Byulleten Pochvennogo instituta im. V.V. Dokuchaeva. 2014. Vol. 76.

TRANSFORMATION OF CLAY MINERALS IN SOILS OF SANDY DESERTS AFFECTED BY DIFFERENT SAXAUL (*HALOXYLON*) SPECIES

© 2014 N. P. Chizhikova, M. P. Lebedeva

V.V. Dokuchaev Soil Science Institute, 119017 Moscow, Pyzhevskii 7, bld. 2
e-mail: chizhikova38@mail.ru

As a result of experimental studies carried out for the first time with the aim at determining the impact of black saxaul (*Haloxylon aphyllum*) and white saxaul (*Haloxylon persicum*) on the mineralogical composition of fine-dispersed fractions in sandy desert soils, it seemed reasonable to conclude that the transformation of minerals is quite different in soils used under different saxaul species. This is explained by differences in biogeochemical turnover of elements in soils under black saxaul and as a consequence by a higher Na content in the litter and the soda formation in the soil profile. The latter serves as a cause of alkalinization of soil solutions and transformation of minerals affected by alkaline hydrolysis.

Keywords: Kara Kum, sandy soils, mineralogical compositions, fine-dispersed fractions, black Saxaul.

INTRODUCTION

The role played by plant communities in the development of soil profiles and the soil cover especially at the territory of sandy deserts attracted special attention of many researchers long ago [10, 15, 25, 3, 4]. The most promising are the studies carrying out in reservations, where the functioning of ecosystems has being observed for a long period of time. It may be exemplified by the biosphere Repetek reservation recognized by UNESCO to be an ecological center in the Eastern Kara Kum [19].

The Eastern Kara Kum occupying 29 thousand km^2 is a territory characterized by complicated natural conditions. The communities of black saxaul (*Haloxylon aphyllum*) on solonchakous soils of biogenic origin with the stagnant water regime are very important from the viewpoint of ecological refuge for many animal and plant organisms [18, 15]. These ecosystems situated in old-alluvial plain of the pra-Amu Darya river and its tributaries reveal all the hydromorphic and semi-hydromorphic stages of their formation, being finally developed in late Pleistocene – early Holocene [18]. At the present time, the ecosystems are found to be under the influence of the aeolian factor. According to Gunin and Veiiesov (1987) the climatic conditions determine the natural process of the automorphic ecosystem development, where the barchane sands are constantly covered by xeromorphic plant communities consisting of three monodominant stories of shrub, grass and moss species.

The problem relating to the rational use of plant resources in the desert and the increase in the productivity of arid rangelands by phytomelioration was always of great significance; it is becoming very acute under conditions of the climate aridization now [11, 26, 7]. The black saxaul (*Haloxylon aphyllum* (Minkw.) Iljin, Chenopodiaceae) is the most important environment forming plant in sandy deserts [21, 24, 2, 13, 27]. *Haloxylon aphyllum* is a woody shrub of 1–9 m in height with photosynthesized succulent growth shoots. It is widely spread in alluvial plains of recent and ancient river channels and in great depressions of deserts in Central Asia. Being in an adult stage *H. aphyllum* combines the features of xerophytic and halophytic plant and can grow on sands, solonchakous and gypsum-containing substrata, occupying huge areas by its population [22, 23, 21, 13].

The given study is aimed at analyzing the behavior of minerals in the clay fraction (<1 mkm), in fractions of fine (1–5 mkm) and middle (5–10 mkm) silt under the influence of saxaul. An attempt is made to study differences in the biological turnover of chemical elements and transformation of the mineral fine-dispersed fractions in soils under different saxaul species.

OBJECTS OF RESEARCH

The soil sampling was taken from genetic horizons to compare the development of soil profiles under different saxaul species. The fine earth fraction was extracted from the root layer under white and black saxaul with the view of analyzing the transformation of minerals. The fine-dispersed fractions of clay minerals (<1 mkm, 1–5 and 5–10 mkm) were fractionated by sedimentation after Gorbunov (1963) and coagulated by the solution of chloride magnesium. The minerals were diagnosed in these fractions on the cover glass of the water suspension. The X-ray (diffraction) method was used to analyze the air-dried soil samples after their dissolution by ethylene glycol and ignition at 550°C for 2 hours. For diagnosing the chlorite the soil samples were treated by 0.5 M HCl. The methods of Biskay (1968) and Cook (1975) permitted to detect the ratio between mineral phases in the fraction less than 1 mkm and in the 1–5 and 5–10 mkm fractions respectively.

The objects of research were the fined-dispersed fractions of minerals extracted from the desert soil developed under different Saxaul species at the territory of Repetek reservation in South-Eastern Kara Kum (Fig.1). According to Bazilevich (1972) the projecting cover of black saxaul (*Haloxylon ammodendrom*) makes up 20% and white saxaul (*Haloxylon persicum*) – 1%. The other area (8%) is occupied by woody and shrubby plants and 71% – by *Carex physodes.*

RESULTS AND DISCUSSION

The old alluvial deposits retreated by aeolian processes served as a basis for sands covered by the above vegetation. In Repetek reservation the deposits are represented by sandy strata with a huge amount of lenses and stratified by clay and loam sandy layers from several centimeters to 1 m in thickness [29]. In upper horizons there are accumulations of “repetek” gypsum. Alluvial sands are usually polymineral, being enriched with quartz, feldspar and mica.

Fig. 1. The landscape of sandy barchanes under black Saxaul.

The data about the petrographic composition of sands under saxaul obtained in our studies seemed identical to those presented in literature sources [28]. In the soils the content of middle sand (0.25–0.05 mm) is varying from 65 to 75%, the physical clay (<0.01mm) makes up 5–6% including the silt (<0.001mm) in the amount of 4–5%. The content of the 0.1–0.05 mm fraction is 45–50%, the 0.25–0.1 mm fraction – 40% and 2% of silt and clay. The sandy fractions contain quartz (30–50%), feldspar (10–20%) and different-sized mica of muscovite-sericite and biotite-phlogopite type with varying weathering degree. Among the minerals of fine fractions are feldspar and quartz associations, in the coarse fractions – epidote and amphibole. The quartz grains are angular, angular-rounded with gaseous and liquid pebbles and inclusions of zircon, tourmaline, feldspar and black mica. Feldspars accounting for 15–20% are represented by potassium varieties (orthoclase and microcline) and seldom by plagioclase. The grains are usually angular, intensively changed, frequently corroded, sometimes they have a completely pelite structure [20, 12]. The fine fractions contain mica fragments consisting of muscovite, biotite and green mica. The carbonates (calcite) are represented by rounded, prismatic grains and clay aggregates. The carbonate grains are not only residual; they are resulted from mineralization of plant residues especially in fine fractions (chemical calcite).

It is worth of note that the complex soil cover of sandy deserts is conditioned by functioning of different vegetation, the latter being associated with differences in the biogeochemical plant activity. Of great interest is the study of the biogeochemical turnover of elements in soils revealing peculiar features under Saxaul community. Fig. 2 demonstrates such differences in the element turnover under black and white Saxaul conditioned by different biochemistry and productivity of these plants.

Every year the soil litter receives from leaf debris 0.94 t/ha of terrestrial organic mass of black saxaul including 72% of the green part. The return input to soil makes up 128.6 kg/ha of ashy substances (0.24 kg/ha of microelements and 13 kg/ha of nitrogen). The main elements are Na, K, Ca, Mg and N, among microelements – Mn, Sr, B. As regards the white saxaul the topsoil obtains together with its leaf debris 0.05 t/ha of the terrestrial organic mass including 5 kg/ha of nutrients,

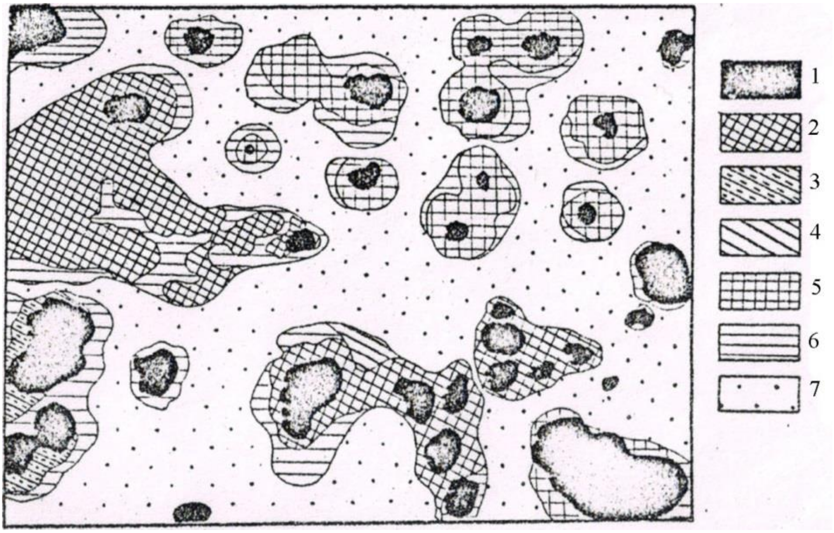

Fig. 2. Mosaic picture of biogenic salinity in the upper (0–30 cm) horizons (crust, subcrust) of sandy desert soils in ecosystems of black Saxaul (*Haloxylon aphyllum*) in depressions of the Eastern Kara Kum (according to Gunin, 1990). I *–under the crown of black Saxaul:* 1 – solonchak with soda, 2 – strongly saline soda-chloride soil under the closed grass cover; 3 – middle saline chloride soil; 4 – weakly saline chloride soil; 5 – weakly saline, chloride-sulfate soil under grass vegetation; II – *along the edges of the black Saxaul crown*; 6 – weakly saline and nonsaline, compact soils under grass communities; III – *the area between the crowns:* 7 – nonsaline, typical sandy desert soils under the grass cover.

0.7 kg/ha of N and 0.016 kg/ha of microelements. K, Na, Ca and Si are dominant there. The leaf debris of the black saxaul covers the area occupied by this plant and the biogeochemical effects are locally manifested. It was shown that 1 m^2 of the area under black and white saxaul receives an identical amount of plant residues from the leaf debris (about 0.0002 g) but under the black saxaul 0.07 kg of ashy elements and N, under the white saxaul – 0.04 kg. Under the black saxaul there are 2677 meq/m^2 of cations and only 201meq/m^2 of anions. The excessive cations are associated with the air CO_2 and form carbonates. As a result of the leaf debris decomposition Na_2CO_3 is formed in the amount of 42 g, K_2CO_3 – 32 g, $CaCO_3$ – 27 g, $MgCO_3$ – 26 g as well as 4 g of

NaCl+ KCl and 4.4 g of gypsum. Under the white saxaul – Na_2CO_3 – 8 g, K_2CO_3 – 18 g, $MgCO_3$ – 18 g, $CaCO_3$ – 40 g, NaCl+KCL – 1.7 g and gypsum – 3.9 g. In the course of mineralization process in the litter under the white saxaul Ca is intensively accumulated as compared to that under the black saxaul. Under *Carex physodes* the leaf debris contains 0.0004 t/m^2 of plant residues and forms in the course of mineralization 1 g/m^2 of K_2CO_3 and $CaCO_3$, less than 0.5 g of $MgCO_3$, 0.1 g of NaCl and 0.1 g of gypsum; there is no soda at all.

Thanks to the accumulated salts under the crown of the black saxaul the upper layer of the sand becomes very alkaline reaching 20 meq in the upper crust 2 cm thick. The salt content exceeds 2%, the soil Ph is alkaline, the amount of exchangeable Na makes up 20–45% at the exchange capacity of 7 meq. Due to a higher amount of ashy elements under the crown about 40% of toxic carbonic soda are formed and leads to the soil alkalinity (Table 1).

The qualitative composition of mineral fractions < 1 mkm of sandy desert soils is represented by hydromica, chlorite, mixed-layered mica-smectite and chloride-smectite formations with a small admixture of highly dispersed quartz. The minerals in the 1–5 and 5–10 mkm fractions consist of mica and chlorite, the increased content of quartz, feldspar appears (Table 2).

Mica and hydromica are dominant in fine-dispersed fractions. The X-ray (diffraction) analysis permitted to determine them as those of trioctahedric type (Fig. 3, 4). The measurement of the relative reflex intensity from 003 to 002 and 004 showed that chlorite is also by trioctahedric type, magnesium-ferruginous in these fractions. Apart from the chlorite phase the fraction less than 1 mkm as well as the 1–5 mkm fraction to a lesser extent contain the product of its change resulted from destruction of brusite interlayers and formation of those by smectite type. The mixed-layered chlorite-smectite formations are identified according to a reflex asymmetry of 1.4 nm in the samples enriched with ethylene glycol and the reflex asymmetry of 1.2 nm in samples ignited at 550ºC. The soil samples contain the mica-smectite formations with a lower (< 50%) amount of swelling smectite pockets with an asymmetry towards the reflex of 1.0 nm in the air-dry state and towards the reflex of 1.6–1.7 nm after their saturation by ethylene glycol.

Table 1. Chemical properties of the investigated semidesert soils

Depth, cm	Humus, %	CO_2, %	pH	Fe_2O_3 after Jackson %	Compact residue %	Alkalinity		Cl	SO_4	Ca	Mg	Na	K
						CO_3	HCO_3	meq-100 г					
Desert solonchakous sandy soil under black saxaul													
0–1.5	3.30	8.10	9.00	0.65	2.63	13.33	22.55	2.72	2.40	0.88	4.83	18.63	5.76
1.5–8	0.37	6.00	9.10	0.44	0.35	1.96	2.90	0.95	0.08	0.18	0.26	3.37	0.12
8–18	0.21	5.80	9.00	0.26	0.23	0.78	2.04	0.55	0.09	Нет	0.09	2.50	0.09
18–32	Нет	6.20	8.30	0.17	0.14	0.39	1.26	0.47	0.15	”	0.18	1.17	0.53
32–50	”	5.80	8.30	0.26	0.10	0.39	1.06	0.16	0.14	0.09	0.09	0.78	0.40
Desert weakly solonchakous sandy soil under white saxaul													
0–3	0.40	5.70	8.50	0.34	0.38	0.63	1.25	1.27	1.63	0.94	1.87	0.77	1.20
4–15	0.20	5.70	8.00	0.26	0.25	0.42	1.25	0.15	1.08	1.26	0.63	0.26	0.75
15–42	0.20	5.20	7.90	0.20	0.12	0.30	1.50	0.24	1.00	0.68	0.82	0.52	0.52
42–60	0.20	5.50	7.90	0.16	0.37	0.10	1.33	0.68	1.73	1.26	1.26	0.78	0.54
Desert sandy soil under *Carex physodes*													
0–5	0.12	5.70	7.60	0.24	0.05	Нет	0.55	0.08	Нет	0.18	0.18	0.10	0.17
5–12	0.21	6.40	7.90	0.26	0.06	»	0.51	0.08	0.09	0.35	0.09	0.11	0.13
12–22	0.16	6.40	7.90	0.26	0.06	»	0.59	0.08	0.02	0.26	0.09	0.17	0.17
22–30	0.16	5.90	8.10	0.14	0.06	»	0.63	0.04	0.03	0.26	0.18	0.07	0.19
30–40	0.21	5.90	8.10	0.17	0.05	»	0.67	0.08	Нет	0.18	0.26	0.13	0.18
40–50	0.06	5.90	8.10	0.26	0.05	»	0.67	0.08	”	0.26	0.09	0.23	0.17

Table 2. The ratio between the mineral fractions of less than 1, 1–5 and 5–10 mkm extracted from the sandy desert soils

Layer, cm	< 1mkm			1–5 mkm		5–10 mkm	
	hydromica	chlorite	MLS	biotite	chlorite	biotite	chlorite
Desert solonchakous sandy soil under the black Saxaul							
0–2	78	13	9	86	14	78	22
2–27	78	12	10	80	20	84	16
27–40	76	12	12	80	20	84	16
40–67	80	13	7	80	20	84	16
67–95	81	11	8	80	20	84	16
At the contact with roots	59	12	29				
Desert weakly solonchakous sandy soil under the white Saxaul							
0–4	81	9	10	84	16	90	10
4–15	81	10	9	77	23	84	15
15–42	81	13	6	75	25	83	17
42–65	82	15	3	90	9	91	9
At the contact with roots	78	16	6				

Note: MLS – mixed-layered mica-smectite.

The quantitative ratio between the above minerals and their distribution along the soil profile serve as evidence of the following changes. In the desert solonchakous sandy soil under the black saxaul the profile of the clay material was developed, in which some changes in the ratio between mineral phases took place. This is characteristic of all the desert sandy soils [1, 6]. Dominant are hydromica of trioctahedric type, the amount of which is varying from 76 to 81%. Chlorite of trioctahedric type makes up 10–13% from the total sum of components. The disordered mixed-layered formations of mica-smectite and chlorite-smectite types account for 7–12%. In the 0–2 cm surface crust there is the increased amount of chlorite as compared to the underlying part of the profile. The upper 2–40 cm horizon displays a lower content of trioctahedric hydromica (76–78%), whereas the amount of mixed-layered formations is increased being considered as the transformation products of hydromica by biotite type into mica-smectite as well as chlorite into chlorite-smectite.

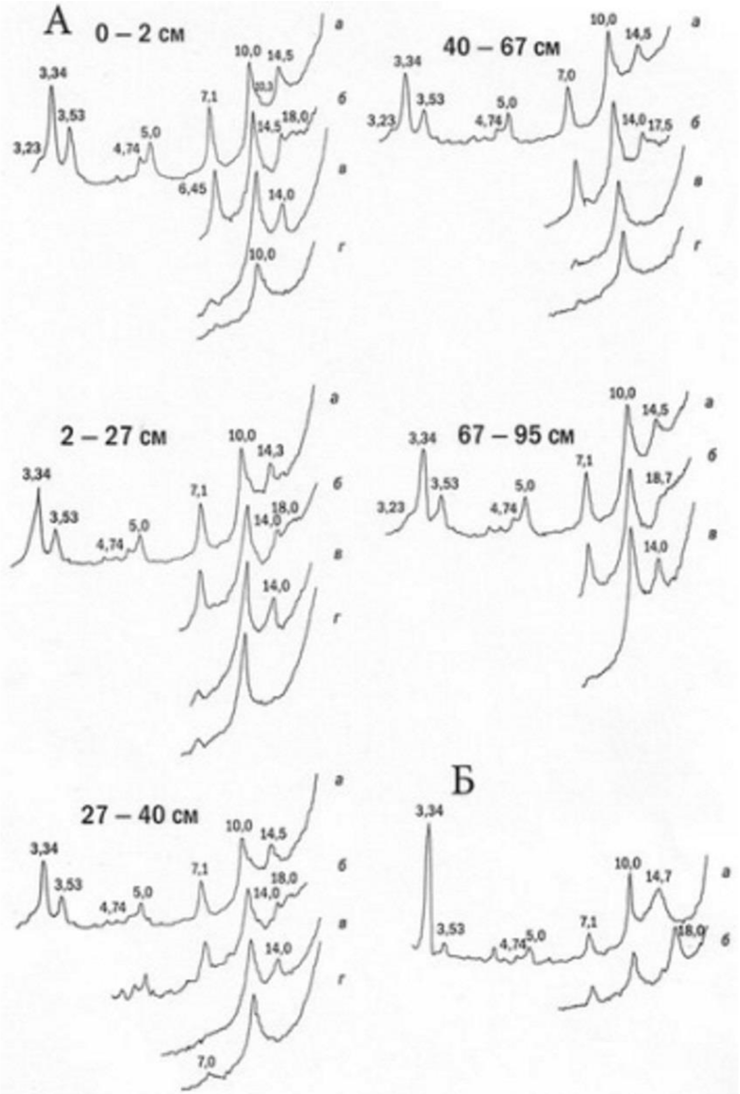

Fig. 3. X-ray diffractograms of the fraction < 1 mkm, separated from the samples of the desert soil under the black Saxaul (A): a – in the air-dried state, б – after solvation by ethylene glycol, в – after ignition at 550ºC, г – after treatment by 0.5 M HCl; the samples taken in soil near the roots of the black Saxaul (Б): a – in the air-dried state, б – after salvation by ethylene glycol.

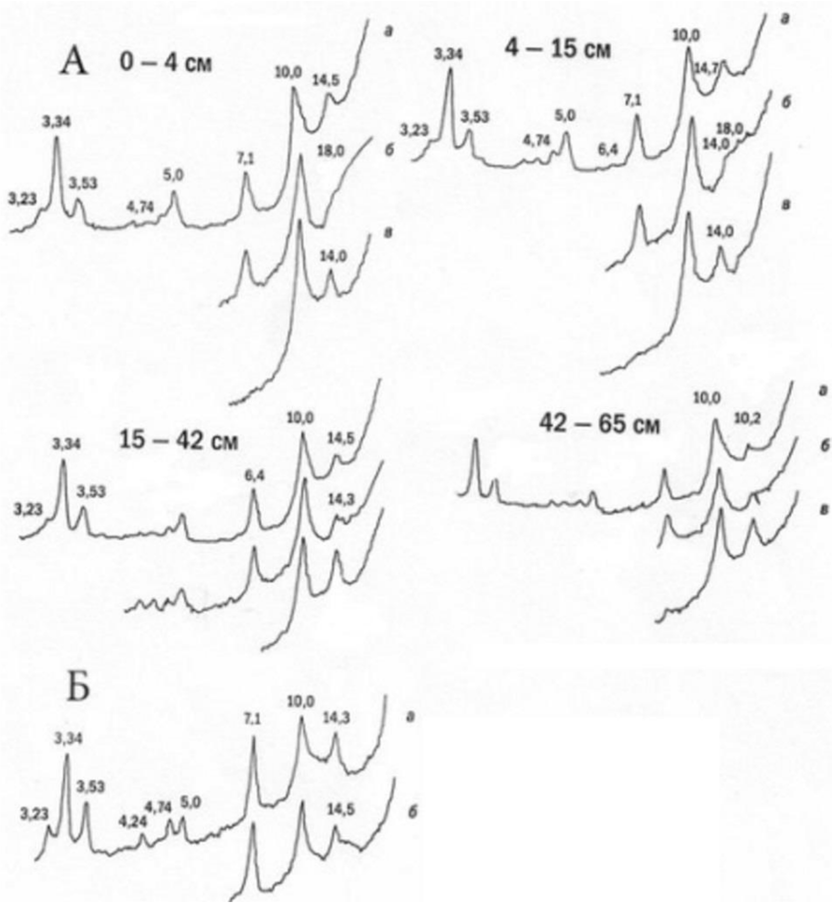

Fig. 4. X-ray diffractograms of the fractions < 1 mkm, separated from samples of the desert soil under the white Saxaul (A): a – in the air-dried state, б – after salvation by ethylene glycol, в – after ignition at 550ºC for 2 hours (Б): a – in the air-dried state, б – after salvation by ethylene glycol.

In the soil profile at a depth of 40 cm the content of hydromica and chlorite is stable and makes up 80% and 14% respectively.

In the fine-dispersed fraction the content of fine-dispersed quartz and feldspar is highly increased. The ratio between layered silicates is uniform: biotite is estimated as 80%, chlorite – 20%. Biotite is increased in the surface crust.

In the fraction of middle silt the amount of quartz and feldspar becomes increased to a considerable extent, the ratio between biotite and chlorite speaks about the prevailed content of biotite (84%) and chlorite in the amount of 16%.

Under the white saxaul the desert slightly solonchakous soil is characterized by a higher content of trioctahedric hydromica as compared to that in the soil under the black saxaul. The profile of clay materials is even and reveals 81–82% of hydromica and 9–15% of chlorite. The greatest amount of mixed-layered formations is observed in the crust (10%). Downwards the soil profile it becomes declined to 3%. In the fraction of fine silt the biotite is dominated, the amount of quartz and feldspar is sharply increased as compared to the clay fraction. In the fraction of middle fraction the amount of fine-dispersed quartz increases to a considerable extent; the biotite content is also increased to 90% in the crust.

Thus, the profiles of the clay material in soils developed under different saxaul species reveal the varying intensity of changes in minerals. The fine-dispersed fractions of minerals in these soil profiles contain the layered silicates capable to be easy weathered under the changed conditions. The biotite of silt fractions is transformed into the trioctahedric hydromica of the clay fraction that is characterized by mild outline of reflexes and the asymmetry towards the little angles. Under the crown of black saxaul where the soil pH is alkaline the transformation-degradation process becomes intensified and resulted to the formation of mixed-layered structures with smectite pockets. Both biotite and chlorite as regarded to the easy weathered category of minerals are subjected to transformation. According to Bazilevich (1972) “under conditions of the sharply expressed alkaline pH in soil under the crown of black saxaul such processes take place as galmirolysis, peptization and dispersion of the soil mineral part resulting in the increased amount of the fine earth (sometimes to the depth of 0.5 m)”.

In the wet soil under the black saxaul there are the redistribution processes of chemical elements; Si, Fe and the organic substances become more mobile. In view of this, the soil profile under the black saxaul is differentiated and as a result a relatively compact brown B horizon is developed.

The formation of desert solonchakous soil profiles under the black saxaul is confirmed by data about the distribution of the mineral fine-dispersed fractions along the soil profile. For the short period of the black saxaul growing the trioctahedric mica and chlorite have being transformed into the mixed-layered formations being fixed in the brown B horizon.

To understand the role played by the roots of different saxaul species, the fine earth mass taken in the soil near the roots has been studied in detail. The X-ray analysis showed a significant difference in the structure of minerals. The composition of mineral components in soil samples taken near the roots of the white saxaul revealed no differences from that in the main soil mass (78% of biotite, 16% of chlorite, 6% of mixed-layered formations). The composition of minerals in the soil under the black Saxaul served as evidence of transforming the layered silicates to a considerable extent. The amount of biotite became highly decreased to 59%, whereas the transformation products of biotite, chlorite and the mixed-layered formations were increased to 29% (Fig. 3Б).

CONCLUSIONS

1. The mineralogical composition of the fractions < 1 mkm extracted from desert sandy soils under different saxaul species is represented by trioctahedral hydromica which is predominated as well as chlorite, kaolinite and the mixed-layered formations with smectite pockets to a lesser extent. The fractions of fine (1–5 mkm) and middle (5–10 mkm) silt consist of mica, chlorite, quartz and feldspar.
2. The mineralogical composition of the fractions extracted from the soil near the roots of the black saxaul differs from that in soils under the white saxaul; the swelling phase is dominant as resulted from transformation of trioctahedric mica affected by the alkaline hydrolysis.
3. The differences in the mineralogical composition of soils near the root system are explained by the peculiar biogeochemical turnover of elements under different saxaul species.

REFERENCES

1. Abaturova T.I., Chizhikova N.T. Glinistye mineraly serozemov obyknovennykh i lessov yuga Golodnostepskoi ravniny, *Pochvovedenie,* 1972, No 8, pp. 109–111.
2. Akzhigitova N.I., Brekle Z.V., Vinkler G., Volkova E.A., Vukhrer V., Kurochkina L.Ya., Makulbekova G.B., Ogar' N.P., Rachkovskaya E.I., Safronova I.N., Khramtsov V.N. *Botanicheskaya geografiya Kazakhstana i Srednei Azii (v predelakh pustynnoi oblasti),* St. Peterburg, Boston-Spektr, 2003. 424 p.
3. Bazilevich N.I., Chepurko N.L., Rodin L.E. Miroshnichenko Yu.M. Biogeokhimiya i produktivnost' chernosaksaul'nikov Yugo-vostochnykh Karakumov, *Problemy osvoeniya pustyn',* 1972, No 5, pp. 3–8.
4. Bazilevich N.I., Chizhikova N.P. Pochvy, *Karakumy, statsionar Repetek: Sb. Produktivnost' rastitel'nosti aridnoi zony Azii. Itogi sovetskikh issledovanii po mezhdunarodnoi biologicheskoi programme 1965–1974 gg,* Leningrad: Nauka, 1977, pp. 121–124.
5. Biscaye P.E. Mineralogy and sedimentation of the deep-sea clay in the Atlantic Ocean, *Geol. Soc. Amer. Bull.,* 1965, V. 76, № 7, P. 803–832.
6. Chizhikova N.P., Evtifeev Yu.G., Pankova E.I. Mineralogicheskii sostav ilistykh fraktsii pustynnykh pochv Mongolii, *Pochvovedenie,* 1988, No 8, pp. 44–54.
7. Christmann S., Martius Ch., Bedoshvili D., Bobojonov I., Carlo C., Devkota K., Ibragimov Z., Khalikulov Z., Kienzler K., Herath M., Mavlyanova R., Nishanov N., Sharma, Ram Tashpulatova B., Toderich K.,Turdieva M. *Food Security and Climate Change in Central Asia and the Caucasus. Discussion paper. CGIAR Program for Central Asia and the Caucasus,* Tashkent, Uzbekistan, 2009. 78 p.
8. Cook H.E., Johnson P.D., Matti J.C., Zemmels I. Methods of sample preparation and X-ray diffraction data analysis, X-ray mineralogy laboratory, Deep sea Drilling project, University of California, *Inst. Repts. DSDP,* Vol. 28, 1975, pp. 999–1007.
9. Dubyanskii V.A. Peschanaya pustynya Yugo-Vostochnye Karakumy, ee estestvennye raiony, vozmozhnost' ikh sel'skokhozyaistvennogo ispol'zovaniya i znachenie dlya irrigatsii, *Tr. po priklad. i botan., gen. i selek-tsii,* 1928, T. 19, Vol. 4, pp. 1–86.
10. Gael' A.G. O roli rastenii v pochvoobrazovanii v pustyne Kara-kum, o peschanykh pochvakh i ikh plodorodii, *Izvestiya gosudarstvennogo geograficheskogo obshchestva,* 1939, T. 71, Vol. 8, pp. 1105–1128.
11. Gael' A.G. Oblesenie aridnykh oblastei Aralo-Kaspiya, *Lesnoe khozyaistvo,* 1975, No 3, pp. 2–9.

12. Gael' A.T., Khabarov A.V. Pochvenno-ekologicheskie kharakteristiki Tsentral'no-Karakumskogo statsionara// *Osobennosti peschanykh pochv i ikh ispol'zovaniya*, Moscow, 1979, pp. 4–55.
13. Gintzburger G., Toderich K.N., Mardonov B.K. and Makhmudov M.M. *Rangelands of the arid and semi-arid zones in Uzbekistan*, Monpellier: Centre de Cooperation Internationale en Resherche Agronomique pour le Development (CIRAD), 2003, 498 p.
14. Gorbunov N.I. *Vysokodispersnye mineraly i metody ikh izuche-niya*, Moscwa, 1963, 303 p.
15. Gunin P.D. *Ekologiya protsessov opustynivaniya aridnykh ekosi-stem*, Moscow, 1990. 354 s.
16. Gunin P.D., Darymov V.Ya. Novye dannye o raspredelenii vlazhno-sti pochvogruntov v Vostochnykh Karakumakh, *Vestnik Mosk. un-ta*, 1969, Ser. Geografiya, No 3, pp. 46–53.
17. Gunin P.D., Darymov V.Ya., Veiisov S.V. Landshaftnaya kharakteri-stika Repetekskogo zapovednika, *Opyt izucheniya i osvoeniya Vostochnykh Karakumov*, Ashkhabad: Ylym, 1972, pp. 12–22.
18. Gunin P.D., Veiisov S.V. Repetekskii zapovednik kak regional'-nyi ekologicheskii tsentr Vostochnykh Karakumov, *Problemy osvoeniya pustyn'*, 1987, No 5, pp. 54–60.
19. Gunin P.D., Veiisov S.V., Radziminskii P.Z. Rol' Repetekskogo biosfernogo zapovednika v reshenii zadach okhrany prirody v usloviyakh pastbishchnogo zemlepol'zovaniya, *Problemy osvoeniya pustyn'*, 1985, No 4, pp. 53–62.
20. Khabarov A.V. Mineralogicheskii sostav peschanykh pochv Tsentral'-nykh Karakumov, *Pochvovedenie*, 1976, No 2.
21. Kurochkina L.Yu., Osmanova L.T., Karibaeva K.N. *Kormovye raste-niya Kazakhstana*, Alma-Ata, 1986, 208 p.
22. Nechaeva N.T. *Dinamika pastbishchnoi rastitel'nosti Karakumov pod vliyaniem meteorologicheskikh uslovii*, Ashkhabad: AN TSSR, 1958, 214 p.
23. Nikitin S.A. *Drevesnaya i kustarnikovaya rastitel'nost' pustyn' SSSR*, Moscow: Nauka, 1966, 253 pp.
24. Pyankov V.I., Black C.C., Artyusheva E.G., Voznesenskaya E.V., Ku M.S., Edwards B. Features of photosynthesis in *Haloxylon species* of Chenopodiaceae that are dominant plants in Central Asia deserts, *Plant Cell Physiology*, 1999, Vol. 40, pp. 125–134.
25. Rodin L.E, Bazilevich N.I. *Dinamika organicheskogo veshchestva i biologicheskii krugovorot zol'nykh elementov i azota v osnovnykh tipakh rastitel'nosti Zemnogo Shara*, Moscow– Leningrad, 1965, 253 pp.
26. Shamsutdinov Z.Sh. *Sozdanie dolgoletnikh pastbishch v aridnoi zone Srednei Azii*, Tashkent, 1975, 175 p.

27. Toderich K.N., Shuyskaya E.V., Ismail S., Gismatullina L.G., Radjabov T., Bekchanov B.B., Aralova D.B. Phytogenic resources of halophytes of Central Asia and their role for rehabilitation of sandy desert degraded rangelands, *J. of Land Degradation and Development*, 2009, Vol. 20(4), pp. 386–396.
28. Veiisov C.B. *Dinamika rel'efa barkhannykh peskov*, Ashkhabad: Ylym, 1976, 196 p.
29. Veiisov S.V. Dinamika litogennoi osnovy i ee rol' v formiro-vanii biogeotsenozov, *Biogeotsenozy Vostochnykh Karakumov*, Ashkhabad: Ylym, 1975, pp. 13–17.
30. Zonn S.V., Leont'ev V.L. O pochvoobrazovatel'nom znachenii sak-saula v peskakh pustyni Karakumy, *Pochvovedenie,* 1942, No 8.