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Identification of erosion processes in the soils of the coastal territory of lake Kandrykul (Republic of Bashkortostan)

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Abstract. ***Relevance.*** The change of certain environmental factors (water or wind erosion, anthropogenic component) leads to changes of the structure and properties of the soil body. Coastal area soil can already be affected by erosion, which can also negatively affect the quality of water, because washout of the soil particles from the organic-rich upper part of the soil profile can lead to an acceleration of eutrophication processes. Moreover, the recreational activity of these territories increases the anthropogenic load on the soil cover, thereby aggravating soil degradation. That is why the importance of a comprehensive study of the soil disturbance problems caused by erosion and anthropogenic factors is beyond doubt. ***Aim.*** To analyze the behavior of the magnetic and humus profiles during soil cover degradation due to water erosion. ***Object.*** Soil profiles of the coastal area of Lake Kandrykul (Republic of Bashkortostan). ***Materials and methods.*** Magnetic susceptibility was measured using MFK-1A Kappabridge (AGICO). The hysteresis parameters of the studied sedimentary deposits were determined using a coercive spectrometer (J_meter), the Tyurin method was used to determine the level of humus in the soil. ***Results.*** According to the magnetic susceptibility data, the studied soil profiles can be divided into accumulative (soil profiles 2, 6, 7, 10) and eluvial-illuvial (soil profiles 1, 3, 4, 8, 9) types of distribution of magnetic components. According to the Day–Dunlop diagram, the magnetic grains of the samples of the studied soil profiles belong to the category of pseudo-domain particles. ***Conclusions.*** Studying magnetic susceptibility and humus level helped us to determine soil profiles as accumulative and eluvial type of magnetic components and humus distribution. We proved that the ferromagnetic component makes the main contribution to the magnetic susceptibility. The method of coercive spectrometry has shown that magnetic grains in the studied soil profiles are pseudo-domain particles, which may indicate their pedogenic origin.

Keywords: coastal area soil, lake eutrophication, soil magnetism, soil erosion, magnetic susceptibility, coercive spectroscopy, soil humus

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Выявление эрозионных процессов в почвах прибрежной территории озера Кандрыкуль (Республика Башкортостан)

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Аннотация. ***Актуальность.*** В последние несколько десятилетий достаточно остро стоит проблема разрушения почв из-за процессов эрозии. Изменение тех или иных факторов природной среды (водная или ветровая эрозия, антропогенная составляющая) приводит к изменению структуры и свойств почвенного тела. Почвы, расположенные в прибрежных территориях акваторий, уже априори могут испытывать воздействие эрозионных процессов, что также негативно может отражаться на качестве воды в акваториях, ведь смыв почвенных частиц с верхней, богатой органическими веществами, части почвенного профиля может привести к ускорению процессов эвтрофикации. К тому же рекреационная активность данных территорий только увеличивает антропогенную нагрузку на почвенный покров, тем самым усугубляя процессы деградации почв. Таким образом, важность всестороннего изучения проблем деградации почв из-за процессов эрозии и антропогенного фактора не вызывает сомнений. **Цель.** Изучение степени деградации почвенного покрова при возможных процессах протекания водной эрозии с использованием комплекса современных методов магнитного анализа, включающих магнитометрию и коэрцитивную спектрометрию, а также определение содержания гумусового вещества в данных почвах. ***Объект.*** Почвенные профили прибрежной к озеру Кандрыкуль (Республика Башкортостан) территории. ***Методы.*** Магнитная восприимчивость получена с использованием MFK1 A Kappabridge (AGICO). Гистерезисные параметры исследуемых почвенных профилей были определены с помощью коэрцитивного спектрометра (J_meter). Для определения гумуса в почве применялся метод Тюрина. ***Результаты.*** По данным магнитной восприимчивости и определению содержания гумусового вещества изученные почвенные профили можно разделить на аккумулятивный (профили 2, 6, 7, 10) и элювиально-иллювиальный (профили 1, 3, 4, 8, 9) типы распределения магнитных компонентов и гумуса. Согласно диаграмме Дэя–Данлопа, магнитные зерна образцов изученных почвенных профилей относятся к категории псевдооднодоменных частиц. ***Выводы.*** По результатам измерений магнитной восприимчивости и анализу содержания гумусового вещества показано, что изученные почвенные профили определяются аккумулятивным и элювиально-иллювиальным типом распределения магнитных составляющих и гумуса. Показано, что ферромагнитная компонента вносит основной вклад в магнитную восприимчивость. Методом коэрцитивной спектрометрии показано, что магнитные зерна в исследуемых почвенных профилях представляют собой псевдооднодоменные частицы, что может говорить об их педогенном происхождении.

Ключевые слова: прибрежные почвы, эвтрофикация озера, магнетизм почв, эрозия почв, магнитная восприимчивость, коэрцитивная спектроскопия, почвенный гумус

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Introduction

Soil is the most important natural resource on Earth. The quality of life of all living things, like plants, animals, humans, depends on soil quality and of its condition.

One of the urgent problems today is soil erosion that affects degradation of the soil cover under the impact of such natural factors as water and wind [1, 2]. Water erosion often occurs in the coastal areas of reservoirs, especially during high water season, and leads to the movable topsoil ablation. Therefore, the soil structure is destroyed, nutritious matters are washed out into the reservoir in the form of suspension [3]. This, in its turn, accelerates the processes of reservoir eutrophication and disrupts the natural organo-mineral balance of the soil.

At the same time, the shores of lakes are actively used as a resting-place by a large number of people; this not only exacerbates the problem of soil erosion, but also increases the degree of anthropogenic impact on soils. Therefore, the issues of soil degradation due to the impact of erosion are extremely relevant today and are being studied by scientists from all over the world. For example, the soil erosion as a global problem of our time was emphasized in the scientific literature [4–7]. Moreover, in [1] it was stated that erosion dramatically worsens the agrochemical characteristics of soil, reducing humus, nitrogen, phosphorus and potassium level. According to N.M. Zholinsky, I.N. Korableva, N.N. Nuzhdin, climate change, especially an increase in average annual temperature, affects the increase in erosion processes formed on arable agrarian landscape [3].

Usage of magnetic methods in the study of both water and wind erosion has been widespread mainly abroad. For example, P. Nazarok and co-authors in their research state that the indicator of soil magnetic susceptibility can be used as a diagnostic criterion of soil erodibility [8]. Also Z. Ding and co-authors studied the characteristics of magnetic susceptibility under various types of land-use in an area subject to wind and water erosion. They made a conclusion that magnetic susceptibility can be used as an indicator to study soil redistribution in areas subject to erosion [9]. Despite the fact that scientific literature has a large number of manuscripts on soil erosion [1, 2, 4] and even manuscripts on using magnetic susceptibility for study soil erosion [8–10], there is almost no data on the study of erosion of reservoir coastal areas by using coercive spectrometry and soil humus state determination.

Materials and Methods

The aim of the research is to analyze the behavior of magnetic and humus profiles during investigation of the soil cover degradation degree of the coastal territory of Kandrykul Lake due to water erosion.

To achieve the research aim, the following tasks were set: to build a graph of the magnetic susceptibility and humus values distribution of the studied soil profiles; to determine the contribution of dia/paramagnetic (χp) and ferromagnetic (χf) components to magnetic susceptibility; to obtain coercive spectra of isothermal magnetization.

The area of our research is the territory on the shore of the second largest lake of Republic of Bashkortostan – Kandrykul. It lies in a lobe between two low northeastern spurs of the Bugulma-Belebeevskiy upland in the basin of the Usen river. The lake basin is embedded in Ufa sandstones, clay and marly rocks, below which lie Kungur gypsum and anhydrite [11].

The object of our research is the soil profiles of the western riparian land of Lake Kandrykul. The vegetational cover of the studied territory includes groves of broad-leaved oak, birch and oak-birch trees and meadow steppe. Along the coastline of the lake there has been taken 10 soil profiles in total with depth of 120 cm (Fig. 1). 12 soil samples were taken from each profile in layers of 10 cm.

Due to the great difference of parent rocks and the diversity of flora in the research area, there can be found many types of soil: peat-bogie and slimy-gley types of soil on the north-eastern side of the first lake terrace and calcareous chernozems on the northern. Dark gray cryptopodzol soils are common for the terraces of the southeastern part of the lake drainage area. On the western terraces there are chernozem-like meadow soil with signs of gleyzation [11].

The preliminary preparation of soil samples was carried out in accordance with SS ISO 11464-2015 Soil Quality [12]. The multifrequency magnetic susceptibility meter AGICO MFK1-FA was used to measure magnetic susceptibility χ. Prior to this, all samples were ground in an agate mortar.

Coercive spectra can be used to determine the contribution of the dia/paramagnetic (χp) and ferromagnetic (χf) components to the magnetic susceptibility. Coercive spectra of isothermal magnetization in the magnetic fields of up to 0.5 T were obtained using a coercive spectrometer (“J_meter”) [13, 14], which allows separate recording of remanent and induced magnetization at room temperature. Samples were magnetized from their natural state. The following parameters were derived from the magnetization curves: saturation remanent magnetization (Jrs), saturation magnetization corrected for the paramagnetic component (Js), bulk coercive force corrected for the paramagnetic component (Bc), coercivity of remanence (Bcr).

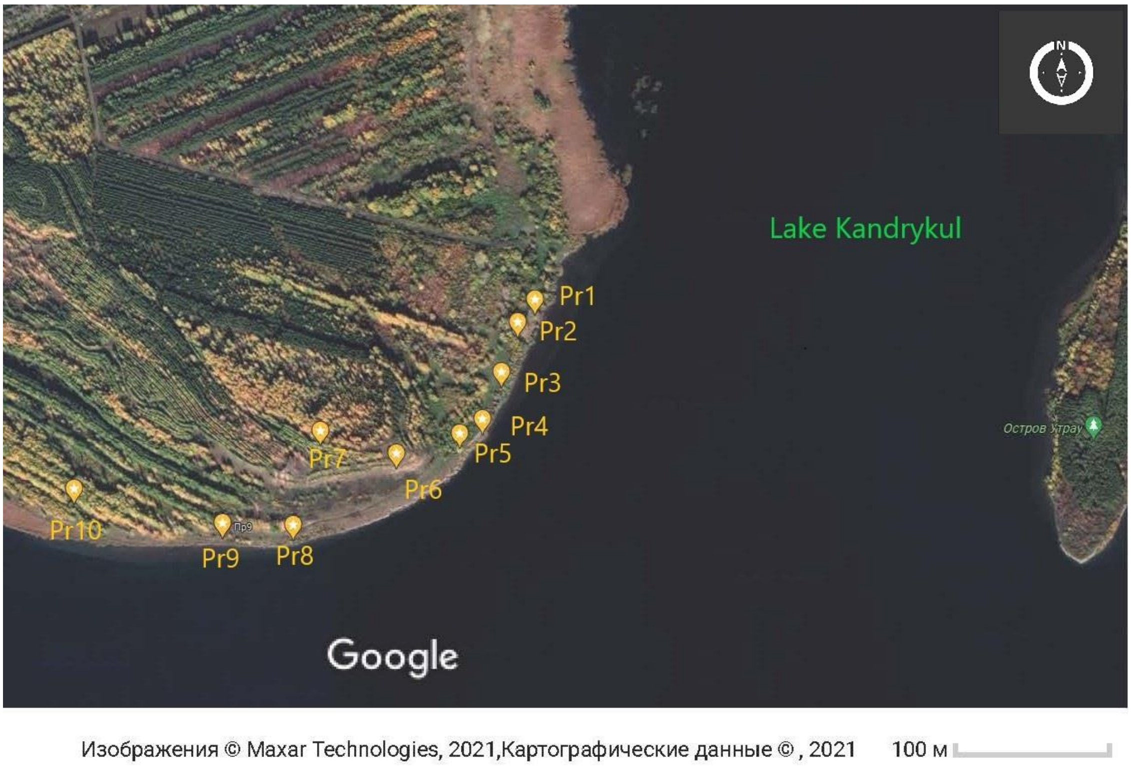

Fig. 1. *Sampling scheme*
Рис. 1. *Схема отбора проб*

The humus level was determined by the Tyurin method [15].

The obtained data was processed by using MS Excel and Grapher program.

Results

The magnetic properties of all substances on our planet, including soil, are reflected in their ability to magnetize in an external magnetic field. An important indicator of magnetic properties is magnetic susceptibility that shows the ratio between the magnetization of a substance and its magnetic field intensity. The magnetic properties of soil mainly reflect the combination of primary and secondary minerals and organic matter of soil solid phase. Soil magnetic susceptibility changes during its formation, transformation and migration of iron compounds. This suggests that magnetic susceptibility reflects soil formation and can be considered as a diagnostic indicator.

The humus state of soil is a set of morphological features, total reserves and organic matter properties and processes of its creation, transformation and migration in the soil profile [16].

The characteristics of magnetic properties and the humus level not necessarily to be functionally dependent on each other. However, it is worth considering that the uniform behavior of these parameters values profile curves may partly be mediated by the contribution of biogenic organo-accumulative surface horizons organic matter to the creation of optimal conditions for heterotrophic microorganisms that synthesize magnets [17].

The shape of the curves of humus and magnetic susceptibility along the depth of the profile in Fig. 2–4 shows that the distribution of these parameters is significantly inhomogeneous. The behavior of the curves in Fig. 2 is more typical for the eluvial-illuvial type of profile curves – with the removal of organic matter, clay, sesquioxides, magnetic minerals from the upper horizons and their accumulation in the illuvial horizon with a gradual decrease in their content approach to the soil-forming rock [16]. It can be assumed that soil drainage and movement of finely-dispersed particles with prevailing water currents are taking place in this area.

The graphical analysis in Fig. 3 shows that the distribution curves of the humus content along the depth of the profile are characterized by an accumulative type of distribution, which means the maximum accumulation of organomineral substances from the surface with a gradual decrease in their content with depth [16]. It can be assumed that the washing of the soil column in these profiles occurs only to a certain depth, below which there is a constantly dry dense layer, which leads to a weak differentiation of these soils and the appearance of a pronounced accumulative type of humus distribution. A slight difference in the behavior of the curves (not a homogeneous but a more ladder-shaped decrease of the humus with depth) is possibly due to different granulometric composition of soil horizons or the type of soil-forming rock. In this way according to the profile humus level curves, the presented soil profiles are mainly characterized by an accumulative type. However, in profiles 1, 4 and 5 we can see obvious movement of humus components deep into the profile, which indicates its eluvio-illuvial nature.

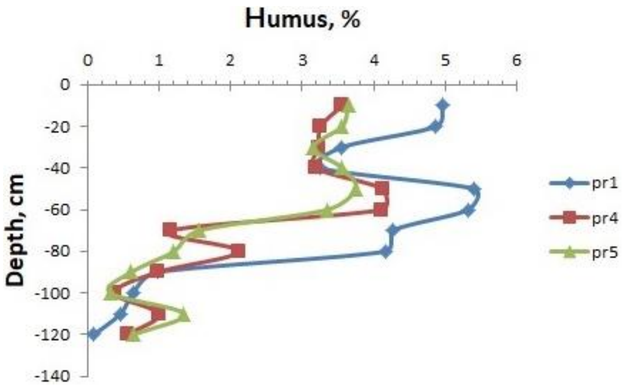

Fig. 2. *Humus distribution in profiles 1, 4, 5*
Рис. 2. *Распределение гумуса в профилях 1, 4, 5*

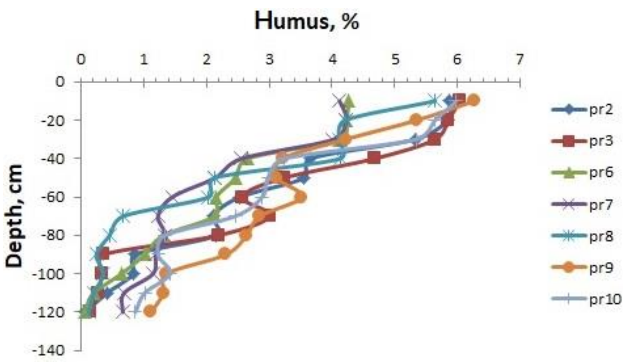

Fig. 3. *Humus distribution in profiles 2, 3, 6–10*
Рис. 3. *Распределение гумуса в профилях 2, 3, 6–10*

According to the magnetic susceptibility curves, they can be divided into accumulative (2, 6, 7, 10 profiles) and eluvio-illuvial (1, 3, 4, 8, 9 profiles) types of magnetic component distribution. The fifth profile is difficult to attribute to any type of magnetic components distribution. The accumulative magnetic susceptibility distribution means the pedogenic origin of magnets [18]. In this case, the maximum number of magnetic components is located in the upper part (0–20 cm) of the soil profile, whereas it is difficult to attribute profiles of a mixed type to the accumulative and eluvial-illuvial type of distribution of magnetic minerals, since they are concentrated throughout the profile and their decrease is observed only from a depth of 60–80 cm. In profiles 2 and 6, the maximum humus content drops to a depth of 15–20 cm, probably due to being in proximity to recreational areas (picnic areas).

The contribution of various components of magnetic susceptibility (dia- and paramagnetic (χp), superparamagnetic (χsp) and ferrimagnetic (χf)) was estimated by using coercitive spectrometry. According to the results obtained, the main contribution to the magnetic susceptibility is made by its ferrimagnetic component (χf) (Fig. 5), while the contribution of the diamagnetic and superparamagnetic components is much lower.

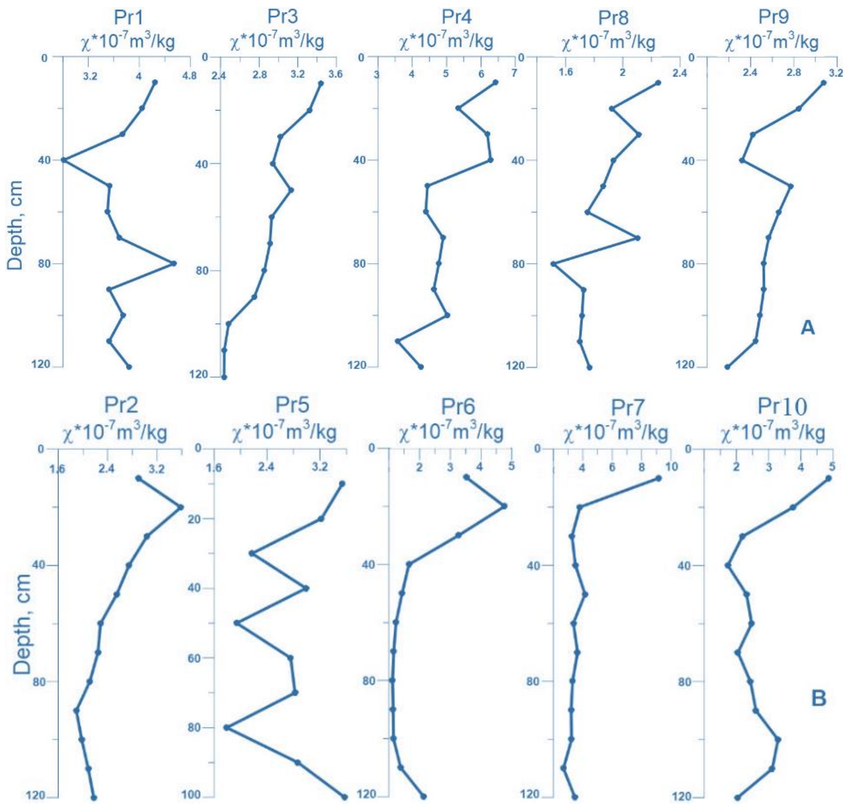

Fig. 4. Distribution of magnetic susceptibility components in profiles by depth: A) profiles 1, 3, 4, 8, 9; B) profiles 2, 5, 6, 7, 10

Рис. 4. Распределение компонентов магнитной восприимчивости в профилях по глубине: A) профили 1, 3, 4, 8, 9; B) профили 2, 5, 6, 7, 10

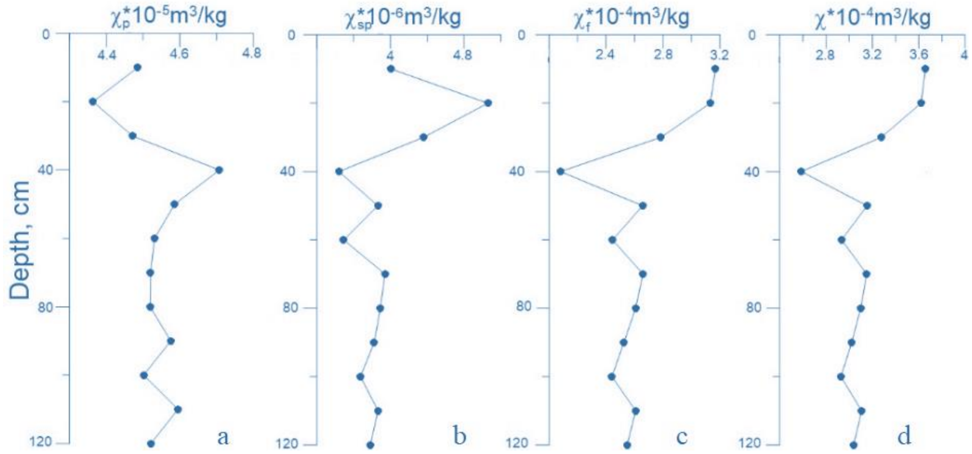

Fig. 5. Contribution of paramagnetic (a), superparamagnetic (b) and ferromagnetic components (c) to magnetic susceptibility (d) (profile 1)

Рис. 5. Вклад парамагнитной (a), суперпарамагнитной (b) и ферромагнитной компонент (c) в магнитную восприимчивость (d) (профиль 1)

Analysis of Bc, Bcr, Js, Jrs magnetic hysteresis parameters that depend on the composition, concentration of the magnetic fraction, shape and size of the magnetic grains was conducted to determine the magnetic rigidity and the domain state of the grains of the magnetic fraction [19] (Fig. 6).

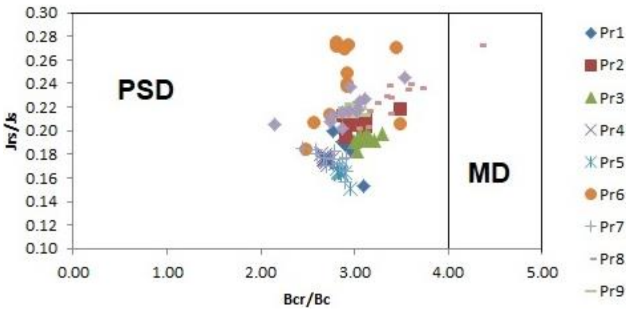

Fig. 6. *Day plot*
Рис. 6. *Диаграмма Дэя*

The Bcr/Bc and Jrs/Js ratios depict the prevailing grain size and the ratios between magnetic fraction and different domain structures. According to the Day–Dunlop diagram [20], magnetic minerals of the studied soil samples fall into the category of pseudo-single-domain particles. Getting into the area of pseudo-single-domain particles suggests that the magnetic components of the studied soils are present in the clay fraction.

Discussion

Being near the lake, the soil cover of the studied territory is formed in conditions of a wide variety of flora, different geomorphology of the area that cause its heterogeneity.

According to P.R. Slezkin, "humus-forming agents" are fixing in the soil due to gradual accumulating in the soil profile in the form of water extract of the plant litter [21]. According to B.R. Grigoryan, soil humus content is a set of morphological characters that consists of total reserves, organic matter properties and its creation, transformation and migration in the soil profile [16]. The studied meadow chernozemic soil can be characterized as a type of low humus content. The maximum value of humus is not typical for this type of soil and is about 6% on the topsoil (0–30 cm) in the accumulative type of profiles, and about 4.5% at a depth of 50–60 cm in the eluvio-illuvial. Grigoryan considers that humus content in various chernozems ranges from 6 to 12% [16]. As the surface soil layers (top soil) are organo-mineral horizons of humus accumulation during the growth of plant litter, they can protect the soil from water or wind erosion [16]. However, being also an active recreational zone, Kandrykul Lake coastal territory is under strong pressure on the vegetation cover of the topsoil. Consequently, this leads to the plant litter destruction and increases the risk of erosion, which definitely affects the humus content.

Besides, expert M. Martynova and co-authors think that the highly dispersed structure of the topsoil, where there is plant litter destruction by compaction, leads to losses of humus by the soil [22].

The transformation and migration of iron compounds during the soil-formation change soil magnetic susceptibility. It means that magnetic susceptibility reflects soil-formation and can be considered as a diagnostic indicator [23]. As for the results of magnetic susceptibility within the research area, some magnetic profiles behave like humus profiles. There is both an accumulative type of profile magnetic components distribution, which demonstrates a gradual decline in the magnitude of magnetic susceptibility (profiles 2, 6, 7, 10), and a mixed type (profiles 1, 3, 4, 8, 9), which is characterized by the magnetic component transformation into the upper and middle layers of the soil, where their accumulation occurs.

The presence of more magnetic components in the topsoil could also be explained as consequence of anthropogenic impact, because the indicator of magnetic susceptibility can also be an indirect indicator of technogenic soil pollution [24, 25]. However, due to M. Evans, the accumulative type of magnetic susceptibility distribution in virgin soil obviously implies the pedogenic origin of magnetic components [26]. The particles of pedogenic magnets, as a rule, are determined by fine-dispersed grains, which cause bioinert interactions [26]. According to the obtained coercive spectra measurement data, both accumulative and eluvio-illuvial profiles are characterized by the contribution of the ferrimagnetic component to the magnetic susceptibility and the predominance of pseudo-single-domain particles. This also means that fine-dispersed mineral components were formed as a result of structural transformations of iron minerals that emerged in the soil from the parent rock. Thus, the low humus level can be correlated with possible soil erosion, because magnetic profiles demonstrate the accumulation of magnetic components mainly in the clay fraction, which may be the result of a subsurface structure substance transformation of magnetic minerals of the soil-forming material. Consequently, the elevated values of magnetic susceptibility are not the result of an anthropogenic factor, but a consequence of pedogenesis.

Conclusion

By using the complex of modern methods of magnetic analysis and humus content analysis we studied soil profiles of the coastal area of the Lake

Kandrykul. It was found that the studied soil samples have an accumulative and eluvio-illuvial type of magnetic components and humus distribution. More than that, it was established that the ferromagnetic component of magnetic susceptibility in the studied soil profiles affects its growth. It was also established that magnetic components are present mainly in the clay fraction of the studied soil profiles.

The research shown that the control of soil cover humus level is one of the important tasks of ecological soil monitoring since it can be used to judge the impact of erosion processes occurring in the soil. Thus, outwash, destruction and re-accumulation of soil material due to erosion affects not only the soil disturbance and changes in the properties of soil profiles, but also enriched with organic matter soil material that accumulates in the upper part of the sediment beds; this can accelerate reservoir obliteration. Therefore, to control this process, monitoring studies can be carried out by using magnetic methods and by analyzing the soil humus level. Also, in order to slow down erosion, it is necessary to carry out special reclamation work of protecting the soil cover.

It is intended in the future to study soil samples and separate <2.5 μm specimens using the differential thermomagnetic analysis to gain more information on the magnetic and mineralogical features of the studied soils.

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