Ratios and ranges of soil-forming factors influence on pedogenesis

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Abstract
The issue of ratios and ranges of soil-forming factors influence on pedogenesis was discussed during the whole history of genetic soil science. Most of opinions were that all soil-forming factors are, in effect, of the same importance and take equal part in soil formation. At the same time, any of factors could become leading one in the development of soils under certain situations limited in time and/or space. Different bioclimatogenic, lithogenic, volcanogenic, palaeohydrogenic and other macrostructures of soil cover were described. An attempt was made to formulate the ratios and ranges of soil-forming factors influence on pedogenesis in the form of laws. There were shown numerous situations when, along with relief, other factors, such as hydromorphism, parent materials, etc., acquire prime importance in the catenary differentiation of soil cover. Three cycles of soil development in time (biological, biogeomorphologic and bioclimatic) were described. The alternation of evolutionary phases of convergence and divergence between the components of soil cover caused by the domination of lithogenic, biogenic, topogenic or climatogenic factor was revealed. It is possible to assert rather reasonably that there are certain ratios between factors in terms of their influence on different aspects of a soil-forming process: energy; substantive; and process-dynamic.

Key words
Soil zonality, soil catenas, soil evolution.

Introduction

The issue of ratios and ranges of soil-forming factors influence on pedogenesis was discussed during the whole history of genetic soil science. Sometimes it was put in the form of a special theoretical problem, but more often it arose as an adjacent problem during soil geography studies or while making soil maps and determining soil classifications. There is an established opinion that Dokuchaev considered climate to be a leading factor of soil formation. This is inconsistent with the fact that, Dokuchaev constantly underlined that «all soil-forming factors are, in effect, of the same importance and take equal part in formation of a normal soil» (1889). This approach was an essential part of the Dokuchaev's paradigm. On the other hand, in his works Dokuchaev spoke about predominance of this or that soil-forming factor at different levels of soil cover organization. For example, he considered horizontal and vertical zonality of soils to be a result of global or regional bioclimatic zonality (Dokuchaev 1899), but he also paid attention to «topography of soils» meaning that local features of soil cover depend on the morphological variability of terrain. Nevertheless, there were attempts in soil science to identify leading factor of soil formation, namely climate (Sibirtsev 1951, Hilgard 1892, Coffey 1912), biota (Viliams 1949), parent materials (Lyon *et al*. 1915; Shaw 1930), and to insist on its universal predominance, i.e. the «leadership» of this factor under all conditions and at all stages of soil formation process. It is obvious that such point of view contradicts both the essence of the genetic concept of soil-forming factors, and the actual regularities of soil distribution and evolution of soils on the Earth's surface. At the same time, any of soil-forming factors could really become leading one in the development of soils and soil cover under certain situations limited in time and/or space.

Results and Conclusion

The factors limiting the development of soils

The limiting role of soil-forming factors can be found in various classifications of soils. For example, climatic (arctic, desert) and non-climatic (eroded, alluvial) imperfectly developed soils with (A)C or AC profiles are identified in the French classification system which is based on an evolution-genetic principle (Duchaufour 1965). Their immaturity is the result of climatic features, erosion processes or intensive accumulation of deposits. In this case the soil-forming potential of other factors, for example, rocks, remains unrealized.

The concept of "zonal soils" dominating in the Russian soil science for a long time understood them as soils which are formed on flat surfaces built of moderately water-permeable sediments (loams) without any

specific chemical or mineralogical features, without influence of ground waters, in the absence of both washing-off and deposition. According to this concept zonal soils reflect a certain balance of soil-forming factors which means that the difference between soils is only due to climatic features. The soils which do not meet the above-mentioned conditions, are not "zonal", therefore they have been classified as biolithogenic, biohydrogenic and biohalogenic. Later Liverovskii (1987) formulated the law of plurality of zonal soils according to which a variety of combinations of bioclimatic factors with lithological and historic-genetic factors results in the occurrence of several zonal types of soils within the same soil zone.

In the modern US Soil Taxonomy the presence of less developed diagnostic horizons (histic, cambic, ochric) and the absence of well developed ones (argillic, oxic, etc.) in soils are considered to be the result of the limiting influence of climatic (Aridisols), lithological or chronological factors (Inceptisols, Entisols). Within these orders relatively more developed soils occur at the levels of suborders and soil great groups reflecting the total results of the "opposition" of this or that soil-forming factor to the principal factor limiting soil development.

Domination of factors in the organization of soil cover
Ratios and ranges of soil-forming factors influence on pedogenesis can be revealed through the analysis of soil cover pattern at different levels of its organization. Birkeland (1974) collected and compared the materials on vegetation-soil, topography-soil and climate-soil relationships influencing on soil cover organization. The influences were ranged in terms of scale: from variation in soil with distance from trees and with tree species to regional soil trends related to climate.

It is a catenary approach to the analysis of soil formation phenomena that makes it possible to demonstrate the role of relief in the formation of soil cover and its structure. The works of Milne (1935), Bushnell (1942), Polynov (1953) and others describe diverse lateral genetic relations between soils, stemming from the leading role of geomorphologic factor. Classification of soil catenas by Kasimov and Perelman (1992) shows numerous situations when, along with relief, other factors, such as hydromorphism, lithogenic base etc., acquire prime importance in the catenary differentiation of soil cover.

Fridland (1986) has found out that there are several genetic types of climatic zonality of soil cover and the transition of one zone into another is governed by the change of this or that climatic parameter. He distinguished zonality of soils caused by thermal factor changes for a) the areas with high humidification and b) the extremely arid areas. Zonality based on the changes of climatic humidification was distinguished for the situations when a) the spatial trends of humidification coincide with the changes of thermal conditions, and b) the spatial trends of humidification differ markedly from those of thermal conditions. Each of these types of zonality manifests itself in specific forms on the Earth's surface.

Bockheim (2005) elucidated the concept of soil endemism and ranged soils according to degree of their "uniqueness" and distinguishing soil-forming factors such as unusual parent materials (volcanic ash, smectitic clays, paralithic contacts), extreme soil climate conditions (aridic soil moisture regime), specific local topography (closed depressions), etc. Sokolov (2004) made an attempt to formulate different ratios and ranges of soil-forming factors influence on pedogenesis in the form of laws. He introduced the law of maximum lithogenic divergence of soil formation under humid climatic conditions and the law of maximum topogenic divergence of soil formation under arid ones. In the first case (under humid climate) soil-forming processes differ on different parent rocks whereas the soils of various geomorphologic positions (autonomous and heteronomous) are quite similar in soil-forming processes. In the second case (under arid climate) the variety of soils and contrasts in the soil cover are caused by relief features. Autonomous and heteronomous soils usually differ in water regime and, consequently, in the type of soil formation.

Domination of factors in the evolution of soils
Ratios and ranges of soil-forming factors influence on pedogenesis can be revealed through studying the evolution of soils. Rozov (1956) suggested three cycles of soil development in time, i.e. biological, biogeomorphologic and bioclimatic. This means that under the invariance of other factors the balance between soil and the environment could be destabilized by changes of either biota, or relief, or climate. Similarly, any factor could become a driving force of evolution not only for particular soils, but also the multicomponent structure of the soil cover. Thereupon a principle of "stages discrepancy of co-evolving elements of soil combinations" has been suggested (Gennadiyev 2001). The stages discrepancy means

alternation of evolutionary phases of convergence and divergence between the components of soil cover, and it could be biogenic, lithogenic, topogenic and climatic according to the leading factor of soil evolution.

As geographers-soil scientists pointed out over and over again, the results of soil formation in various bioclimatic and topolithological conditions could be correctly interpreted only if soils of rather similar absolute age are considered. Thereupon a concept of «time correction of soil-forming potential of the environment» was suggested (Gennadiyev 2001). It postulates that it is expedient to find and compare soils of the same age in order to evaluate the role of climate, biota, rocks and relief in the evolution of soils. It is this approach that makes it possible to avoid erroneous attributing to these soil-forming factors the influence which actually relates to the duration of soil formation. The results obtained on the basis of this approach were used for a hypothetical modeling of two isochronous soil cover patterns formed within the modern and Late Holocene stages of pedogenesis (about the last 1000 and 3000 years, respectively) in the Russian Plain and the Great Plains of North America.

Contribution of factors to the components of soil-forming process.
It is possible to assert rather reasonably that there are certain ratios between factors in terms of their influence on different aspects of a soil-forming process: energy; substantive; and process-dynamic. The general scheme illustrates differentiated contribution of various factors to the energy, material base and dynamics of soil formation (Figure 1).

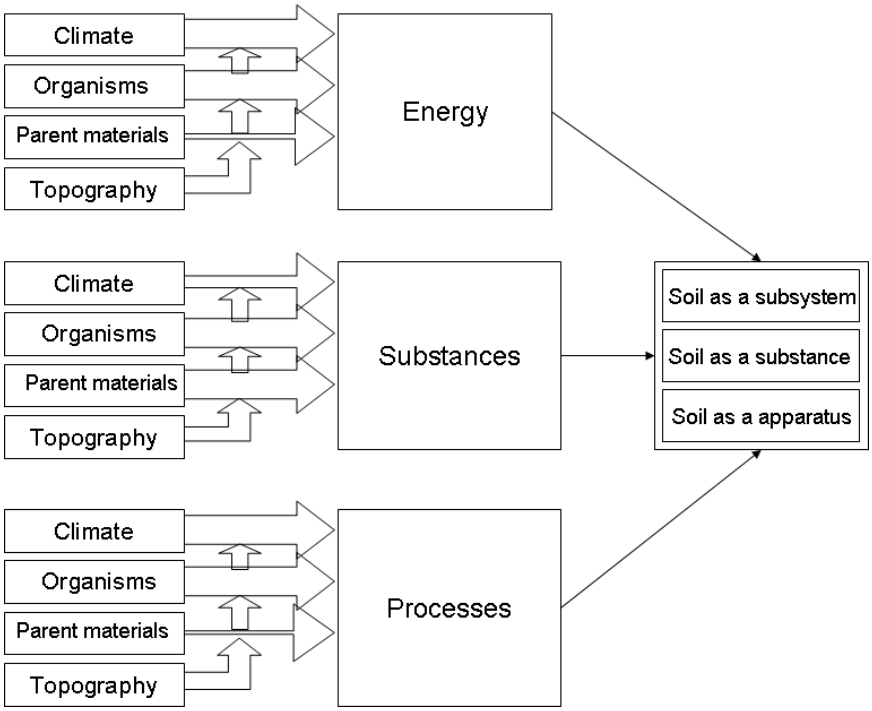

Figure 1. The general scheme of soil formation: contribution of factors to the components of soil-forming process.

The most powerful energy source of soil formation is solar radiation which is a main component of climatic factor. Coming as direct flows on the Earth's surface, it is transformed into thermal and other kinds of energy. The solar energy is mainly spent for the processes of heat and water exchange in the system of "soil-vegetation-atmosphere". Considerable input of energy into soil occurs during dying off of organisms, especially plants which contain solar energy bounded through photosynthesis. The energy contribution of the geological factor results, mainly, from the gravitational influence on soil and, accordingly, on the processes of radial and lateral migration of soil matter. Energy which comes to soil from the deep layers of the lithosphere, or as a result of disintegration of radioactive elements, is insignificantly small. Thus, there are certain ratios between the amounts of energy delivered into soils by climatic, biological and geological factors. The geomorphologic factor provides no direct energy contribution; it just supports energy redistribution over the surface of soil cover.

The material base of soil formation appears mainly due to two factors - geological and biological. Rocks deliver various mineral components which during each given moment of time usually account for more than 90% of the total soil mass. Organic compounds account for a smaller part of soil mass; however in the course of time the cycles of biomass production and decomposition considerably increase total participation of organic substances in the interaction with the substances of geological origin (which form rather inert mineral part of soils). The contribution of climatic factor to the material base of soil formation is the enrichment of soil with atmospheric water, air and dust. The influence of relief in this aspect is only the redistribution of material soil components.

The contribution of factors to soil-forming processes is also rather differentiated. Needless to say, both energy and substantive contributions of factors influence the dynamic phenomena in soils. However in this case we mean the direct transfer of those mechanisms of functioning which are inherent in the factors of soil formation. So, rocks and relief are generally rather inert as functioning systems. On the contrary, the biological factor is very variable. The most universal mechanism of soil formation, related to the functioning of biota, is the biological cycle, first of all in the system of soil-living plants-litter-soil. The climatic factor of soil formation is no less dynamic than the biological one. Water, thermal and air regimes of soils (which are also fundamental mechanisms of soil formation) are interrelated with water, air and heat exchange cycles between the atmosphere and soil. Cyclic and reversible dynamic phenomena in soils are soil microprocesses. They naturally fit four groups: 1) an exchange of matter and energy between soil and other natural bodies; 2) transformations of matter and energy within soil; 3) changes of substance consistence in soil; 4) movement of matter and energy in soil. Certain combinations of simultaneously occurring soil microprocesses are characterized by incompleteness of their cycles and the accumulation of residual effects. This does result in the elementary soil-forming macroprocesses, or specific soil-forming macroprocesses (Rode, 1984) which lead to the evolutionary changes of soils. All three aspects of the notion of "soil" (soil as a substance, as a set of dynamic phenomena, i.e. a functioning apparatus, and as a part of a system) and their relation to the substantive, functional and energy aspects of soil formation are shown at Figure 1.

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