International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:8, No:5, 2014

Features of Soil Formation in the North of Western Siberia in Cryogenic Conditions

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***Abstract*—**A large part of Russia is located in permafrost areas. These areas are widely used because there are concentrated valuable natural resources. Therefore to explore of cryosols it is important due to the significant increase of anthropogenic stress as well as the problem of global climate change. In the north of Western Siberia permafrost phenomena is widespread. Permafrost as a factor of soil formation and cryogenesis as a process have a great impact on the soil formation of these areas. Based on the research results of permafrost-affected soils tundra landscapes formed in the central part of the Tazovskiy Peninsula in cryogenic conditions, data were obtained which characterize the morphological features of soils. The specificity of soil cover distribution and manifestation of soil-forming processes within the study area are noted. Permafrost features such as frost cracking, cryoturbation, thixotropy, movement of humus are formed. The formation of these features is increased with the development of the territory. As a consequence, there is a change in the components of the environment and the destruction of the soil cover.

***Keywords*—**Gleyed and nongleyed soils, permafrost, soil cryogenesis (pedocryogenesis), soil-forming macroprocesses.

I. Introduction

AREA of soils formed in permafrost in Russia is 63.5% and it determines the need for consistent and detailed investigation [1]. The processes of exchange, transformation, movement of substances and energy are influenced by permafrost in the soil. In this case the specific combination of elementary (processes which common for different types of soil formation) and typical (macroprocesses) soil-forming processes are implemented.

"Freezing and frozen soil conditions have a significant impact on soil formation, greatly slowing down or significantly altering the chemical and biochemical conversion processes, migration of substances and dramatically reducing the active period of soil formation" [2]. Influence of permafrost and prolonged seasonal frost on soil properties and soil moisture regimes so great that cryogenesis is regarded as soil formation sub-factor (hierarchical unit within the soil-forming factors), which combines climate (sub-zero temperature of the soil profile) and rocks (ice cementation) features.

It is expected that global climate change and its impact on landscape processes will be greatest in the Arctic (subarctic) areas confined to areas of shallow permafrost [3]. This scenario is compounded forecast largest amplitude changes of climatic parameters on the territory of Western Siberia, which has already confirmed the temperature trend of recent times. Under slow evolutionary development of cryogenic processes impact of permafrost leads to the formation of specific permafrost soils and degradation causes a change in soil cover. Knowledge of the basic laws of soil formation on permafrost rocks as well as perception of the global biosphere functions of soil will provide an opportunity to solve a number of theoretical and practical problems [4].

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II. Permafrost and Soil Formation

The first information of soil scientists and botanists about specificity of soil formation in permafrost areas and seasonal freezing of soil was in the papers of soil-botanical expeditions in Russia in the period 1908-1915 years, which was led by Russian soil scientist and geologist K. Glinka. In recent years the interest in the permafrost soil areas of the planet has increased significantly, due to the awareness of global biospheric functions of soil cover. Along with the traditional problems of pollution and destruction of soils and soil cover of northern territories of Western Siberia, also the great attention is paid to the carbon balance of tundra ecosystems due to the threat of the greenhouse effect, and the possible degradation of permafrost.

Permafrost is located close to the surface and influence on the overlying soil layer. In this regard, one could argue that it affects not only the formation of microrelief and development areas, but it also determines the nature of soil processes [5]. Freezing and frozen soil conditions have a significant impact on soil formation of Tazovskiy Peninsula study area. In this way slowing or significantly modifying chemical, biochemical processes conversion and migration of substances and dramatically reducing the active period of soil formation.

The effect processes of freezing and thawing and the presence frozen horizons in the soil profile have different consequences for soil formation. In one case, soils develop in a free draining loose depth (there are physical fragmentation of the solid phase, coagulation and denaturation of colloidal dissolved and amorphous compounds). In another case, soils develop in difficult draining, overmoistening depth and cryogenic mass transfer and moisture exchange leads to the development of various processes. Thus most typical of the tundra soil forming such macroprocesses as cryogenesis, gleying, accumulation of undecomposed and semidecomposed remains of plants and animals (detritogenesis).

A. Soil Cryogenesis (Pedocryogenesis)

Above all subzero temperatures in the surface layer of the atmosphere, defined by radiation and thermal balance of the earth surface and the nature of the atmospheric circulation are factors of soil cryogenesis. The soil freezing depth changes depending on the thermal conductivity and the heat exchange between soil and atmosphere. In permafrost areas to the cooling surface of the soil is also added influence of permafrost, which creates a second lower front subzero temperatures.

Relevant features, regimes, specific horizons and soil taxons are formed as a result of pedocryogenesis in soils. Phenomena of these processes are reflected in relief, changing the structure of the soil cover, soil profile, separate genetic horizon and have a significant impact on the molecular and ionic levels [5]. The role of soil cryogenic processes affects the character of the transformation plant remains, composition and properties of humus and its distribution in the soil profile. Therefore humification in soils in this area takes place in very specific conditions. The frozen condition, overmoistening of soils leads to the preservation of organic remains or transformation to raw humus (mor) [6], [7].

The main mechanism of differentiation cryogenic of soil mass of these areas is reducing the mobilization of iron, migration to the freezing front and deposition on the oxidation barrier on the upper and lower boundaries of the gley horizon. A characteristic feature of the structure of the profile of a cryogenically ferruginized gleysols is a brightly colored in blue-gray tone gley horizon, which above and below usually has dramatically contrasting ocher border of “oxygenated gley”, often having “roe” structure (Fig. 1).

Fig. 1 Cryogenically ferruginized gleysols

B. Gleying

Gleying is one of the main soil-forming processes, which forms the profile and leads to the formation of Gleysols, where the process can be combined with cryogenesis and differentiation of iron. Important to note that disaggregation of the soil mass occurs during gleying. It is associated with the destruction of iron oxide films, which play the role of "glue" and do not let the soil aggregates are destroyed. In the tundra, this process leads to such formative landscape and significant properties as thixotropy. As a result, the process of solifluction is widespread and strong flatness of landforms in the tundra zone is associated with solifluction (Fig. 2).

Fig. 2 Solifluction on slopes

C. Detritogenesis

Detritogenesis is characterized by accumulation of undecomposed and semidecomposed remains of plants and animals [7]. For considered territory, this process occurs widely due to poor intensity of transformation of plant litter, thereby mortmass is accumulated. Process factors are low temperature, overmoistening whole profile in the presence of permafrost, in view of such conditions the biological cycle is very slow. This scenario is compounded by extremely plant's ash content. Because the transformation of plant remains limited, formed peat, roughly the humus horizon (Fig. 3).

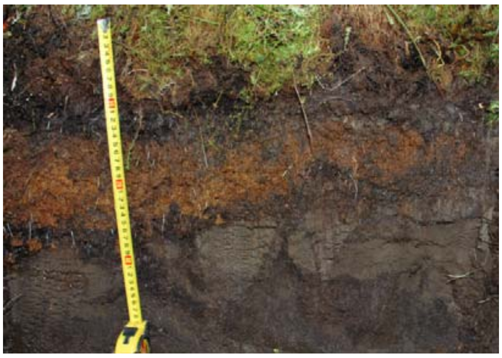

Fig. 3 Formation of peat horizon

The above-mentioned processes form studied landscapes of the northern territories of Western Siberia. Namely triple combination of these processes, which are in various degree of manifestation and generally total domination of this combination over other processes, characterizes the tundra zone. It is connected with the specific climatic conditions (overmoistening, a great influence subzero temperatures, permafrost, geomorphological and lithological structure the West Siberian North.

III. Survey Area

Research area is located in the north of Western Siberia in the range permafrost zone in the central part of the Tazovskiy Peninsula. According to the geographical zoning study area is located on the territory of Nadymskiy District (Tyumen Region, Yamalo-Nenets Autonomous Area), in the west central part of the Tazovskiy Peninsula, within of spread of southern (shrub) tundra. By soil-geographical zoning [8], this area belongs to the North-Siberian (Tazovskiy) province, facies of cold permafrost Gleysol and tundra illuvial-humus Podzols of tundra, polar zone of the Eurasian region (Fig. 4).

Fig. 4 Geographic location

Feature of the study area is mainly in the extreme combination of heat and moisture, the predominance of oligotrophic plants on watersheds with small capacity of the biological cycle. Climatic conditions are quite severe and are caused by the uneven solar radiation throughout the year, the atmospheric circulation of air masses of marine origin. The cyclonic circulation creates a large daily variability in air temperature, a significant frequency of strong winds and not intensive precipitation [9]. However, the climate of the north of Western Siberia more temperate compared to tundra climate in Eastern and Central Siberia.

In accordance with the zonal division of the studied part of the Tazovskiy Peninsula is located in the zone of the subarctic tundra, in the southern tundra subzone [10], [11] and cryogenic conditions here create a special habitat plants. All of tundra landscapes are characterized by specific vegetation composition and originality of its spatial distribution, so the shrub-lichen tundra is the predominant type. Major factors correlating with tundra plants are landforms, temperature, ice content soils, seasonally thawed layer. High degree of heterogeneity of macro- and nanorelief are determined by cryogenic conditions, processes of freezing - thawing, differentiation permafrost landforms this in turn effect on heterogeneity of the soil cover. It is observed that in the study area, thermokarst (Fig. 5) has wide development, which is determined by the presence of icy soil subsidence. Occurrence of thermokarst actively manifested under the influence technogenesis as a result disturbance and destruction of plant cover. All components of the biocenosis and above all the vegetation are very sensitive to these phenomena. As a result, the influence of cryogenic and permafrost on vegetation, conditions are created for waterlogging [5].

Fig. 5 Thermokarst manifestation

It is noted, that frost crack as the most evident cryogenesis manifestation is widespread in the Western Siberia area [5]. Thanks to this process complexly organized pedocryogenic structures are formed. On the surface of cryogenic structures are manifested in a specific microrelief depressions and cracking soil blocks as shown in Fig. 6.

Crack and subsequent filling of cavity soil fractions are cryogenic processes. So there is a moving of humus in the lower horizons, which means the exclusion part of the humus out of biological cycle. Crack humus material is a kind the new «body», which is subjected to zonal factors of weathering and soil formation [12].

Fig. 6 The soil spot

Thus, in Western Siberian tundra due to frost cracking formed specific permafrost soil of cracks and their development is aimed at acquiring zonal image. Cryogenic crack processes greatly complicate morphological organization of the soil profile this is clearly manifested in the soil profile (Fig. 7).

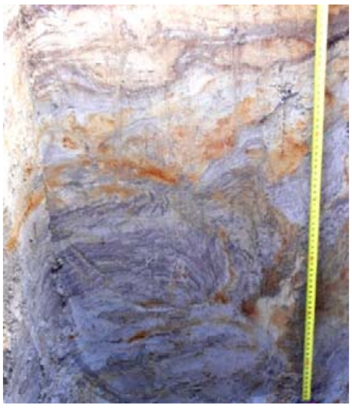

Fig. 7 Cryoturbation

As a result of uneven freezing, thixotropic mass is formed, which may flow out as a rounded spot. In general, cryogenic processes associated with the existence of permafrost, determine the nature of the modern micro-and mesorelief. Noting the role of soil-forming factors in soil formation of this territory, it should be noted that above mentioned factors are inextricably linked with each other, but the main differentiating factor is permafrost.

IV. Characteristics of Soils Formed under the Influence of Cryogenesis

Evolutionarily and genetically tundra soils are regarded as permanently young soil and substrate is often mixed. In this regard, it is difficult to define a typical soil profile, as any profile can be any stage of soil formation. Climatic conditions of tundra determine overmoistening of soils overwhelming part landscapes. In this connection, the soil are widespread in the tundra, experiencing moisture transfer from overlying relief elements and these soils are called "genetically subordinate" or "heteronomous" soil [13].

In cold humid regions, the direction of the processes of transformation and migration of substances, the nature emerging from this product and soil structure of the soil profile depends on how excessive atmospheric moisture in the soil mass is realized. For watershed areas considered territory of Tazovskiy peninsula there are two principally different groups of soils (gleyed and nongleyed soils), depending on the nature of the internal drainage of the soil profile.

Gleysols are shown in Figs. 8 (a) and (b) are predominant in the investigated territory. Mostly these soils are formed on loamy-clay and and layered sand and sandy-loam rocks, in which excessive atmospheric moisture realized in sustainable overmoistening and gleying whole soil profile or a significant part of its [14].

(a) (b)

Fig. 8 Cryogenically Ferruginizated Gleysols (a) and Peaty Gleysols (b)

In this area with shallow thawed permafrost, the presence of permafrost confining layer in the soil layer often increases the overmoistening and gleying. Gleying and overmoistening can cover the whole soil profile or part of it, but in these two cases these processes are prolonged and stable and they are carried out throughout most of the warm period. As a result, brightly colored in blue-gray tone gley horizon is formed, which above and below usually has dramatically contrasting ocher border as a result of the cryogenic differentiation of the soil mass. Also distinctive features of this group of soil are viscous consistency, often fluid condition and thixotropy of overmoistening horizons.

In soils with free internal drainage excess atmospheric moisture is not realized in a sustainable overmoistening profile. Climate-caused annual or seasonal excess moisture from the soil layer is discharged. It is primarily associated with water-physical properties of loose strata, permafrost regime and with the possibility of rainfall runoff (soils are well dissected watersheds in homogeneous sandy-loamy rocks in deep permafrost horizon location or in the presence of dry permafrost in the soil) [13].

Leaching regime and free migration of all mobile connections within the profile and outside are typical for nongleyed soils with free internal drainage. Formation of the soil profile occurs under the domination of oxidizing conditions during most of the warm season; however, seasonal overmoistening and gleying some horizons of the soil layer is manifested, but in general, these processes are short duration and unstable within the profile [15]. These soils are characterized by morphologically and analytically expressed illuvial accumulation of aluminum-iron-humus compounds forming specific chemogenic Al-Fe-humus horizon of brown or ocher-brown tones.

Podzols is shown in Fig. 9, belong to this group of soils are widespread in the study area. Soils having a spodic horizon (a dark coloured subsurface horizon with illuvial amorphous alumino-organic substances). Colouring horizon depends on the ratio of organic substances and iron oxides. In areas of the territory, composed of sand deposits under leaching moisture regime podzolization process is manifested. This process is rather weakly manifested due to weak engagement in the biological cycles of chemical elements, located in the primary minerals, despite the morphologically distinct manifestation.

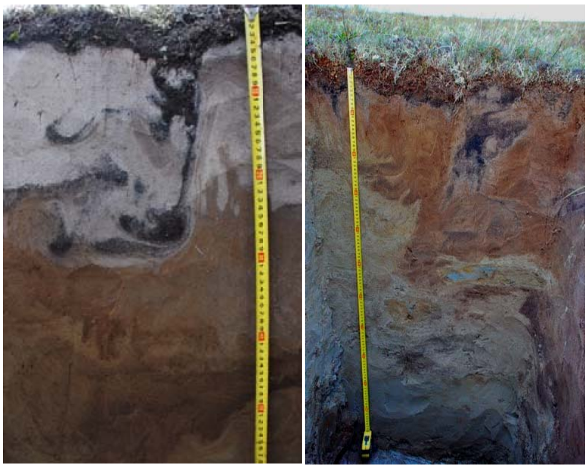

Fig. 9 Soils with illuvial accumulation of aluminum-iron-humus compounds

V. Conclusion

In conclusion, it is important to emphasize that the permafrost is a complex natural phenomenon which requires further scientific justification study. Complex of climatic conditions, especially the impact of permafrost becomes very significant factor in soil formation. Formed permafrost features such as frost crack, cryoturbation, thixotropy, movement of humus. Effect of permafrost determines manifestation of the specificity of podzolization, pedocryogenesis, gleying and identifies a variety of soils of this area. Cryogenesis determines the manifestation of such phenomena as the reaggregation of mineral mass, easing of podzolization and radial transport of bio- and pedogenesis products, staining of the soil profile by organic matter to a considerable depth due to the high mobility and lateral migration.

Under slow evolutionary development of cryogenic processes the impact of permafrost leads to the formation of specific permafrost soils and degradation causes a change in soil cover. It is noted dominance gleysols under hydromorphic conditions and soils with morphologically and analytically expressed illuvial accumulation of aluminum-iron-humus compounds under conditions of free surface and subsurface drainage on sandy rocks. In this way it controls the biological productivity of landscapes and determines the ability to use soil. Undoubtedly, a proper understanding of the issues in the tundra soil requires a comprehensive coverage of the soil processes diversity that lead to the formation of certain soil types and varieties.

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