bureya Upland, Khabarovsk region) are described. Several types of these formations are distinguished. Their morphological features and physicochemical characteristics are compared with those in the background natural soils.

INTRODUCTION

Technogenic surface formations (TSFs)—substrates that are formed on the earth surface under the impact of the economic activity of humans and that perform ecological functions of soils—were included in the sphere of interests of soil scientists long ago. The new classification system of Russian soils [4] contains a separate chapter devoted to TSFs; a special classification scheme has been developed for TSFs. However, this scheme proves that our knowledge of the specific features of TSFs and their diversity is still insufficient. There are only two taxonomic categories (groups and subgroups) suggested for TSFs in this classification; according to the proposed scheme, TSFs with different morphological and chemical properties should be placed into the same subgroup (distinguished on the basis of the proportion between mineral and organic materials in the composition of the TSF). There are no quantitative criteria for the diagnostics of TSFs.

This situation is quite natural. As a rule, the study of TSFs by soil scientists is restricted to environmental problems, i.e., the problems of technogenic pollution, rehabilitation of polluted soils, prevention of environmental contamination from waste dumps, etc. Less attention is paid to the fundamental problems of the classification of TSFs with respect to their origin and further transformation under the impact of pedogenetic processes, the study of the evolution of TSFs and their transformation into soils under different environmental conditions, and the distinction between TSFs and soils proper. At the same time, TSFs represent a very convenient object for the study of initial pedogenetic processes. Indeed, there are TSFs of similar initial composition but different (and strictly fixed) ages; these TSFs can be found under different environmental conditions. These TSFs can be considered as soil chronosequences, the main object for evolutionary soil studies.

However, before dealing with these theoretical problems, one has to accumulate sufficient materials on

the real diversity of TSFs of different origins and ages and on their properties in different natural zones. In other words, it is necessary to develop a database on TSFs. We believe that this paper will contribute to the development of such a database on TSFs in the Russian Federation.

OBJECTS AND METHODS

Our studies were performed within the Bureya Upland in the Olga River basin, Khabarovsk region. The Bureya Upland is elevated to about 900 m a.s.l.; it is characterized by a cold humid climate with a sum of active temperatures of about 900–1300°C (degree-days) during the growing season [5]. The mean annual air temperature is -7.2°C . The mean annual precipitation is 714 mm with a predominance of summer rainfalls. The winter season is very severe; the mean winter temperature is -25.4°C . The mean summer temperature is relatively low (13.1°C). The duration of the frost-free period is only 44 days; the average date of the first frost on the soil surface is August 17 [7].

This area belongs to the mountainous taiga zone. The slopes of mountains are covered by larch (*Larix cajanderi*) forests and thin forests; the initial forest vegetation is strongly disturbed by timber logging and fires; secondary forests are represented by birch (*Betula platyphylla*) and, locally, spruce (*Picea ajanensis*) groves. The flood plain of the Olga River is covered by small-leaved forests composed of chosonia (*Chosonia arbutifolia*), poplar (*Populus suaveolens*), and other tree species.

Placer gold mining is performed in river valleys and on the adjacent footslopes with alluvial fans. We studied dredged areas and the areas subjected to hydraulic washing in the valleys of the Olga River and the Kanak and Gorelyi creeks. The ages of these areas are well documented; the first mining operations were performed 36 years ago. Overall, 29 soil pits were studied

on different elements of the local technogenically modified topography; the descriptions of soil pits were combined with the study of local vegetation conditions. A number of soil pits were dug in adjacent areas to characterize virgin soils of the region and, also, the soils disturbed but not destroyed by the anthropogenic activity. Soil samples (101) were collected from the main horizons of natural soils and technogenic surface formations. The physicochemical properties of the soils and TSFs were determined by routine laboratory methods [1, 2].

The interpretation of the materials obtained was complicated by the vagueness of the notion of TSF. Though the central concepts of soil and TSF are quite distinct, it is hardly possible to delineate the boundary between these notions at the current level of our knowledge. Indeed, the fresh dump can be attributed to the group of primitive soils, as well as to the group of TSFs. Visible morphological changes in this dump that can be attributed to the pedogenetic process are limited to the formation of a very thin plant litter (<1 cm) on its surface. As the boundary between soils proper and TSFs is very indistinct, it may be reasonable to introduce some transitional categories in the classification of these objects. For example, Gennadiev *et al.* [3] suggested that four groups of soil objects can be distinguished. Soils proper (natural bodies) and technozems (technozems, or TSFs) are the end members of this sequence. The categories of technogenic–natural and natural–technogenic soils can be placed between them. However, the discussion of classification problems lies beyond the scope of this paper. In our work, TSFs (made grounds, artificial soils, surface dumps, etc.) are classified with respect to the major mechanism of their origin, i.e., with respect to the technological process leading to the creation of a given TSF. The further alteration of these TSFs by some initial pedogenetic processes (e.g., litter accumulation on the surface) leads to the formation of evolutionary sequences of the TSFs. Overall, four different groups (evolutionary sequences) of TSFs were studied: (a) stripping grounds, (b) crushed gold ore (refuse grounds), (c) dredged dumping grounds, and (d) bottoms of sedimentation basins.

As there are no standard indices for the horizons and layers composing TSFs, we used Roman numerals to designate them. At the same time, the indices of soil horizons (O and A1) were applied to designate the uppermost layers of TSFs subjected to corresponding alteration by pedogenetic processes.

RESULTS AND DISCUSSION

Natural Soils

Before analyzing the TSFs studied, it is reasonable to characterize natural (virgin) soils in the area of our studies. A detailed characterization of these soils has already been published [8]. It should be noted that virgin soils are, on one hand, those bodies that are

destroyed in the course of gold mining activities and, on the other hand, they can be considered the ideal final product of the transformation of TSFs under the impact of pedogenetic processes.

Alluvial peat gley soils are formed on the flood plains of small creeks. Such a soil was described in the upper reaches of the Gorelyi Creek under a sparse larch forest with reed grass in the ground cover. The soil profile consisted of the surface peat layer (0–21 cm) underlain by the mucky gleyed horizon; at a depth of 33 cm, the soil was frozen (the description of the pit was made on August 1). The peat horizon contained a considerable admixture of clay particles; the organic matter content in this horizon varied from 25 to 43%; in the underlying mucky gleyed horizon, the organic matter content was 13.6%. The total acidity in the peat horizon reached 37.7 meq/100 g soil decreasing to 16.9 meq/100 g soil at the bottom of the soil profile. The pH of the water suspension ranged from 4.80 to 5.45; i.e., the soil had a moderately acid reaction. The CEC values ranged from 38 to 63 meq/100 g soil, and the degree of base saturation varied from 35 to 55%.

Oligotrophic peat soils are widespread on local slopes under larch forests with sphagnum mosses in the ground cover. These soils consist of a thick layer of sphagnum peat with a very low bulk density; the degree of decomposition of the sphagnum residues increases down the soil profile. The lower layer of the peat deposit is permanently frozen even on the south-facing slopes. The permafrost layer is found at a depth of 35–51 cm and consists of the frozen sphagnum peat with a considerable ice content. The presence of permafrost impedes the further deepening of the pit. The organic matter content in the oligotrophic peat soils varies from 52.5 to 95.7%; in most of the horizons, it exceeds 90%. The actual acidity of the peat is strong to moderate (pH H₂O 4.23–5.56), and the total acidity varies from 47.3 to 133.7 meq/100 g soil with a minimum in the permafrost layer. These soils have the highest CEC (82–130 meq/100) among all the studied soils and TSFs. The adsorption complex of oligotrophic peat soils is dominated by exchangeable hydrogen and aluminum, so that the degree of base saturation is less than 45% (Table 1, pit 16).

Al–Fe-humus soils are developed under larch forests with green mosses in the ground cover. A typical profile of these soils was described at a height of 1050 m not far from the top of the local mount near the settlement of Sofiisk. The soil was developed under a very sparse larch forest in the former cutting area. The soil surface was covered by low shrubs (dwarf birch and wild rosemary) and green mosses. The forest litter (O horizon, 0–12 cm) in the profile of this soil was underlain by the highly decomposed (mucky) organic material (H horizon, 12–17 cm) of black color. Below, a bleached mineral horizon with dove tint (gley features) was found (Eg horizon, 17–37 cm). The humus-illuvial horizon (BHg, 37–63 cm) had a bright ochreous

Table 1. Physicochemical properties of TSFs and topsoils of stripping grounds in the Bureya Upland

Horizon	Depth, cm	Organic matter, %	pH		Total acidity	H ⁺ , according to Gedroitz	CEC	Base saturation, %
			H ₂ O	KCl				
Pit 16-2000, undisturbed oligotrophic peat soil, south-facing slope of 10°								
T0	0–16	95.18	4.52	3.43	112.14	38.79	113.05	0.01
T1	16–25	95.09	4.92	3.83	81.46	23.85	121.36	32.88
T2	25–35	62.59	4.87	3.97	61.99	20.49	83.71	25.95
T3	35–40	52.50	5.56	4.46	47.26	14.45	84.10	43.81
Pit 7-2000, degraded peat gley soil, east-facing slope of 1°–2°								
O	0–8	88.49	5.33	4.41	62.65	9.88	118.07	46.94
i1	8–30	31.32	5.07	3.97	45.80	22.26	46.81	0.02
i2	30–46	30.99	4.95	3.89	49.37	20.90	51.02	0.03
G	46–88	2.38	4.75	3.75	7.76	3.69	7.99	2.88
Pit 18-2000, the Gorelyi Creek, south-facing slope of the stripping ground dump of 1998, slope of 30°								
Mossy crust*	0–0.5	17.51	4.76	3.87	10.92	7.40	20.61	47.02
I	0.5–24	10.18	4.95	3.80	11.16	8.08	4.50	61.85
II	24–37	29.83	4.90	3.84	16.13	10.79	26.37	38.83
III	37–60	17.15	4.32	3.70	18.75	14.17	19.58	4.24
IV	60–95	12.40	4.44	3.63	15.19	12.85	22.26	31.76
Pit 34-2000, the Olga River basin, north-facing slope of the stripping ground dump of 1986, slope of 10°								
O	0–7	70.22	5.95	5.28	30.24	1.60	87.05	65.26
I	7–11	5.07	4.82	4.15	8.38	4.47	12.49	32.91
II	11–25	4.64	4.82	4.18	7.66	4.37	11.64	34.19
III	25–60	5.86	4.83	4.21	8.56	5.48	10.10	15.25
IV	60–90	5.07	5.08	4.25	6.96	3.30	9.21	24.43
Pit 31-2000, the Kanak Creek, top of the stripping ground dump of 1976, flat surface								
O	0–7	81.67	5.70	4.92	40.05	3.79	104.94	61.84
I	7–14	5.12	4.41	3.66	9.36	5.13	12.97	27.83
II	14–28	5.12	4.60	3.75	8.12	4.12	11.31	28.21
III	28–56	3.79	4.63	3.78	6.96	3.35	11.18	37.75
IV	56–63	3.86	4.64	3.83	6.43	3.02	8.91	27.83

* Hereinafter, the term mossy crust is used to denote a thin fine-earth crust fixed by live mosses on the soil surface.

brown color and was underlain by the stony BC horizon (63–81 cm) with grayish brown color. The organic matter content in the profile of this soil varied from 88.23% in the O horizon to 1.99% in the Eg horizon with a further 1% increase in the BHg horizon, which attests to the illuviation of humus. The maximum acidity was noted in the mucky H horizon and podzolic Eg horizon (pH H₂O 3.35 and 3.69; pH KCl 2.49 and 2.46, respectively). Above this layer (in the O horizon) and below it (in the BHg and BC horizons), the values of pH H₂O and pH KCl were higher: 4.36–5.10 and 3.39–4.57, respectively. The CEC values decreased from 91 meq/100 g soil in the upper horizon to 5 meq/100 g soil in the BC horizon. The soil was unsaturated with bases:

the maximum base saturation (17%) was registered in the H horizon.

Gold-mining activities not only completely destroy some soils but also transform the soil cover in adjacent areas. In particular, the drainage of the territory becomes more intensive. This leads to the lowering of the ground-water level. As a result, the peatlands lose their connection with the ground water and their degradation takes place. One of the peatlands on slopes was artificially drained (due to the mining works downslope) in 1965. At present, the vegetation at this site is represented by willow shrubs with herbs in the ground cover. An 8-cm-thick forest litter has formed on the soil surface. The litter horizon is underlain by a thickness of

strongly decomposed peat (8–46 cm), below which the grayish dove gleyed horizon with ochreous mottles is found (Table 1, pit 7-2000). This soil can be classified as the destroyed (partly mineralized) peat gley soil [4]. The organic matter content in the peat (31%) is considerably lower than that in the initial oligotrophic peat soil; the pH values correspond to the moderate acidity (pH H₂O 4.95–5.07). The CEC value in the peat has decreased to 46–49 meq/100 g soil. The degree of base saturation remains low, with a maximum of 47% in the surface horizon.

TSFs of Stripping Grounds

Stripping areas are formed due to the removal of the surface soil layer and underlying rocks from the gold-mining sites. The removed material is stored on special plots and forms stripping grounds. The stripping rock is composed of a mechanical mixture of pebbly or gravelly sands (colluvial or alluvial deposits) and topsoil horizons; the thickness of stripping grounds may reach several meters. When the thickness of the removed deposit is relatively low (from tens of centimeters to several meters), the topsoil material is not stored separately; instead it is mixed with the removed underlying rock. Stripping grounds have relatively favorable conditions for the growth of many plant species. When the removed topsoil is represented by peat, the admixture of the latter into the stripping ground makes the organic matter content in it relatively high (5–30%). In turn, the presence of a high amount of organic matter improves the chemical and physical properties of the stripping rock. It is probable that the temperature regime in the stripping rocks is also more favorable than that in the adjacent soils due to the active decomposition of peat with the release of heat. The permafrost is absent at least to a depth of 1 m, whereas in the natural peat and peat gley soils, it is found at a depth of 30–50 cm.

Organic-rich stripping grounds are overgrown with vegetation soon after their formation. In the first years, their surface is covered by willow shrubs (*Salix schweini* and *S. rodida*), willow herbs (*Chamerion angustifolium*), grasses (*Calamagrostis langsdorfii*), sedges, and other herbs. Older stripping grounds are overgrown by mixed forests composed of poplar, birch, willow, and arch trees, under which a relatively thin cover of dwarf shrubs and mosses and lichens is developed. The TSFs of stripping grounds are characterized by the highest spatial variability. It is difficult to suggest the central concept of this group of TSFs. Most often, they are represented by a mosaic of chaotically mixed fragments of compacted (in comparison with the natural state) peat, gleyed mineral horizons, nongleyed mineral horizons, and stones (20–40 vol %).

The reaction of stripping grounds is moderately acid (pH H₂O 4.32–5.48); i.e., it close to that in the background natural soils; the total acidity varies from

4.06 meq/100 g soil in the mineral layers to 37.9 meq/100 soil in the peat-enriched layers.

Along with the decomposition of peat within the thickness of stripping rocks, pedogenetic processes in this group of TSFs manifest themselves in the formation of the surface litter layer. The litter layer is formed very quickly under the rich vegetation. In 10 years, it may reach a thickness of 5 cm. The litter layer differs from the underlying substrate by its specific morphology, high content of organic matter (70–82%), lower actual acidity (pH H₂O 5.25–5.95), and higher total acidity (30.24–60.51 meq/100 g soil).

The changes in the cation exchange capacity of the TSFs of stripping grounds have an irregular character; they depend on the organic matter content in a given layer. According to the latter criteria, all the layers that can be found within the thickness of the stripping ground can be subdivided into three groups. In the first group, the organic matter content is less than 10% (normally, 2–9%). In this material, the CEC value varies from 9 to 16 meq/100 g soil and the degree of base saturation is from 15 to 54%. In the second group, the presence of decomposing peat increases the organic matter content from 10 to 30%. A typical range of CEC values is from 18 to 40 meq/100 g soil, and the base saturation degree is from 0 to 47%. Finally, in the recently formed layers of forest litter, the organic matter content is from 70 to 82%, the CEC is from 87 to 130 meq/100 g soil, and the degree of base saturation is above 50% (53–65%).

TSFs of Refuse Grounds

Refuse grounds are formed due to heavy washing of gold-containing rocks by special hydraulic machines. Refuse rock forms cone-shape mounds with a height of 4–6 (10) m. This substrate is not so favorable for plant growth as the stripping material. In the first years, only separate plants can be found on such mounds. In the 8th–9th year, one can see both separate plants and their groups on the surface of the mounds. The tree species are represented by poplar and willow with some admixture of birch, larch, and some other species. The height of the young trees is about 0.5–1.0 m, and their age is normally 1–3 years with separate older (6–7 years) trees. The projective cover of herbs and dwarf shrubs is only 1–3%; mosses cover about 2–12% of the surface. On the 35th year, tree stands are formed on the surface of refuse grounds. The stands consist of larch trees with a height of 7–8 m and a canopy density of about 0.9; in some cases, a mixture of poplar and larch trees with a height of 5 m and a canopy density of 0.5 is settled on the surface. Herbs and dwarf shrubs cover about 10–20% of the surface; mosses occupy from 30 to 50%.

The section of refuse grounds (forming the mounds) displays their relatively simple morphology: the thickness is poorly stratified into separate layers; pebbles and gravel predominate (fine earth constitutes only

Table 2. Physicochemical properties of TSFs of refuse grounds

Horizon	Depth, cm	Organic matter, %	pH		Total acidity meq/100 g soil	CEC	Base saturation, %
			H ₂ O	KCl			
Pit 17-2000, the Gorelyi Creek, top of the dump of 1998, flat surface							
I	0–26	1.93	5.57	4.92	1.35	4.54	70.26
II	26–45	1.95	5.44	4.70	1.61	4.24	62.03
Pit 13-2000, the Gorelyi Creek, east-facing slope of the dump of 1991–1992, slope of 20°–30°							
Mossy crust	0–0.5	2.61	6.51	5.89	1.07	7.12	84.97
I	0.5–11	1.80	7.00	6.45	0.59	4.24	86.08
II	11–33	1.88	7.35	6.70	0.56	4.02	86.07
Pit 8-2000, the Gorelyi Creek, top of the dump of 1990–1991, flat surface							
Mossy crust	0–0.5	2.29	7.00	6.72	0.84	12.65	93.36
I	0.5–5	1.80	7.22	6.85	0.59	6.20	90.48
II	5–25	1.81	7.60	6.97	0.57	6.75	91.56
III	25–40	1.48	7.36	6.71	0.48	4.67	89.72
Pit 9-2000, the Gorelyi Creek, northeastern slope of the dump of 1990–1991, slope of 70°							
I	0–5	1.58	7.21	6.69	0.48	4.58	89.52
Pit 11-2000, the Gorelyi Creek, southwestern slope of the dump of 1990–1991, slope of 32°							
I	0–5	1.69	7.25	6.80	0.51	4.50	88.67
Pit 1-2000, the Kanak Creek, top of the dump of 1965–1966, flat surface							
O	0–1	71.43	4.51	3.89	52.78	60.77	13.15
I	1–17	1.83	5.70	4.85	1.41	8.91	84.18
II	17–41	1.78	6.30	5.15	1.00	8.08	87.62
III	41–57	1.73	6.80	5.72	0.77	7.05	89.08
Pit 3-2000, the Kanak Creek, top of the dump of 1965, flat surface							
O	0–0.5	67.40	4.81	4.10	41.26	65.00	36.52
I	0.5–18	2.40	5.67	4.60	1.93	12.61	84.69
II	18–40	1.71	6.35	4.94	1.05	11.86	91.15
III	40–50	1.73	6.96	5.56	0.79	10.19	92.25
Pit 5-2000, the Kanak Creek, western slope of the dump of 1964–1965, slope of 1°–2°							
O	0–2	76.89	4.93	4.04	38.47	56.22	31.57
I	2–11	3.73	5.72	5.07	1.41	5.64	75.00
II	11–35	1.85	6.42	5.75	0.89	5.89	84.89
III	35–45	2.15	6.46	4.75	0.85	5.48	84.49

1–30 vol %); the surface is covered by a thin mossy layer. Later, after the development of tree stands, a thin litter horizon is formed on the surface. In those cases, when higher plants have already developed on the surface of refuse grounds, a horizon containing living roots can be distinguished. However, its properties and morphology do not differ much from the underlying substrate.

The humus content in the TSFs of refuse grounds (except for the litter layer) is low (1.48–3.73%) (Table 2). It is interesting that the fine earth of a recently formed (in 1998) TSF already contains about 1.91–1.95% humus. It is probable that this humus is inherited from the organic matter of the buried alluvial sediment com-

posing the refuse ground. As a rule, refuse grounds in creek valleys consist of the local alluvial sediments.

The formation of the litter horizon on the surface of refuse grounds takes place much slower than on the surface of stripping grounds. The thickness of the litter of 34-to-36-year-old refuse grounds is 0.5–2.0 cm; the organic matter content in it reaches 67.4–76.9%. Below the litter, some accumulation of humus in the mineral sediment takes place.

The acidity of refuse grounds depends on the nature of sediments composing them and varies from slightly acid to slightly alkaline values. The litter is moderately acid (pH H₂O 4.51–4.93); the underlying mineral hori-

zon is also acid (pH H₂O 5.67–5.72) in comparison with the main thickness of the mound (pH H₂O 6.30–6.96). The CEC values are low (4–13 meq/100 g soil; as a rule, 4–7 meq/100 g soil), except for the litter layers (56–65 meq/100 g soil). Some increase in the CEC is observed in the topmost mineral layer of refuse grounds in the 10th year. In the main thickness of refuse grounds, the CEC value is dictated by the particle-size composition and mineralogy of the fine earth fraction. The degree of base saturation varies from 62 to 93% (as a rule, it exceeds 75–80%). The degree of base saturation in the litter is low (13–37%).

TSFs of Dredged Dumping Grounds

Dredged dumping grounds are formed of redeposited gold-containing sediments after their washing by drags. These sediments form crescent-shaped mounds on the surface. The height of the mounds may reach several meters. The uppermost layer is composed of stony (pebbles and gravel) material. Thus, the conditions for plant growth (and the development of soils) on dredged dumping grounds are unfavorable.

The most unfavorable conditions are registered on high (3–5 m) piles of dredged material composed of washed pebbles and boulders. In this case, the porosity of the rock is very high and the fine earth content is negligibly small. The highest infiltration capacity of such deposits leads to the leaching of nutrients and the fine earth fraction. The contrastive temperature conditions (the surface heating on sunny days and deep cooling at night) also do not favor the development of vegetation. Vascular plants may be absent on the surface of dredged dumping grounds for decades. However, gradually, the surface becomes occupied by lichens, mosses, and algae. For example, on the dredged dumping ground of 1969 (pit 26-2000), mosses (*Racomitrium cenescens*) cover about 6% of the surface; lichens (*Stereocaulon paschale*), 5%; and algae (*Trentepohlia odorata*), 25%.

However, the settling of plants on the surface and the development of vegetation cover (with a corresponding development of soil horizons) may be intensified [6]. In particular, surface leveling with a bulldozer favors more rapid development of vegetation. On plots leveled about 25–30 years ago, a young tree stand has formed. It is composed of poplar, larch, birch, and other tree species. It has a height of 6–10 m and a canopy density of 0.7–1.0. Mosses cover about 10–15% of the surface; the other species (low and dwarf shrubs, grasses, and lichens) do not form continuous associations. The plot leveled in 1986 (pit 32-2000) is also overgrown by chosenia and poplar trees with a height of up to 2 m; however, they still do not form a continuous stand. The soil surface is covered by algae (about 15% of the surface) and lichens (5%).

The edge of the dredged dumping ground of 1969 (pit 27-2000) remained under water for a long time (the high water level was maintained to facilitate dredging).

As a result, a considerable amount of silty material accumulated on its surface. After the lowering of the water level, the overgrowing of this site by trees was very fast. At present, it is covered by a stand composed of poplar, alder (*Alnus hirsuta*), and larch trees with a canopy density of 1.0 and a height of 12 m. Herbs and dwarf shrubs cover about 10% of the surface; lichens and mosses, 6%.

The humus content in the fine earth of the dredged dumping grounds of 1991 is only 0.21%; in the grounds of 1969, it increases to 1.32–6.37% (at a depth of 0.5–30 cm). Surface litters contain from 62 to 92% organic material. The A horizon described by us in a local place contained 36% organic matter. The pH H₂O values vary from 4.96 to 7.02, with a predominance of slightly acid reaction (Table 3).

In the case when a surface organic layer consisting of a thin (0.5 cm) mossy crust was formed, its CEC reached 46 meq/100 g soil and its degree of base saturation was 26%. The thickness of the litter increases considerably under trees; in this case, the litter horizon has a thickness of 3–8 cm, its CEC is 89–130 meq/100 g soil, and the degree of base saturation is 69–88%. The fine earth matter within the main thickness of the dumping ground has the CEC of 4–13 meq/100 g soil and the base saturation degree of 54–80%. The uppermost mineral layer of a relatively young dumping ground (1991) had the CEC of only 3.5 meq/100 soil and the base saturation degree of 87%.

TSFs of the Bottoms of Sedimentation Basins

The initial pedogenetic transformation of sediments may proceed at the bottoms of sedimentation basins before their drying (the subaqual stage of pedogenesis). In our work, we have only studied sedimentation basins that have been dried. The surface of former sedimentation basins is relatively flat; the material composing the surface layer consists of fine earth, which favors the overgrowing of such substrates by plants. The thickness of the sediments accumulated at the bottoms of sedimentation basins resembles that in the primitive alluvial soils. The sediment column is stratified into fine layers, sometimes, with contrastive lithology. These sediments may contain buried humus-rich horizons. For example, the upper 60 cm of a pit made at the former bottom of a sedimentation basin (dried in 1998) contained 9 layers of different textures. Thus, the humus contents within this thickness varied from 0.47 to 0.99% and the reaction was slightly acid (pH H₂O 5.11–6.20).

The further pedogenetic transformation of such sediments may follow two different patterns. In the case of the coarse-textured deposit (at least, in the upper part), the topsoil layer is well drained and is not subjected to swamping. Willows (*Salix schwerinii* and *S. udensis*) appear on the surface of the former bottoms of sedimentation basins, and normal soil development begins.

Table 3. Physicochemical properties of TSFs of dredged grounds

Horizon	Depth, cm	Organic matter, %	pH		Total acidity	CEC	Base saturation, %
			H ₂ O	KCl	meq/100 g soil		
Pit 32-2000, the Olga River, top of the dump of 1991							
I	0–5	0.21	7.02	6.43	0.44	3.46	87.28
Pit 26-2000, the Olga River, north-northeastern slope of the dump of 1969							
Mossy crust	0–0.5	87.11	4.96	3.92	34.02	45.81	25.74
I	0.5–10	6.37	6.08	5.73	2.12	10.38	79.58
Pit 27-2000, the Olga River, south-southwestern slope of the dump of 1969, slope of 25°							
O	0–3	89.07	6.30	5.99	20.07	129.62	84.52
A1	33–7(8)	36.08	6.06	5.51	26.71	110.16	75.75
I	7(8)–30	3.29	4.96	4.28	6.13	13.45	54.42
Pit 29-2000, the Olga River, planed top of the dump of 1969, slope of 25°							
O	0–3(4)	61.99	6.62	6.30	11.13	89.03	87.50
I	3(4)–15	1.58	6.20	5.60	1.43	6.51	78.03
Pit 30-2000, the Olga River, planed top of the dump of 1969							
O	0–3	91.99	5.80	5.48	27.72	90.24	69.28
I	3–11	1.74	5.10	4.48	2.86	8.86	67.72
II	11–22	1.32	5.60	4.84	1.37	3.62	62.15

In 30 years, the thickness of the humus horizon may reach 6 cm. The accumulation of humus is rather pronounced: in about ten years, the humus content increases to 1.15% from 0.31–0.63% in the initial sediment. At the same time, the tendency for humus accumulation may be masked by the irregular alternation of the layers with initially different humus contents. The reaction of the substrate varies from moderately acid to alkaline (pH H₂O 4.95–7.68), which is conditioned by the local peculiarities of the sediments and the admixture of organic material, the source of acids.

In the case of the heavy-textured substrate, the surface of former bottoms of sedimentation basins is subjected to swamping. Sedges and other herbs (*Equisetum palustre*, *Carex appendiculata*) occupy the surface to produce the future peat horizons. Thus, the soil development is directed toward the formation of peat gley soils. The admixture of silt and clay is considerable in the peat; the organic matter content in recently formed thin peat layers is only 4.43–11.49%. However, their morphology resembles that of typical peat horizons. In our work, such clay-rich peat horizons were designated by the GT index. In the underlying mineral horizons, the organic matter content varies from 0.63 to 1.95% (the sediment dried in 1991) and from 7.24 to 7.67% (the sediment dried about 35 years ago). Thus, the rate of the organic matter accumulation is considerable. In both cases, the reaction of the medium is slightly acid (pH H₂O 5.78–6.53 and 5.45–5.68, respectively). The total acidity varies from 0.89 to 5.0 meq/100 g soil (the sediment dried 10 years ago) and from 6.55 to 10.22 meq/100 g soil (the sediment dried 35 years ago).

The CEC values and base saturation degree in different layers of the sediments correlate with the organic matter content. Therefore, the same as in the case of stripping grounds, it is possible to differentiate between the three groups of sediment layers. The layers with a low (<1%) organic matter content are typical of the surface of recently dried (2–10 years) bottom sediments with coarse texture. In such layers, the CEC values are low (3–9 meq/100 g soil) and the base saturation is relatively high (68–92%). The organic matter content of 1–5% is seen in the sediments dried about 9–31 years ago. As a rule, their texture is sandy to sandy loamy; the CEC is 5–14 meq/100 g soil, and the degree of base saturation is 64–82%. Finally, sediment layers with a high content of organic matter (5–11.5%) are found in the former bottoms of sedimentation basins dried about 10–35 years ago and subjected to swamping after their drying. As mentioned above, these sediments are heavy-textured. Their CEC varies from 8 to 21 meq/100 g soil, and the degree of base saturation is from 39 to 68%.

The classification of the TSFs studied is a problem. As noted above, the boundary between TSFs and soils proper is unclear. According to [4], the TSFs studied by us should be placed into the group of “naturefabricates” (made grounds composed of initially natural substrates). Stripping TSFs should be placed into the subgroup of organolithostrates (stratified mixtures of organic and mineral (litho) substrates), whereas the other three kinds of TSFs (refused TSFs, dredged TSFs, and TSFs of former sedimentation basins) are lithostrates (stratified mineral substrates). However, as fol-

Table 4. Physicochemical properties of TSFs of bottom sediments

Horizon	Depth, cm	Organic matter, %	pH		Total acidity	CEC	Base saturation, %
			H ₂ O	KCl	meq/100 g soil		
Pit 20-2000, the Gorelyi Creek, sedimentation basin dried in 1998							
I	0–5	0.68	6.01	5.33	1.00	8.13	87.70
II	5–11	0.47	5.97	5.16	0.89	4.93	81.95
III	11–15	0.58	6.20	5.59	0.83	4.11	79.81
IV	15–18	0.84	5.88	4.99	1.00	3.16	68.35
IX	41–59	0.99	5.11	4.38	2.71	8.56	68.34
Pit 10-2000, the Gorelyi Creek, sedimentation basin dried in 1990–1991							
I	0–8	4.43	5.86	5.29	3.57	5.68	37.15
II	8–12	1.16	6.03	5.55	1.19	5.20	77.12
III	12–17	7.57	5.78	5.24	5.06	8.25	38.67
IV	17–23	1.95	6.06	5.59	1.91	10.74	82.22
V	23–30	0.63	6.53	6.07	0.89	6.61	86.54
Pit 33-2000, the Olga River, sedimentation basin dried in 1986							
Mossy crust	0–1	1.15	6.42	5.88	0.94	4.88	80.74
I	1–8	0.63	7.18	6.73	0.41	3.80	89.21
II	8–16	0.31	7.17	6.36	0.47	3.93	88.04
III	16–25	0.58	7.68	7.40	0.29	3.67	92.10
Pit 28-2000, the Olga River, sedimentation basin dried in 1969							
A1	0–6	1.99	5.10	4.56	3.06	8.95	65.81
I	6–37	1.25	5.40	4.60	1.65	4.63	64.36
II	37–67	3.38	4.95	4.64	3.48	13.67	74.54
III	67–90	5.07	5.85	5.37	3.01	9.42	68.05
Pit 6-2000, the Kanak Creek, sedimentation basin dried in 1964–1965							
GTI	0–12	11.49	5.45	4.82	10.22	16.80	39.17
I	12–19	7.24	5.60	4.78	6.55	20.50	68.05
II	19–32	7.67	5.68	4.69	7.27	19.84	63.36

lows from the above discussion, this classification is insufficient for the correct identification of the very different kinds of TSFs in the studied anthropogenically modified landscapes.

CONCLUSIONS

The study of placer gold mining areas is of considerable methodological interest for pedologists. First, it is possible to select sites with precisely known dates of formation of the initial substrates. Second, these areas contain contrastive ecotopes (both primary and secondary) in many replicates. Often, these human-made ecotopes have their natural analogues in places with catastrophic natural processes. Third, similar sites can be found in different natural zones. Thus, placer gold mining areas represent a perfect object for studying the rates of pedogenetic processes on contrastive ecotopes under different environmental (bioclimatic) conditions.

Two problems related to the study of TSFs seem to be of great interest for theoretical pedology. First, is the study of the evolution of TSFs under the impact of pedogenetic processes (i.e., the study of the transformation of initially barren TSFs into soils). Second, is the problem of the development of an adequate classifica-

tion of TSFs and the soils formed on their surfaces. However, before dealing with these problems, one has to systemize the available data on technogenic surface formations of different origins, morphologies, and ages, and located in different regions.

As shown in our work, TSFs formed in the areas of placer gold mining within the Bureya Upland can be subdivided into four main groups related to their genesis: TSFs of stripping grounds, TSFs of refuse grounds, TSFs of dredged dumping grounds, and TSFs of the bottoms of sedimentation basins. These groups differ from one another not only in their genesis but also in their morphology and physicochemical properties. The rates and directions of pedogenesis of different groups of TSFs are unequal. Therefore, no leveling in the properties of the initially different TSFs is observed for at least 35 years.

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