Changes in physico-chemical and biological properties of rocks during weathering and soil formation

N V Dolgopolova and E A Batrachenko

1 Kursk State Agricultural I I Ivanov Academy, 70, Karl Marx street, Kursk, Russia;
2 Kursk State University, 33, Radishchev street, Kursk, Russia

E-mail: dunaj-natalya@yandex.ru, ostkat@yandex.ru

Abstract. Currently great attention is paid around the world to the problem of protecting the biosphere and the rational use of biological resources. The issues of protection of the atmosphere, water sources, flora and fauna, soil cover are becoming increasingly acute. Research is underway to develop the most rational principles for organizing industrial production that exclude environmental pollution. Particularly noteworthy are the issues of protection and rational use of soil cover. In the entire history of the development of human society, it has lost 20 million km2 of land resources. Currently, the loss of land on the planet for agricultural use is 5-7 million hectares annually. These lands go for building settlements on them, laying roads, mining, are lost due to erosion and salinization, the creation of industrial complexes, reservoirs, etc. Scientists estimate that the world’s population is growing by 68–70 million people every year, population growth and its increase is associated with the solution of major national and international problems, and this is the focus of the work.

Russia has a huge land fund and the total territory, and the area of agricultural land ranks first in the world. However, the ever-increasing scale of mining (open and closed), industrial and civil construction, etc. each year lead to a reduction in land suitable for agricultural production [1, 2]. The development of methods for the restoration of lands disturbed by industry is largely determined by the specifics of soil cover disturbance. To develop measures for the rational restoration and subsequent use of lands disturbed in the process of industrial development and construction, all land users of the region are divided into six groups. The grouping is based on the features of soil disturbance and the possibility of further use of disturbed territories. The grouping of lands by these criteria allows for each of the identified groups to develop land restoration schemes that will form the basis for the preparation of restoration projects (table 1). The table was developed by S. A. Shulga.

Table 1. Classification of land disturbed by industry in the Kursk region.

| Groundbreaking enterprises | Type of soil disturbance | Man-made landforms | Degree of suitability | Recovery method | Possible use after recovery |
|----------------------------|--------------------------|--------------------|----------------------|----------------|-----------------------------|
| Mining from significant depths a) KMA enterprises | Overburden of parent and underlying rocks | Careers, dumps of various types | I-IV | Leveling the coating with a humus layer of soil | Arable land, gardens, fodder land forest |
| Leading mining without | Overburden of shallow depth | I-III | Smoothing the sides | Arable land, |

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overburden of underlying rocks; mining of raw materials from construction industry enterprises

Paving communications

Having waste sumps:
A) toxic;
B) harmless;
D) irrigation fields

Occupying territories for permanent withdrawal

| overburden of underlying rocks; mining of raw materials from construction industry enterprises | soils and parent rocks | pits of the quarries | embankment of the humus layer of the soil | gardens, forage land |
|---|---|---|---|---|
| Paving communications | Overburden of soils and ditches of parent rocks with their subsequent return to their place | I-II | Selective overburden | Forage land, ponds |
| Having waste sumps: A) toxic; B) harmless; D) irrigation fields | Accumulation of production waste on the soil surface | Sedimentation tanks | Preliminary removal of the soil of the humus horizon and the application of a humus layer; removal of accumulated material; levelling | Arable land, gardens, forage land |
| Occupying territories for permanent withdrawal | Land withdrawal from agricultural use | I | Removing the humus horizon | Land use of unsuitable land |

The first group consists of enterprises engaged in open-pit mining of minerals located at great depths. This group includes KMA enterprises. Mining at these enterprises was carried out through the creation of quarries that reveal the entire or almost the entire thickness of sedimentary rocks. At the same time, such technogenic forms as dumps and quarries are created that affect the entire surrounding territory. Quarries drain the area, violating the existing water balance of the territory, dumps, occupying significant areas of agricultural land, are a source of environmental pollution, foci of water and wind erosion [3, 4, 5]. In 1969, due to the depletion of phosphate reserves, the plant changed its profile and transferred to another management. Accordingly, the material and raw material base has changed. At the enterprise it was decided to produce plastic products for industrial and domestic purposes. The natural overgrowth of the dumps proceeds slowly and very nonuniformly, varying strongly in species and quantitative terms depending on the properties of the rocks and topography (table 2).

Table 2. The weight of the aerial and root mass of plants, depending on the parent rocks and topography (air-dry mass, kg/ha).

| Rocks, relief | Aboveground mass | The root mass in the layer is 0-50 cm | Number of plants per 1 m² |
|---|---|---|---|
| Natural overgrowing | | | |
| Chalk dump 20 years, sowing | 30 ° slope | 17.33 | 21.0 | 2,000 |
| south slope 30 ° | | 1.0 | 1.0 | 6 |
| saddle | | 27.73 | 41.3 | 3,400 |
| Loam, 18-year dump southern slope 15 ° | | 21.54 | 40.76 | 755 |
| The same, north. slope 12° | | 23.51 | 60.26 | 1,000 |
| Clay Callovian, 18-year-old dump, plateau | | 20.45 | 14.10 | 1,000 |
| Natural soil - dark gray forest, meadow | | 31.4 | 109.0 | 2,000 |

The complexes that are most intensively transformed are subject to investigation [6, 7]. Loams are most intensively overgrown - first by forbs, and then by legumes and cereals; on 18-year-old dumps, there are up to 400 species (700–1000 plants per m²); among them are creeping clover, red and white, horned lamb, creeping wheatgrass, meadow bluegrass, yellow alfalfa, yellow clover yellow and white, and others. The northern slopes are better to overgrow, where the largest biomass is formed (at an 18-
year dump overground 23.5 c/ha, root - 60.25 kg/ha). Clays of Callovian and chalk are most slowly and weakly overgrown. For the first 2-3 years, plants on clay are practically absent, then a stepmother appears, wormwood is bitter and annual, white gauze, quinoa, bird highlander and individual microgroups of legumes (red and white clover, corolla, wiki, etc.); on 3-year dumps in the conditions of a plateau and northern slopes, there are 240 specimens of plants per 1 m², on 18-year-olds - more than a thousand. The root mass in the latter reaches 14.1 kg/ha, aboveground - 20.45 kg/ha. The steep, crumbling slopes, especially of the southern exposure, overgrow poorly, where on 8-year-old dumps it often does not exceed 7-15 plants per 1 m². Cretaceous heaps are overgrown with difficulty, the steep slopes of insulated exposures remain bare even at the age of 20 (table 2), the upper parts of the shadow crypts also overgrow very poorly. Plants settle mainly by micro depressions in the deep saddles between the hills, at the bottom of the quarry, in the lower parts of the northern slopes, the aerial mass in the latter (a 20-year dump) reaches 17.33 c/ha, the root - 21 c/ha, respectively saddles - 27.73 and 41.3 c/ha with the number of plants more than 2-3 thousand per 1 m². Overgrowing of chalk dumps occurs mainly with white gooseberry, yarrow, wormwood and bitter wormwood, cloitsfoot, oriental overgrowth, gray hiccups, thistle, and in lowering reliefs - creeping wheatgrass, white and red clover, ulcer, meadow bluegrass, vetch, etc. Sedimentary rocks that have lain for tens and hundreds of millions of years in the bowels of the earth at great depths (more than 100 m), being taken to the surface, change greatly under the influence of weathering and soil formation [8, 9, 10].

Some rocks (siltstone, Batian sands) containing inclusions of easily oxidizing minerals (pyrite) are able to strongly acidify when weathering, become toxic and do not overgrow. So, the total exchange acidity in siltstone from the quarry was 0.105 mg – equiv/100 g, and in the samples taken from the surface of (0–10) 18-year dumps, 27.28 mg-equiv/100 g; respectively, the content of mobile aluminum and iron is 0.010 and 11.57 mEq, the dry residue in the aqueous extract is 0.63 and 1.78%, the sum of the exchange bases is 4.25 and 6.55 mEq/100 g. On the other the sides containing an increased amount of soluble salts (Callovian clay) are able to gradually brine, forming at some depth temporary horizons of salt accumulation.

It should be noted that so far there is no consensus on the development of the soil formation process with the involvement of soils in production [11, 12, 13]. Callovian clays for 2-3 years from the moment they enter the dumps are covered with cracks from the surface, peel off, lose their adhesion and become more friable. This leads to shedding, sliding and washing off loose material from the slopes of the dumps. The movement of deep material along the slopes inhibits the germination of seeds and the development of plants. This, apparently, is one of the reasons for poor overgrowing of slopes and dumps from clay. Flat areas overgrow much better. Due to the intensive weathering of clays, their bulk weight decreases from 1.4–1.8 to 1.17–1.30 g/cm³ (in a layer of 0–10 cm), specific - from 2.7 to 2.6 g/cm³; porosity increases to 50–55% and water permeability - from 0.00 to 0.11–0.4 mm/min. Similar changes in water-physical properties are observed in the Cretaceous: bulk density in 20 year old dumps decreases from 1.7 to 0.96–1.20 g/cm³, specific gravity - from 2.8 to 2.50 g/cm³, porosity increases from 37 to 40%, water permeability - from 1.14 to 1.33 mm/min. Full moisture capacity from 40 to 50%. In loams and technical mixtures, there is also a tendency to decrease in volumetric and specific gravities and increase in frost in dumps, in comparison with the natural occurrence in quarries, but this is manifested to a lesser extent; water permeability, as a rule, increases from 0.08–0.20 mm/min, in a quarry, to 0.14–0.42 mm/min in 10–20-year-old dumps. The chemical and biological properties of the rocks in the dumps are also changing.

Fresh rocks from the quarry practically do not contain nitrates and do not have a microbial population, are poor in nitrogen, organic matter (chalk, sands, loams) and mobile phosphorus, are well and moderately supplied with mobile potassium (except for sands), in dumps of different ages all these indicators vary greatly. For example, in Callovian clay in 5–8-year-old dumps, the content of microorganisms reaches 1288–5390 thousand / ha, nitrogen 0.14–0.09%, mobile phosphorus 2.5 mg /100 g, potassium 33 mg/100 g, nitrates 1.53 mg/kg, the organic matter content decreases from 3.39 to 2.41–2.47%, which is due to its mineralization with a sharp increase in aeration of the upper, easily weathered layer. These changes affect the yield of dry mass of buckwheat and barley in the growing
experiment, which increases by 1.3-1.6 times in comparison with the breed from the quarry. In a 20-year dump from chalk, the content of humus and nitrogen increases (compared with chalk from the quarry) three times, the yield of buckwheat and barley in the growing experiment. 1.4-2.5 times, the amount of exchange bases - by 3 mEq, pH decreases from 8.0 to 7.4. Loams in 18-year-old dumps undergo more significant changes than chalk, towards the accumulation of fertility elements in the 0-10 cm layer: the humus content increased by 10 times, total nitrogen - by 1.4, mobile phosphorus - by 3.5 times; the total number of microorganisms (8100 thousand/g) is twice as high as in the same layer (0-10 cm) of a 40-year chalk dump (4100 thousand/g) and 1.5 times more than in An 18-year dump of clay (5390 thousand/g), i.e., loams are significantly superior in chalk and clay microbiological activity.

The yield of barley and buckwheat on loams from an 18-year dump is approximately 1.4 times higher than on the original breed. In general, a general pattern is observed - with increasing age of dumps, the fertility of their upper layer increases, and with it the productivity of agricultural crops [14, 15]. In 18-year-old dumps from apt-neocomian aleurites, the accumulation of fertility elements is almost imperceptible, which is explained by a sharp acidification of the environment during weathering and subsequent death of settling plants; the value of the yield in siltsone and sour batan sands taken from the quarry (before weathering) is also the lowest in comparison with other rocks. 17-year-old soil mixtures (loams + clays + senomanian-alba sands) are slightly inferior to loams in the accumulation of fertility elements, but are significantly superior to clay and chalk. So, in a fresh dump (the first year), the humus content was 0.36%, nitrogen - 0.032%, the amount of exchange bases 21.5 mEq/100 g, mobile phosphorus 4.6 mg/100 g, microorganisms - 11.7 thousand/g, in the seven-year - respectively 0.57 and 0.075%, 32 mEq, 53 mg/100 g and 3500 thousand/g; buckwheat yield - 1.08 and barley - 0.95 g/vessel, i.e. approximately the same; same as on loam. Cenomanian alba sands (in fresh dumps), despite the low content of plant nutrients in them, give satisfactory yields of grasses, barley and buckwheat in field and vegetation experiments, which are approximately equivalent to those on loam from the quarry. The rate of accumulation of fertility elements in the rocks varies greatly depending on the topography and the degree of their overgrowing. So, for example, in a fresh soil mixture the content of humus was 0.36%, nitrogen - 0.032%, mobile phosphorus - 4.6, potassium - 9.9 mg/100 g; under a 3-year-old alfalfa, respectively, 0.49 and 0.070, 15.5 and 15.3 mg/100 g; in a 20-year dump with sparse vegetation - 0.64 and 0.09%, 8.2 and 17.2 mg/100 g, on a well-sodded terrace of 1.59 and 0.14%, 9.2 and 28.2 mg/100 g, under the planting of white acacia at the age of 7 years - 1.17 and 0.10%, 6 and 26 mg/100 g. At the same time, the microbiological activity also changes very much: the nitrate content increases from zero to 11 mg/kg (after composting), and microorganisms from 11.7 to 9900 thousand (under acacia). Judging by the nature of changes in rock properties and the rate of accumulation of fertility elements in them, loesslike loams and sands of Cenomanian Alb have the most favorable edaphic conditions; the lowest “fertility” is distinguished by chalk, sands of Bati and silts, especially the last two breeds, on which seedlings even perish. Callovian clays occupy an intermediate position, and according to the sainfoin yield they can even be attributed to the first group.

If we judge the edaphic conditions of clays only by chemical (high salt content) and physical properties (viscosity, density), they could be attributed to the most unfavorable breeds for biological reclamation. However, field and vegetation experiments give full reason to attribute them to the 2nd group of suitability. The sands of Cenomanian Alb, characterized by a very low content of organic matter, nitrogen, phosphorus and potassium, in the field give a yield at the level of Callovian clays. Based on the study of water-physical, chemical and biological properties, biological productivity, natural overgrowing, field and vegetation experiments, as well as changes in rocks during weathering and soil formation, in which a transition from one fitness group to another is possible, all overburden rocks of the Kursk region are divided by their degree of suitability for biological reclamation into three groups: - Group I - high-quality breeds suitable for agricultural production. and forest reclamation: loess-like loams and mixtures of loams with other species in a ratio of not less than 1: 1; - Group II - medium-quality rocks suitable for afforestation and thinning: senomanian-alba sands, soil mixtures with loam no more than 30-40%, Callovian clay and apt-neocomian silt, altered by weathering for 3-5 years. - Group III - low-quality rocks suitable for afforestation and thinning after preliminary
improvement (Batsky sands, Volga silts, chalk). A radical way to combat rock toxicity is selective overburden and burial of toxic and infertile soils into the lower horizons of dumps [16, 17, 18]. However, in practice, a larger or smaller proportion of toxic and infertile rocks falls on the surface of waste dumps. In this case, the quality of the rocks can be improved in different ways: by introducing appropriate ameliorants, selecting crops that can grow on these rocks, mixing toxic rocks with carbonate loam, applying fertile rocks with a layer of 30–40 cm (humus layer, loam) to infertile ones.

In the Kursk region, pyrite-bearing silts of the Volga and Batsky sands, chalk and partially Callovian clay need improvement. Reclamation of spots of toxic acidic rocks in planned areas can be done by adding lime or chalk at the rate of 40-50 t / ha, by digging, i.e. shifting using technology to toxic spots of fertile soils of neighboring areas. In large areas of aleurites, Batsky sands, prior to their reclamation, it is necessary to grow a sideral mass of lupine with the calculation of transportation and its incorporation in neighboring developed soil sections. Soils with increased salinity (Callovian clay, Elevrit, Aptneocomum), which appeared on the surface, can be saline in the conditions of the Kursk region naturally, with precipitation. Since these soils, especially clay, are viscous and have low water permeability, it is necessary to loosen (plowing, deep cultivation) and snow retention in order to quickly and deeply desalinize them. In addition, on saline soils, specially selected salt tolerant grasses and shrubs can be cultivated [19, 20].

As a method for improving the biological properties of chalk, you can use pond sludge, washing it in the form of pulp on the chalk surface with a layer of 1–1.5 cm. This significantly improves the water-thermal regime of the chalky soils and almost completely eliminates the observed two-week gap in the phases of development of plants grown on chalk and normal soils. At the Shchigrovsky experimental hospital, the crop of herbs and buckwheat in chalk with a background of silt and N15P15K15 was 3–4 times higher than with N15P15K15, but without silt. When mixing chalk with loam, even with a small dose of the latter (15–20%), the biological properties of the chalk sharply improve. The latter, begins to quickly overgrow grassy and woody vegetation. When applying 5 cm of loam to the chalk, the yield of hay from cereal grass increased by 1.5–4 kg/ha in the 3rd year of life, and the hay of legumes by 30–35 kg/ha compared to control (pure chalk). When applying loam to the chalk with a layer of 10 cm, the crop of grass (hay) per year of sowing (without fertilizers) increases by 1.5–3 c/ha. Using a mixture of chalk with loam and sand in a ratio of about 1:2:1, respectively, the following crop of grass hay was obtained in the 2nd year of life (without fertilizers): sainfoin 18.8 c/ha, alfalfa bluehybrid 54.6, grass mix (fescue, sainfoin, alfalfa) 47.5 c/ha, in the control (pure chalk) respectively sainfoin 16.9 c/ha, alfalfa 25.6, grass mixture 29.6 c/ha.

In the productive use of overburden, an important role is played not only by land reclamation and the proper selection of plants - ameliorants and plants - fillers of land voids, but the corresponding performance of mining operations, involving, if possible, mixing some rocks, toxic burial, applying more fertile rocks to unproductive; backfill ravines and quarries to produce toxic and infertile rocks, and not loam, as it happens. The most effective and fastest way to restore the fertility of disturbed lands is to apply a humus layer of soil to the surface of the dump rocks, which is removed from the areas allotted for dumps, quarries, buildings, etc.

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