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GENESIS AND GEOGRAPHY OF SOILS

Classification and Morphological Peculiarities of Coastal Soils

S. A. Shlyakhov and N. M. Kostenkov

Institute of Biology and Soil Science, Far East Division, Russian Academy of Sciences, pr. Stoletiya Vladivostoka 159, Vladivostok, 690022 Russia

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Abstract—The soils of coastal plains are considered. It is argued that these soils have some specific common features and can be placed in the world systems of soil classification under the name of Thalassosols. The subdivision of Thalassosols at lower taxonomic levels and their nomenclature are suggested. Morphological descriptions of separated groups of Thalassosols are given by the example of the soils studied along the Russian coast of the Sea of Japan.

INTRODUCTION

The soils of coastal plains are of considerable interest from scientific, environmental, and even economic standpoints. Their investigation is required for elaboration of the proper policy of land management and soil conservation. In Western Europe and the United States, coastal (especially, marsh) soils are sufficiently studied; in other parts of the world, including the Far East of Russia, these soils have received little attention. The soils of the Russian coast of the Sea of Japan have been described only by Kostenkova [3, 4], who revealed some of their properties and considered the problem of their classification.

The sea dictates the conditions of pedogenesis within the narrow belt of coastal plains. Sea lowlands represent aggradational landforms; they are built up by the sea from coastal deposits. Coastal soils develop under herbaceous vegetation of the littoral ecosystem. Coastal zones have specific microclimatic conditions characterized by the increased humidity and lower amplitude of daily and seasonal temperatures, in comparison with surrounding territories. The sea exerts a strong effect on the hydrological regime of coastal soils; in the case of marsh soils, soil hydrology is dictated by the sea. Terrestrial ecosystems along the coastline are subjected to the considerable geochemical influence of the sea; the degree of this influence rapidly attenuates as we move landward. All these factors lead to the formation of specific coastal soils. Marsh soils and mangrove soils are the most well known varieties of coastal soils, though there are some data on the other soils that develop outside the littoral zone [2, 16, 17, 24].

CLASSIFICATION OF THALASSOSOLS

Analysis of the Russian and foreign literature testifies that coastal soils are often separately distinguished in classifications. In particular, marsh and mangrove soils are distinguished at relatively high (above the soil type) levels in several classification schemes [7, 10, 12, 13]. The type of marsh soils is included in the classification developed under the supervision of Shishov and Sokolov [14]. Dobrovol'skii [1] noted that the effect of sea water on pedogenesis leads to the formation of a group of thalassomorphic soils. He does not consider their taxonomic status, but indicates that this soil group is composed of mangrove and marsh soils, as well as of coastal salt-affected soils and coastal solonchaks.

At present, there is no universally accepted taxonomy and nomenclature of coastal soils in Russia. In some foreign countries (e.g., in Germany), there are official classifications of marsh soils. However, two major classification systems—*Soil Taxonomy* and the legend to the World Soil Map of FAO–UNESCO—distinguish neither coastal soils in general, nor marsh and mangrove soils in particular as separate classification taxa. According to these classifications, various specific groups of coastal soils are distinguished within different categories of a higher level, where they are considered together with their continental analogues. At the same time, there are several soil units specially designed for coastal soils at lower taxonomic levels. For example, Thionic Gleysols and Thionic Histosols are distinguished in the FAO–UNESCO system; Sulfaquents, Hydraquents, Sulfihemists, and Sulfisaprists are distinguished at the great group level in *Soil Taxonomy* [23]. Along with these categories, there are some other typologic groupings of marsh soils that are based on the frequency and duration of tides, the degree of soil salinity, and some physiographic peculiarities of marsh landscapes [15, 18–22, 25]. Often, marsh soils of river estuaries are specially distinguished from the soils of typical sea marshes. Coastal soils that are not subjected to tidal impacts have no specific classification position. Usually, they are named after corresponding landscapes (bog, meadow, or dune coastal soils), or in agreement with the type of soil-forming rocks (sandy coastal soils) [2, 16, 17, 24].

Following the principles of the ecologic-genetic soil classification, we suggest that nonzonal soils of coastal

Table 1. The scheme of classification of Thalassosols

Taxonomic level	Names of taxa					
Group of soil types	Thalassosols					
Subgroups of soil types	Marsh soils		Maritime swamp soils		Maritime meadow soils	
Soil types	Organic	Proper (mineral)	Organic	Meadow–swampy	Organic	Proper (mineral)

plains can be distinguished in the special taxon (Thalassosols) of a high taxonomic level (soil association, or the group of soil types). The name derives from the Greek *thalassa* (sea). The use of the element *sol* in the Russian school of soil nomenclature is not very common; however, there are some precedents of its use, especially for the names of some poorly developed lithomorphic soils (Lithosols, Andosols, Vertisols, etc.) [8, 11]. The group of Thalassosols comprises all poorly developed soils on recent coastal deposits; thus, its name is in full compliance with the unofficial rules of soil nomenclature in Russia.

In dependence on the conditions of modern lithogenesis in the coastal zone and the degree of soil hydromorphism, Thalassosols can be separated into three subgroups. Synlithogenic Thalassosols are widespread within the littoral zone; they are subjected to simultaneous processes of accumulation of coastal deposits and pedogenesis (the hydroaccumulative stage of soil formation). Traditionally, these soils are named as marsh soils. The latter name is preserved in our system for consistency in soil nomenclature. Two other subgroups encompass postlithogenic soils that develop outside the tidal zone, but preserve all characteristic features of Thalassosols. In contrast to marsh soils, they have no commonly accepted name. We suggest that these soils can be distinguished under the general name of Maritime (from Latin *maritimus*, sea, coastal) soils. Maritime soils are subdivided into subgroups of swamp soils (hydromorphic postlithogenic Thalassosols) and meadow soils (mesohydromorphic and mesomorphic postlithogenic Thalassosols). Each of the subgroups can be separated into two soil types (organic soils and soils proper) distinguished by the nature of soil-forming material (Table 1). The separation of organic soils is based on the standard criterion for the thickness of the organic (histic) horizon (>50 cm). Other representatives of marsh and maritime swampy soils can be referred to as synorganogenic soils (the soils in which the surface accumulation of organic matter takes place simultaneously with alteration of the mineral soil matrix). Maritime meadow soils can be placed into the category of postorganogenic soils (the soils that have completed the swamp stage of their development and are currently subjected to mineralization processes).

The scheme of taxonomic division of Thalassosols at lower levels is shown in Table 2. The division of all organic Thalassosols is based on quite traditional principles. The division of mineral Thalassosols at the levels above soil genus is based on different principles and depends on the nature of soils; at the lowest levels of classification, this division is virtually the same for all categories of mineral Thalassosols. The type of marsh soils is subdivided into the subtypes of typical mash soils and alluvial–marsh soils. The latter occur within river estuaries and delta areas and represent the transition from Thalassosols to alluvial soils (Fluvisols). The separation of soil genera within the type of marsh soils is based on the degree of development of the soil profile; in particular, the presence and the thickness of a histic horizon are taken into account. This division is similar to the traditional division of marsh soils into the soils of low, medium, and high marshes, but is based on soil properties rather than on landscape features. Four genera of marsh soils are distinguished: (1) primitive marsh soils that represent recent coastal deposits that have not yet been differentiated into soil horizons by pedogenic processes so that the surface layer does not differ much from the bottom layer; (2) poorly developed marsh soils that are composed of several soil horizons and have a distinct histic or humus surface horizon with a thickness of up to 10 cm; (3) peaty marsh soils that are distinguished by the presence of a histic horizon whose thickness varies from 10 to 30 cm; and (4) peat marsh soils that have a histic horizon of up to 50 cm in thickness.

Maritime soils are not subjected to floods or tides; they cannot be found within flood plains. Therefore, there is no need to distinguish a transitional group of maritime–alluvial soils. The subtypes of maritime meadow–swampy soils are distinguished on the basis of the degree of peat accumulation. Maritime peaty meadow–swampy soils represent a transitional group to maritime swamp organic soils; therefore, the subdivision of this subtype at the genus level is based on the criterion usually used for the differentiation of organic soils, i.e., on the degree of decomposition of plant remains. The subtypes of maritime meadow soils are distinguished on the basis of the degree of soil hydromorphism. Mesohydromorphic maritime meadow soils are characterized by the presence of the gley horizon in the bottom part of their profile; these soils are attributed to the subtype of gleyed maritime meadow soils. Automorphic (mesomorphic) maritime meadow soils lack gley features, except for the deepest part of their profile; they are distinguished at the subtype level as typical maritime meadow soils. Gleyed maritime meadow soils form a transitional group between typical meadow Thalassosols and meadow-bog Thalassosols.

The further division of these subtypes is based on such criteria as the thickness of humus horizon, the

Table 2. The taxonomy of Thalassosols

Taxonomic level	Names of soil taxa					
Types	All organic soils	Marsh proper soils	Maritime meadow–swampy soils			Maritime meadow soils
Subtypes	Mucky–peaty Peaty–mucky Mucky	Typical Alluvial–marsh	Peaty	Slightly peaty	Typical	Gleyed Typical
Genera	Shallow Medium-thick Thick	Primitive Poorly developed Peat Slightly peaty	Peaty Mucky–peaty Peaty–mucky	Peaty Mucky–peaty Peaty–mucky	Primitive Shallow Medium-thick Thick Deep-humus	
Species	Nonsaline					
	Slightly saline Deep-saline	Moderately saline Strongly saline	Profile-saline Surface-saline Extremely saline		Shallow-saline Deep-saline Sporadically saline	
Subspecies	Sulfidic (sulfatic) Non-clayey Slightly clayey Moderately clayey Strongly clayey	Ordinary Normal Multisequal Polycyclic				
Series	By the texture of soil-forming rocks	By soil texture				

degree of decomposition of plant remains in the surface peat layer, the content and distribution pattern of salts, the content of sulfides, and the lithological peculiarities of the mineral mass of soils and soil-forming rocks. In general, these criteria correspond to those accepted in classification of other soils. Thus, our classification decision is in conformity with traditional approaches to soil classification.

FIELD DESCRIPTIONS OF THALASSOSOLS

In order to test our classification decisions, we studied more than 70 soil pits along 23 soil catenas within the coastal plains of the Sea of Japan. The pits were allocated to different geomorphic conditions (coastal lowlands, first sea terraces, the shores of lagoons, river estuaries); various types of soil-forming rocks composed of Holocene marine deposits were studied. We investigated both the soils periodically flooded by sea water (marsh soils) and the soils lying above the littoral zone (maritime soils).

Marsh and maritime soils develop under herbaceous vegetation of littoral and supralittoral ecosystems. Geomorphologic profiles of two soil catenas are shown in Figs. 1 and 2. These profiles show us the allocation of different groups of Thalassosols to certain elements of local topography. However, they cannot reveal the real complexity and diversity of soil sequences within coastal plains. For example, the sites subjected to strong wave action do not have marsh soils; a system of longshore bars dictates a complex sequence of meadow and swamp maritime soils, etc.

The coastal province of the Sea of Japan lies within boreal and subboreal climatic zones [6]. The boreal zone encompasses about two thirds of the Russian part of the coastal province. However, the sites studied are mainly allocated to the subboreal zone that is distinguished in the southern part of the Far East region and in the southwestern part of Sakhalin Island. These territories are characterized by the monsoon type of climate. The sea water temperature varies from 0–2°C in February to 15–20°C in August. Mean annual air temperature in the southwest of Sakhalin is about +4.5°C; in the south of the Far East, it increases up to 5–5.7°C. Mean annual precipitation varies from 700 to 900 mm [5].

It is not easy to reveal some regularities in morphological properties of Thalassosols, because of a relatively short duration of pedogenic processes operating in them. Most of Thalassosols have not yet developed a distinct morphological profile. Soil diagnostics are complicated by a strong variation in the factors of pedogenesis within the coastal zone and by the polygenetic nature of some Thalassosols that have abundant relic features in their profiles. The difficulties in diagnostics of marsh soils are also related to the activity of modern processes of coastal lithogenesis that are superimposed on soil formation. In contrast to most other soils, the profile of marsh soils usually represents not a given system of genetic horizons, but a relatively occasional sequence of layers created by sedimentation processes and somewhat modified by pedogenesis. Natural bodies of that kind can be referred to as pedoliths [11]. The role of pedogenic processes in maritime soils is more distinct; these soils can be placed into the category of

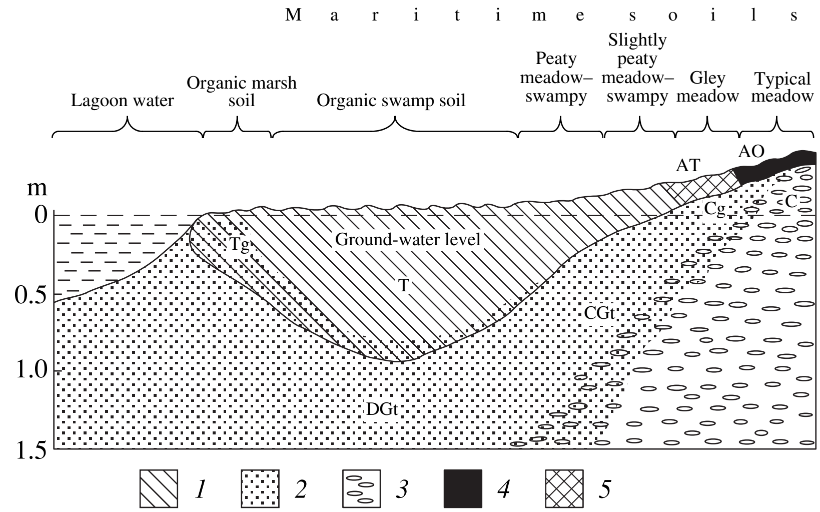

Fig. 1. Geomorphologic profile across the Tsaplich'ya lagoon (the Bay of Amur). (*1*) Peat, (*2*) fine earth, (*3*) pebble deposit, (*4*) humus–mucky horizon, and (*5*) humus–peaty horizon.

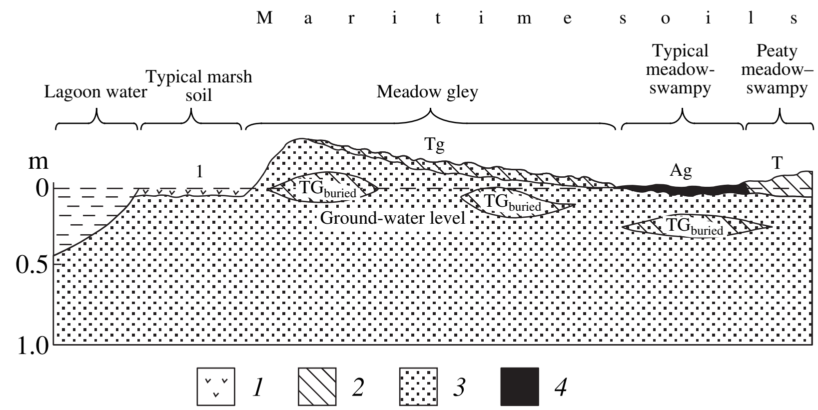

Fig. 2. Geomorphologic profile of the Sukhodol inlet (the Bay of Ussuri). (*1*) A litter consisting of decomposing algae, (*2*) peat, (*3*) sand with some admixture of clay, (*4*) humus-accumulative horizon.

semisols [11] or poorly developed soils. Thus, marsh soils and maritime soils strongly differ from each other. In order to visualize this difference in soil descriptions, we designated the layers of marsh soils by roman numerals (I, II, III, etc.), whereas the layers of maritime soils are designated by traditional symbols of soil horizons, including the symbols for soil-forming rocks (C) and imbedding materials (D). Peat horizons are designated by the T symbol. In some cases, these horizons have a considerable admixture of clay material; the properties of such horizons strongly differ from the properties of typical organic horizons. In particular, clay-rich organic horizons always have evident gley features. The degree of manifestation of the latter depends on the clay content. These horizons are designated by the Tg (relatively low content of clay) or TG (high clay content) symbols.

The profiles of all organic Thalassosols have relatively similar composition. They consist of several peat layers that can differ by the degree of decomposition of plant remains, salt content, and clay content. Organic layers are underlain by the gleyed mineral substrate. Some of these soils have mineral laminae within organic layers, or a thin clay-rich mineral AG horizon. Marsh organic soils develop on tidal flats protected from the wave action (usually, along the shores of lagoons); maritime swamp soils are characteristic of swampy lowlands protected by longshore bars. Maritime meadow soils represent a further stage of soil evolution in the coastal zone. They develop from maritime swamp soils, when the ground-water level becomes deeper and the soils are subjected to mineralization. They are characterized by the following sequence of genetic horizons: TA–Tg–TG–DG.

Not only the subtypes, but also the genera of marsh soils strongly differ from each other by their morphology. It is impossible to characterize them by a standard set of soil horizons or layers. Some primitive marsh soils represent just a sequence of stratified mineral deposits; even their topmost layer lacks distinctive soil features. However, these deposits are capable of supporting higher plants; therefore, they can be attributed to soils in the most broad definition of this word. According to Sokolov [11], these bodies are included into the category of Ecosols (soils proper and soil-like bodies that perform ecological functions of soils). It should be noted that primitive marsh soils, especially those of heavy texture, can be rich in organic matter; the maximum concentration of organic matter can be found in any part of their profiles. The concentration of organic matter in soil layers depends on the concentration of organic matter in the suspensions from which these layers have formed. For example, a typical primitive clayey marsh soil described near the sea lagoon not far from the city of Nakhodka contained 1.5 times more humus in the layer of 25–52 cm, as compared to the surface layer.

Poorly developed marsh soils have a distinct AO or AT surface horizon. These are the soils formed by humus accumulation and gleyzation [9]. Their evolution is directed towards peaty marsh soils that are distinguished by a system of organic horizons underlain by gleyed and stratified mineral marsh deposits: TG–I–II–III, or Tg–GAO–G.

Alluvial–marsh soils differ from typical marsh soils by a finer stratification and somewhat coarser texture.

Primitive alluvial–marsh soils are subjected to regular flooding by tides. They occupy low marshes in estuaries and usually do not support higher plants, except for halophytes that can be found in small patches. The soil surface is covered by green algae; the shells of bivalves are found in some places. These soils are often flooded even during low tides. Their profile consists of a relatively simple sequence of layers, e.g., I (0–10 cm), II (10–21 cm), III (21–40 cm). In the pit described, soil layers were composed of the mixture of black clay, shell detritus, and multicolored pebble.

Alluvial–marsh poorly developed soils are found along the shores of estuaries that are subjected to frequent, but not regular floods. These sites are usually covered by rich vegetation. The soils are composed of the following horizons: AT–Ag–I–II–III, or AT–G–CG–I–II–III. The thickness of the topsoil horizons (AT + Ag) does not exceed 10–15 cm.

Peaty alluvial–marsh soils resemble peaty marsh soils. A sequence of surface peat layers in these soils is underlain by stratified mineral deposits. Sometimes, a distinct G horizon can be observed in their profile.

Meadow–swampy maritime soils, as well as most of marsh soils, are created by the processes of organic matter accumulation and gleyzation. They have passed through the previous hydroaccumulative stage of soil formation, which makes their profiles rather similar to the profiles of marsh soils. However, pedogenic features are better manifested in meadow–swampy soils. We have distinguished three subtypes of meadow–swampy maritime soils. A typical meadow–swampy maritime soil under reed vegetation was described behind the longshore bar. The profile of this soil is composed of the following horizons: AG1 (0–23 cm), AG2 (23–34 cm), DG1 (34–56 cm), and DG2.

The morphology of typical meadow–swampy maritime soils can differ from that described above. For example, some of these soils may have the Ksl–AOg–BG–G profile, if the vegetation is suppressed (because of the high content of salts) and there is no peat accumulation at the surface. The salt crust (Ksl) is very thin (several millimeters) and appears on the surface only during relatively dry seasons. We have also described meadow–swampy maritime soils with a distinct peaty horizon at the surface. The thickness of the peat layer in this subtype should not exceed 10 cm; if it is more than 10 cm, the soil should be referred to as a peaty meadow–swampy soil.

Peaty meadow–swampy maritime soils were described under the sedge–reed grass association and under the herbaceous–sedge swamp. The first soil had the following profile: TG (0–12 cm), G1 (12–66 cm), G2; the second soil was composed of the T1 (0–21 cm), T2G (21–40 cm), GA (40–55 cm), and G horizons.

The type of meadow maritime soils has a polygenetic origin. Some of these soils have passed the stages of marsh and swamp soils; their evolution is directed towards gradual attenuation of hydromorphic features. The other group of meadow maritime soils has always been developing in mesohydromorphic or mesomorphic conditions. Therefore, in spite of the similar character of modern soil-forming processes, the morphology of meadow maritime soils can strongly vary in dependence on the presence of relic features of pedogenesis and the soil age.

Gleyed meadow maritime soils are confined to the footslopes of longshore bars, relatively elevated parts of coastal swamps, and relatively low elements of sea terraces. These soils develop in conditions of a high groundwater level and have distinct gley features already within the top 0.5-m-thick layer. Their surface horizon has a peaty or mucky character and contains considerable amount of organic matter. Gleyed meadow maritime soils were described under the sedge–herbaceous association on the low coast of a lagoon (AT, 0–8 cm; A1, 8–15 cm; Cg, 15–41 cm; CG) and under the sedge association within the hollow on a low sea terrace (AO, 0–24 cm; C1g, 24–46 cm; C2g).

Typical maritime meadow soils occupy the highest geomorphic positions (within coastal plains) that are composed of coarse-textured marine deposits with perfect filtration capacity. These soils do not have gley features in the upper (0–50 cm) soil layer. Some of them are low-humus soils, whereas the others may have a considerable humus content in the topsoil. The content of organic matter gradually decreases with depth. In some pits, we distinguished initial traces of the formation of the B horizon. The presence of relic soil features, including buried surface horizons, complicates the morphology of maritime meadow soils. An example

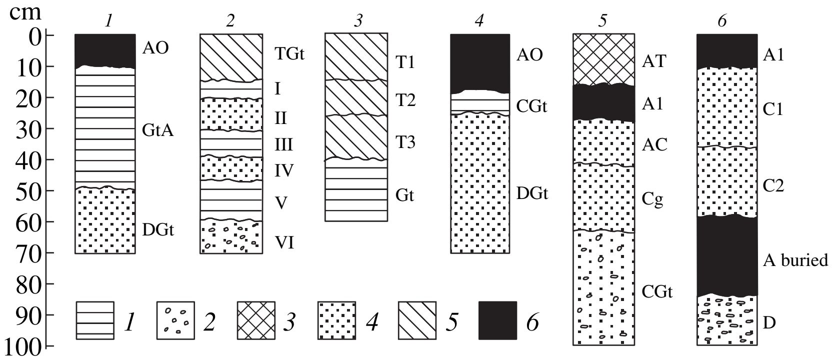

Fig. 3. Schematic morphological profiles of Thalassosols: (1) poorly developed typical marsh soil, (2) slightly peaty alluvial–marsh soil, (3) peaty alluvial–marsh soil, (4) medium-thick typical meadow–swampy maritime soil, (5) thick gleyed meadow maritime soil, (6) low-thick typical meadow maritime soil. (*1*) Loam, (*2*) pebble, (*3*) humus–peaty horizon, (*4*) loamy sand and sand, (*5*) peat, (*6*) humus–mucky horizon.

of a typical maritime meadow soil with buried horizons was described on the first sea terrace under meadow vegetation represented by mixed herbs: AC (0–22 cm), CA (22–31 cm), C (31–46 cm), A buried (46–76 cm), DA buried (76–96 cm), D (96–216), Dg.

Morphological profiles of other genera of typical maritime meadow soils resemble the above-described profile. The distinctions between different genera are seen in the thickness of the A1 or Asod horizons. Most of these soils have a coarse texture, though we have described some loamy varieties underlain by pebble material (AO–AB–BC). The examples of typical profiles of Thalassosols are shown in Fig. 3.

CONCLUSIONS

(1) Coastal plains are characterized by a specific combination of soil-forming factors that leads to the formation of specific coastal soils. Marsh soils develop within the littoral zone. Coastal soils that develop on the territories adjacent to marshes, but not subjected to floods, can be referred to as maritime soils.

(2) The evolutionary sequence of coastal soils is represented by the group of soil types; all these soils can be placed together into the category of Thalassosols.

(3) Thalassosols are subdivided into the subgroups of marsh soils, maritime swamp soils, and maritime meadow soils. These subgroups are distinguished on the basis of the degree of development of soil profiles and the intensity of organic matter accumulation. Every subgroup can be subdivided into the types of organic and organomineral (or mineral) soils. The classification of Thalassosols follows the principles of existing classifications of inland soils, but takes into account the specifics of the object of our study.

(4) The composition and morphology of Thalassosols are controlled by both geological and pedogenic processes; the combinations of these processes are very diverse in nature, which results in a great diversity of soil morphology. The main distinction between typical inland soils and Thalassosols consists of the activity of lithogenic processes in the latter. Differentiation of Thalassosols is caused by the differences in the character, intensity, and duration of pedogenic processes operating in them. The assessment of pedogenic processes in the classification of Thalassosols ensures the genetic essence of this classification; soil diagnostics is performed on the basis of substantive morphological criteria.

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