

The Origin and Geography of Brown Forest Soils

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Abstract: Brown soils, Brown forest soils, Burozems or Cambisols have been studied for more than 100 years, and to this day, their nature, origin and process organization remain controversial. In addition, issues of their geography are quite controversial, especially in such a large country as Russia. A brief review of the literature on the morphological diversity features of the genesis and origin of brown soils in the various geographical locations of Eurasia is given. It was shown that the genesis of brown soils is not as closely related to the type of forest vegetation as previously thought, although, at the same time, the vast majority of brown soils are forest soils. Depending on the geographic situation and local climatic and geogenic conditions, Brown forest soils have related subtypes among adjacent soil types in different natural zones. Thus, in the polar zone, they are close to Entic Podzols, in the subtropics to Cinamonic soil, and in the forest-steppe, they replace zonal Retisols in positions with a relatively less contrasting and even climate. Being to a certain extent intrazonal soils, brown soils are combined with other more intrazonal soils—Rendzinas—and form the so-called Burozem-Rendzinas on uplands, composed of carbonate rocks in various natural zones. The article is illustrated with original photographs of Brown forest soils from various natural zones, taken by the author during numerous expeditions. It has been established that Burozems combine the characteristics of intrazonal soil, which is inherent in all natural zones, and have elements of zonal soils, as well as adjacent intrazonal soils in invariant combinations of soil-forming factors. From this, two conclusions can follow about their further classification fate: a more thorough justification for an independent soil type or a classification of structural metamorphism and in situ transformation of minerals among various existing zonal soil types.



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1. Introduction

Brown forest soils (Russian—Burozems), which have a nearest analogue in Western soil taxonomies as Cambisols, are a rather complex group of soils, very diverse and heterogeneous. This name of the soils, since their discovery by Ramman in 1905 [1], was applied and used very widely; often, the soils most different in genesis and morphology were referred to as brown soils. The largest review of the problem of Brown forest soils formation was previously published by Tavernier et al. [2]. The authors of this review emphasized that the terminology of this soil type is extremely diverse. They wrote: “the names “Braunerde” or “Brown Forest soils” have, during the past fifty years, been defined and used quite differently by various authors. Because the same names have been used for unlike soils the literature is confusing, and the results of experience reported have been misinterpreted. . .” Probably, not much has changed since then; in any case, the application of the said name is quite variable, especially after the introduction of the term Cambisol, derived from the Italian word “cambiare”—to change. Cambisols are known as one of the key reference soil groups in WRB soil taxonomy [3] with the following key types of soil horizon sequences: Ah-Bw-C, Oi-Oe-Ah-Bw-C, and Ah-Bwφ-C. M.I. Gerasimova et al. [4] analyzed extensive

cartographic material concerning Brown forest soils in Russia and pointed out that these soils are distributed in various climatic zones of Eurasia, and the term Cambisol correlates well with the Russian term “Burozem”. In both cases there is in situ weathering and formation of a pronounced pedogenic structure in the B horizon, which according to WRB is designated as Bw, and in Russia, as BM (or Bm; the metamorphosis feature of the B horizon was denoted by a lowercase letter “m” in the Soviet classification) [3,5,6]. A characteristic feature of the Brown soil formation process is in situ weathering and formation of a pronounced pedogenic structure in the B horizon. The reason for intensive in situ weathering in horizon B may be constant moderate moistening of the middle part of the profile; weathering is expressed in the accumulation of fine particles and secondary iron hydroxides.

Soil maps of Russia (and USSR), besides Burozems, include many adjacent types of soils; with this connection, soil-mapping information is currently being updated [7], which in turn leads to rethinking of diagnostic features, practice of implementation of features and verifiers and to the reassessment of areas occupied by either “real” Burozems, soils with signs of Burozem formation or adjacent types of soils, where structural metamorphism in the B horizon is observed. At the same time, the profile organization of soils’ metamorphic horizon BM in Russian soil taxonomy has more diagnostic features than in the interpretation of the cambic horizon in the WRB system [8]. Since the classification of Burozems is widely considered in the works cited above, we will not dwell on these issues. The purpose of this work is to consider some types of climatogenic and lithogenic Burozems of Russia. Numerous works on these soils are quite scattered and varied in the approaches used to classify soils. Therefore, we made an attempt to summarize the existing published and in-house information on brown soils, predominantly in Eurasia. The main question is whether they obey zonality or whether soil metamorphism is a completely intrazonal feature.

2. Materials and Methods

The materials of investigation and data on Brown forest soils of various parts of Russia were published. Data have been processed in terms of the unity and differences of the soil formation process in various combinations of bioclimatic and geogenic conditions. Special attention was paid to the content and quality of organic matter in connection with the problem of metamorphosis of the soil mass of the middle horizon. Our own research concerned the Izhora Upland (Leningrad Region, Russia), the Zhiguli Mountains (Samara Region, Russia), the Chatyr-Dag plateau and Cape Martian (Republic of Crimea), Polar Urals (Yamalo-Nenets Autonomous district, Russia), Vitim Plateau (Zabaykalsky Krai, rep. Buryatia, Russia) and Central and Northern Caucasus (Russia). In this study, we concentrated on soil morphology, horizon naming and sequences of Brown forest soils. Soil chemical and physical properties will be discussed later in a separate paper.

Literature sources for the mini review were searched in MDPI, ScienceDirect, Google Scholar and eLibrary databases of scientific articles. The search query was composed as follows: (“Soil Science”) AND (“Soil”) AND (“Brown forest soils” OR “Cambisols” OR “Burozems”) AND (“Origin” OR “Geography”) AND (“Soil Taxonomy”) AND (“Genesis”). Research articles and review articles were used for the analyses. Articles were searched in the time interval from 1996 to 2024. Also, we have cited older sources, which are classical in terms of soils discussed in this paper. Limitations of the research are related to the small amount of literature on this subject, as well as the fact that these soils receive little attention in soil-geographical and soil-morphological studies due to their transit zonal-intrazonal nature. Another limitation of the study is the limited availability of field photographic materials for this soil type.

3. Results and Discussion

Organic matter plays a huge role in soil formation and in the functioning of the biosphere as a whole. It is well known that organic matter accumulation depends on

pedogenic soil differentiation [9–11]. Moreover, the type of soil organic profile significantly affects the vertical horizontal organization of soils, according to V.V. Ponomareva [10]; humus formation is in many respects synonymous or even equal to soil formation in functional and pedogenetic senses. Of course, the biogenic soil profile is superimposed on lithogenic and topographic conditions, but still, the driving force of pedogenesis is accumulation and redistribution of soil organic matter. Soil organic matter is substituted according to the rule of Dokuchaev soil zonality [12] and in terms of the biotermodynamical rule of humus formation, elaborated by D.S. Orlov [13]. Thus, there is direct evidence that the type of organic profile directly determines soil formation at the typical level. In this regard, the question arises as to what is the specificity of certain types of soils in relation to the type of their organoprofile. Burozem is known as a soil of complicated genesis with features of zonal differentiation, lithogenic conditionality, local vegetation and climatic specificity [14]. V.V. Ponomareva found that soil formation is largely synonymous with humus formation, in the sense that the soil organoprofile intensively determines the horizon organization of soils of a zonal series [15]. Thus, the organoprofile of Brown forest soils is specific in comparison with other forest soils of the subboreal climatic belt, in particular, gray forest soils. In the metamorphic horizon, there is accumulation of the fulvic acid fraction of humus reacting with products of in situ weathering of fine earth. It has been established that fine particles of Brown forest soils intensively accumulate fulvic acids [15]. This is a crucial difference of Brown forest soils from Retisols, where the maximum fulvic acid accumulation is pronounced in eluvial horizons. Brown forest soils of some islands of the Pacific ocean demonstrate some illuviation of humus in a specific horizon BM_{hi}, where the symbol “hi” designates this illuviation process. Illuviation is not a consequence of podzolization as it does not develop in oak forests of the Russian Far East [16]. At the same time, this horizon does not permit change in the soil type or soil subtype. This is a kind of genera of illuviated brown soils. The composition of humus of Brown forest soils and its nitrogen enrichment strongly depends on the forest type, so, when broad-leaved forests are replaced by coniferous forests in the Kaliningrad region, the nitrogen content in soils sharply decreases and the morphology of the forest floor changes—mull humus becomes the major type [17].

Brown forest soils are spread on the uplands of the center of the East European Plain, in particular, in the Zhiguli Mountains (Samarskaya Luka peninsula, Middle Volga region) (Figure 1). Here, as a rule, they do not represent an extended area of soils but are distributed fragmentarily on the most humid slopes of mountain massifs. On the Zhigulevskiy ridges, these are slopes of mountains of northern exposition facing the Volga River and the Saratov water reservoir; here, water bodies have a warming and moistening effect. On the mountain slopes of eastern and western exposition, gray forest soils take the place of brown forest soils, while the southern slope is gentle and gradually passes into the zone of forest-steppe Chernozems [18]. Brown forest soil may be in spatial conjunction with gray forest soils—Umbric Retisols of the forest-steppe zone [19]. The key difference between these soils is the presence of eluviation and fine particle redistribution within the soil profile in gray forest soils. Brown forest soil does not exhibit such a differentiation and has in situ weathering of the mineral part in the middle part of the soil profile.

Brown forest soils have been described in the Leningrad region and even been incorporated into the Red Soil Data Book of the Leningrad Region [20]. Soils of this type are presented as a podzolised version and as a dark-humus (umbric) version, and this differentiation deals with composition of the parent material. Thus, Brown forest soils with features of podzolisation or leaching of clay particles are formed on acid glacial morains or local debris of gabbro weathering. These parent materials are typical for zonal soils of the Russian northwest. At the same time, there are geochemically different landscapes composed by carbonate parent materials. Here, the mull dark-humus Brown forest soil formed on carbonate-containing loams of the Ordovician plateau (here, they are intrazonal soils). The superficial horizon of such soil is designated by the symbol AU, according to Russian soil taxonomy [5]. These dark-humus brown soils are geochemically and genetically related

to Rendzic Leptosols and, normally, represent a subsequent stage of soil weathering and parent material alteration in the humid south taiga climate of the Baltic region. Another soil type, well-known in the Russian northwest, is so-called Eluvial-metamorphic soils described by N. Matynan [21,22]. These soils combine both processes of eluvial differentiation and further intensive weathering of illuviated material, thus, B horizon becomes not BT (clay illuviated) but BM (structural-metamorphic). These soils are separated as a special type in the current Russian soil taxonomy [5]. A prototype of such soils was written by Otowa in 1977. Metamorphism in this case does not contradict clay accumulation [23]. In addition, the podsolization in the A2-like horizon has been referred to as a possible morphological feature of Brown forest soils [24]. Nowadays, this horizon is designated as E or EL.

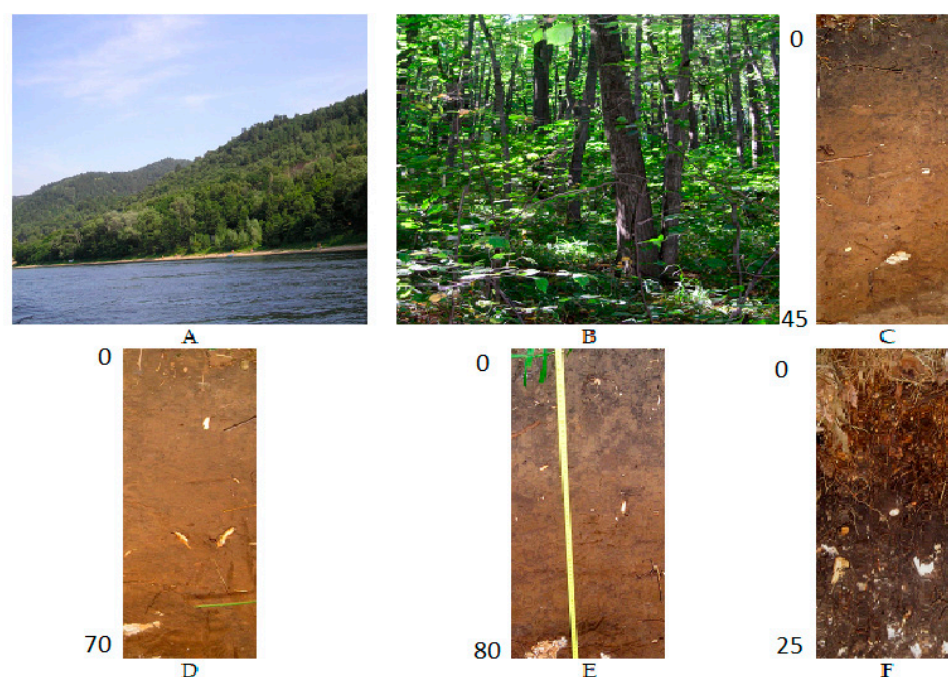


Figure 1. Burozems of the Zhiguly Mountains. (A)—northern slopes of the Zhiguly Mountains occupied by Burozems and Burozem-Rendzinas. (B)—linden and maple oak forests of the northern slopes of the Zhiguly Mountains. (C)—dark Burozem on slope deluviums. (D)—light Burozem on ravine-valley loamy sediments. (E)—dark Burozem on slope deluvium. (F)—Burozem-Rendzinas on limestone eluvium.

The Brown forest soils of Japan and the Russian Far East are climatogenic ones (Figure 2). This means that the key force of structural metamorphism here is a wet climate with a warm and humid winter. These soils are described in detail for Japan by Hirari [25]. This book describes the diversity, chemistry and mineralogy of Japanese brown soil in detail, with emphasis even on differences between brown soils of different prefectures. It seems that the Japanese soil cover consists of up to 70% of Brown forest soils of various subtypes [26], some of them closely related to Andosols or formed in volcanogenic substrates [25]. Dark-humus Brown forest soils are described also for oak forests of the islands of the Russian Far East as a climatogenic Brown forest type [27].

It was shown above that brown soils of different natural zones have different “neighbors” in the form of zonal soils. On the other hand, in each natural zone, zonal soil “transforms” into metamorphosed Burozems. Thus, in south taiga, zonal Podzols are dealt with as podzolised brown soils of dark-humus brown soils. In the forest-steppe zone, Gray forest soil is neighbored to Brown forest soils. The same is true for the subtropical part of the Crimean peninsula, where brown forest soils merge their polypedones with Cinamonic soils. Thus, an important conceptual question arises—whether Brown forest soils are in-

trazonal because they are present in different versions in all natural zones, except for the tropics. Other intrazonal soils—Rendzinas and alluvial soils—also have their specificity in different natural zones. Thus, any zonal soil formation in the case of high humidity and a warm (but not dry and hot) climate can change into brown soils or soils with initial signs of metamorphization.

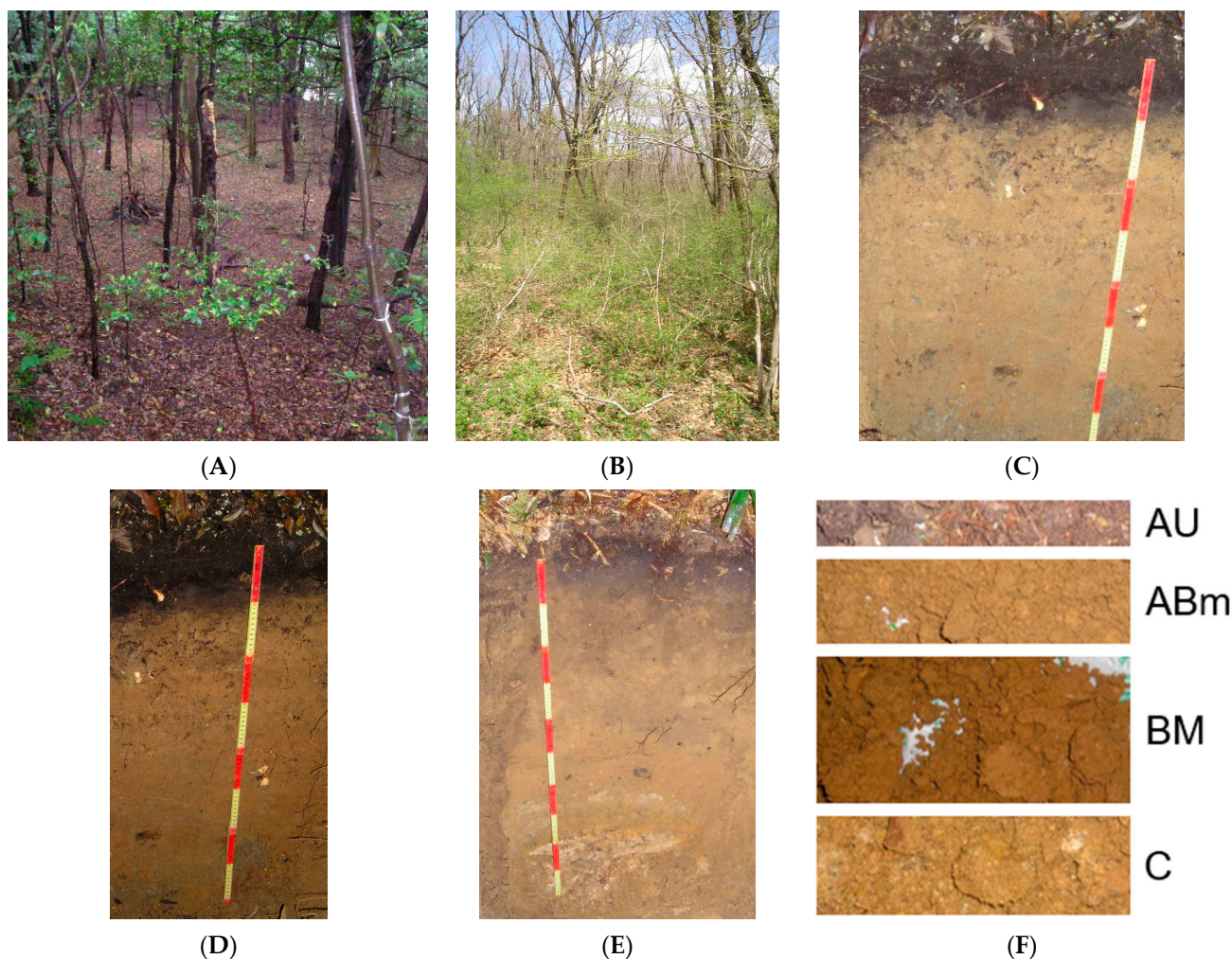


Figure 2. Brown soils of central Japan. (A)—oak forest (*Quercus salicina* + *Quercus myrsinifolia*). (B)—beech forest (*Fagus mongolica*). (C)—dark podzolized Brown earth on slope deluviums. (D)—dark brown soils on slope deluviums. (E)—dark brown soil on shale eluvium. (F)—horizons of previous brown soil (Figure 2E).

Mediterranean soils frequently contain some feature of deep and intensive weathering expressed in a brownish or reddish color. Such examples of soils are classified as brown or Cinamonic soils with terra-rossa (“red earth”) and terra-fusca (“orange earth”) in the middle part of the soil profile. This is a subtropical version of metamorphic soils, which combine signs of soil metamorphism in the presence of carbonates in the lower horizon, characteristic of Cinamonic soils. In the Russian classification, brown and Cinamoninc soil types belong to the same division—structural-metamorphic soils. An example of such a profile is given in Figure 3. In fact, here, soil formation is superimposed on a substrate of weathering crust, and this weathering takes place for such a long time that the limestone material of the Crimean Mountains is almost completely replaced by red-colored or loose material consisting of iron and other metallic oxides. In more northern areas, this process is less pronounced and manifests itself in the infiltration of calcareous eluvium with clay

material of soil origin or iron oxides. These are Burozem-Rendzinas, which the Leningrad region is known for [28].

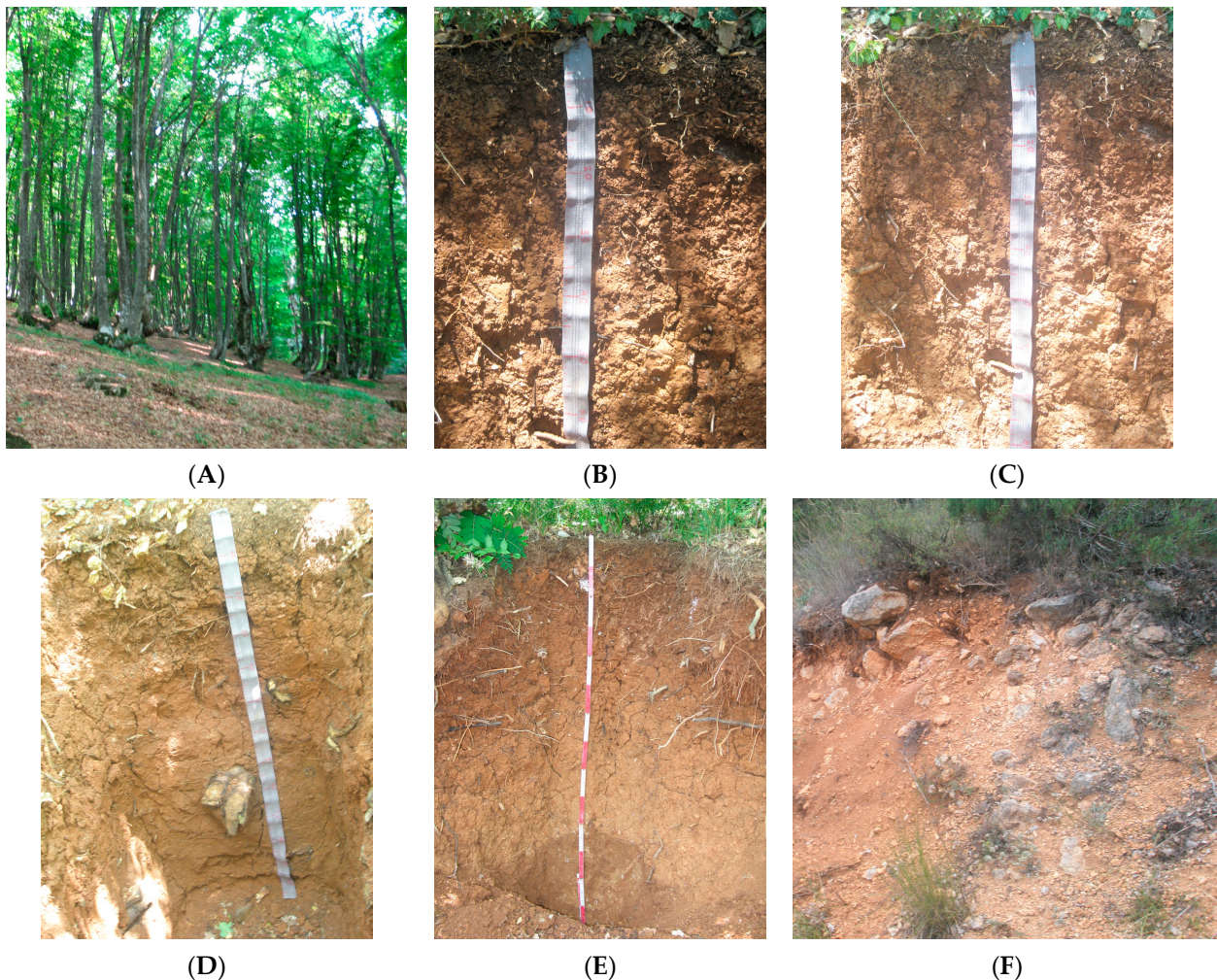


Figure 3. Brown and Cinamonic soils of the Crimea. (A)—beech forest (*Fagus sylvatica*), Aipetrinskaya yaila. (B)—light-colored brown soils, Aipetrinskaya yaila. (C)—dark brown soil, Cape Martyan reserve, South coastal Crimea. (D)—light brown soils, Cape Martyan reserve, South coastal Crimea. (E)—Cinamonic red-colored soil, Cape Martyan reserve, South coastal Crimea. (F)—eluvium of limestone “terra rossa”, Cape Martyan Reserve, South Coastal Coast, xerophytic sparse subtropical forests.

In the periglacial environments of the North Caucasus, Brown forest soils are located in acer communities or fagus forests (Figure 4). The most typical vegetation of brown soil polypedones in the republic of North Osetia are forests composed by *Acer trautvetteri* with rhododendron brush cover and *Vaccinium vitis-idaea* and *Vaccinium oxycoccos*. *Acer* is representative of subboreal flora. It grows in the mountains at altitudes of 1800–2500 m, adjacent to the zone of rhododendron shrubs, mountain ash and birch forests [29]. Maple forests are highly herbaceous; it is noteworthy that in them, as well as in dark coniferous forests of the south of Western Siberia, there are thickets of aconite. The presence of rhododendron plants is also characteristic of Brown forest soils of the Vitim Plateau (republic of Buryatia, south of Eastern Siberia) [30]. Representatives of the *Vaccinium* species are remnants of relic mountain periglacial floras, which still exist in cold and temperate regions of the Central and North Caucasus [31]. Further eastward along the North Caucasus towards Kabardino-Balkaria and Adygea and further to the Krasnodar region, along the mountain massifs, the forest vegetation changes from maples to beeches, lime trees and oak trees.

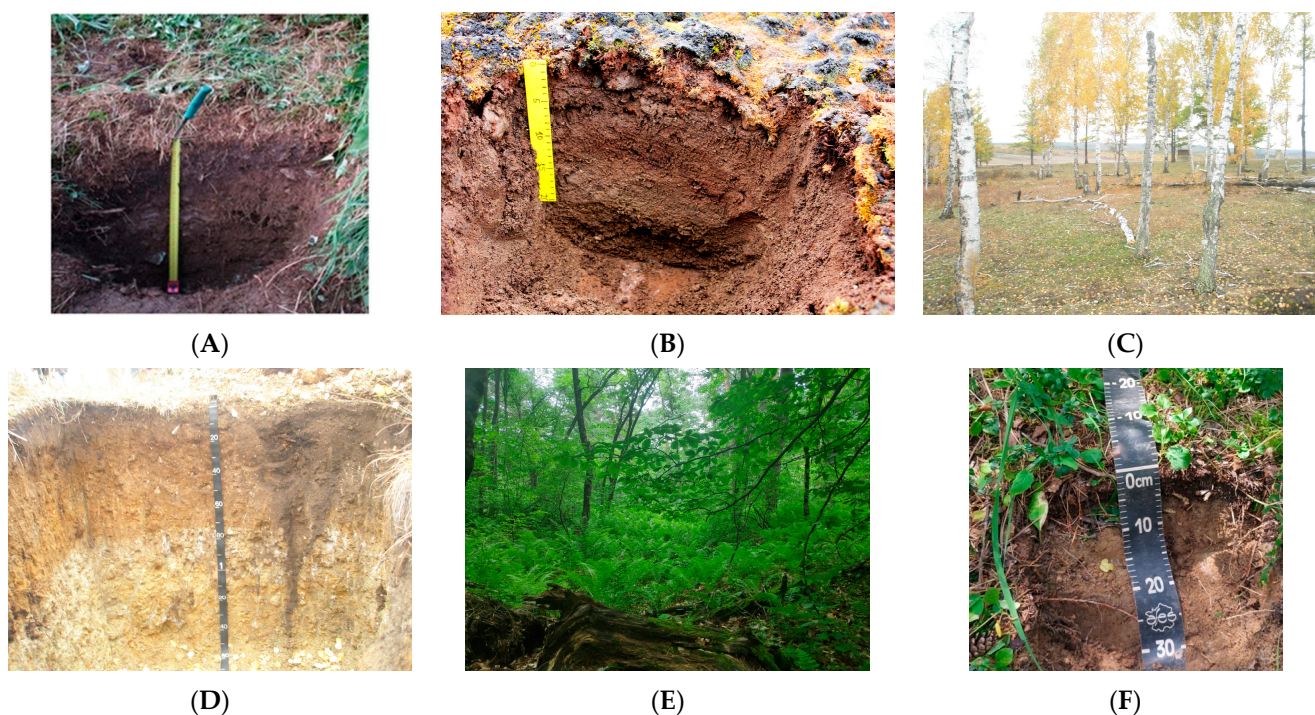


Figure 4. Burozems of cryogenic and polar ecosystems. (A)—mountain Burozem, Polar Urals. (B)—Burozem, subantarctic, King George Island. (C)—sparse stands of taiga forest, Vitimskoe Plateau, Buryatiya, Russia. (D)—Burozem, cryogenic-turbated with fractured permafrost, Vitimskoe Plateau, Buryatiya, Russia. (E)—Trautfetter’s maple forest with high grass stand, Tseyskoye Gorge, North Ossetia. (F)—Burozem in mountain valley, Tseyskoye Gorge, North Ossetia.

The glacial zone disappears and is replaced first by snowfields and then by alpine and subalpine zones. Thus, the connection of Brown forest soil formation with the glacial climate weakens as one moves from North Ossetia to the Black Sea coast of the Caucasus. Thus, in the polar climate of southern Eurasia, we are probably talking about a partly relict origin of brown soils and partly of the corresponding vegetation, mixed subpolar—boreal—subboreal vegetation. The Cambisols could also be found in polar environments, both of the Arctic and Antarctic. Examples of these soils in the Polar Ural mountains (Figure 4) and subantarctic King George Island (Figure 4) are weak developed solums with Bm or Bw horizons of deep weathering of mineral parts. These soils are neighboring to Cryosols and Entic Podzols in landscapes [32]. They are only found in humid polar climates and on Mount Olav in West Svalbard [33]. These soils are not noted for arid and semiarid climates. Thus, brown soils, which are not always forest soils but are always Cambisols, are elements of gradational climatic ecotones both within the natural zone and within the limits of macrogeographical soil zonation. At the same time, in a number of zonal polyhedons of the Polar Urals, which are representative of podzol series, brown soils are represented by local inclusions associated with local combinations of soil formation factors [32]. In subantarctic landscapes, these soils are very typical for some spots of King George Island, e.g., surrounding the Arctowski Polish Antarctic Station [34]. Thus, brown soils are intrazonal, and it is necessary to remove the term “forest” from their name, although in the overwhelming number of cases, they are spatially connected with forest communities of different types. Rather, their intrazonality is related to the specificity of the soil climate, annual precipitation and temperature. At the same time, vegetation can be coniferous, small-leaved and broad-leaved, and even non-vascular, as it happens, in particular, in Antarctica.

Brown soils of the Vitimskoye Plateau in Zabaykalsky Krai, Republic of Buryatia, are cryogenic-tubed and cryogenic-cracked [30]. This is another example of a combination

of two types of profile-forming processes in one, which is often characteristic of the cryolithozone. These soils combine signs of weathering in the BM horizon and deep cracks that repeat after a certain period within one pedon. This affects the distribution of humus at the micro level, the values of its radiocarbon age and key chemical properties. Thus, if in the case of the enclosing Rendzinas soil cover, Brown-earth Rendzinas are formed, and in the case of polypedones of Cinamonic soils, brown soils with signs of carbonate metamorphism, then, in the case of the soil cover of cryogenic soils, intermediate variants combining signs of two profile-forming processes are also formed.

Figure 5 shows the genetic correlation of Burozems as the central archetype of structural-metamorphic soils with adjacent types that can have Burozem features in various combinations of soil formation factors.

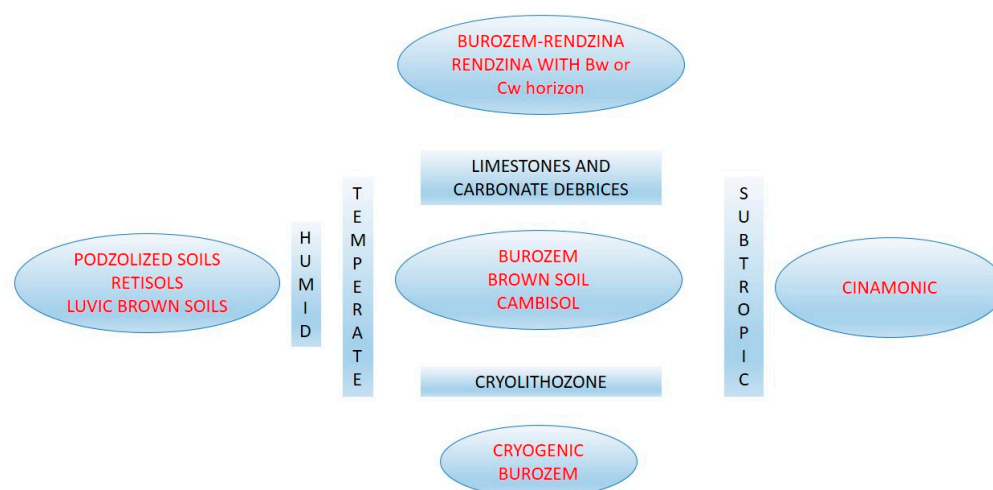


Figure 5. Relation of origin and taxonomy of Brown soils with adjacent soils.

Thus, Burozems are of a zonal type, characteristic of wet and short seasonally frozen forest ecosystems of boreal and subboreal climates. Burozem features are also manifested in soils of cryogenic habitats and in subtropical climates. The essential place of Burozems in the altitudinal zonality of mountain ranges of the Crimea, Caucasus, Urals, Zhiguly Mountains and other different altitudinal mountain ranges should be separately noted.

4. Conclusions

Burozems (Brown forest soils) are distributed in an extremely wide range of geographical (bioclimatic and geogenic) conditions. In this regard, there are a great number of diagnostic and terminological problems in attributing a number of soils to this conventional and large type. The boundaries between Burozems and adjacent types—Rendzinas, Retisols, Podzols, Cryosols and Cinamonic soils—are gradual and not entirely distinct as is the case with other soil types. These boundaries are often associated with ecotonal gradual climatic changes in vegetation and lithological properties.

It has been established that both zonal and intrazonal approaches are applicable to Burozems (Brown forest soils and Cambisols). In a number of natural zones, they have a central archetypal profile with the BM (Bm, Bw) horizon as well as a number of associated properties (redness, cryogenic mass exchange, podzolization, etc.). There are certain classification and diagnostic challenges here.

Burozems of the Central and Southern Caucasus and the mountain ranges of the Crimea are confined to the altitudinal zone of 1700–2600 m a.s.l. and border either directly with the periglacial zone or with alpine meadows, which depend on the proximity of glaciers or a nival zone. Mountain brown soils are characterized by highly productive broad-leaved forests with tree species of subboreal origin and simultaneous penetration into these habitats of forest-steppe species in the lower part of the belt and polar plant species in the upper part.

Interference vectors of Burozems and soils of adjacent types require analysis, comprehension and further expansion of research. Many Burozems traits are in many respects a mask to identify what is difficult to attribute to any obvious process genetic traits. They are nothing more than a temporary decision. It is necessary to answer the question of where the boundaries of the Burozem type in its taxonomic and ecological senses are. Of course, our study does not solve the problem of the origin and classification of brown soils, but it does raise problems of the complexity of this issue. There are still enough such soils in the boundary classification position in the world. Classification cannot be infinitely strict and clear. But it is also necessary to define the framework of soil type. In addition, it should be noted that we were faced with a lack of photographic material and field descriptions of this type of forest soil, although there is enough such material for adjacent soil types.

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