

Some Problems of Soda Salinity

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Soda-saline soils are those, containing in the root-inhabited horizons sodium carbonate or bicarbonate in amounts surpassing 1 meq. of HCO_3^- per 100 g, and having a pH over 8.5—8.6. Both properties are harmful for most agricultural plants.

In the report presented by KOVDA [16] at the Budapest Symposium in 1964, the analysis of origin and conditions favourable for soda (sodium carbonates and bicarbonates) accumulation in soils was made. Since those times new data have appeared that proves the great importance of the problem, as well as the correctness of our general theoretical concepts which have been confirmed by new facts. Therefore, we consider the present contribution as a development and addition to the report presented in 1964.

The urgency of the problem of soda salinity of soils for agriculture becomes still more evident every year. The reasons for it are as follows:

1. In comparison with other soluble salts, soda has the most harmful effect on agrophysical soil properties and is extremely toxic. Its presence results in a very low natural soil fertility. The amelioration and agricultural utilization of soda-saline soils present especially great difficulties.

2. Soils with soda salinity are usually located among highly fertile humic soils of plains, they frequently occur in the regions with intensive farming and restrain the all-round land use, attributing an irregular pattern to the regions with fertile land.

3. Now a real menace of enlarging the areas subjected to soda salinity exists. These areas are the irrigated lands, where the soda salinity appears as the first phase of salt accumulation in the process of secondary salinization. Soda can also appear, if the waters, used for irrigation, contain either a certain amount of soda or a higher amount of sodium chlorides and sulphates. Theoretically, according to GEDROITZ, the soda salinity may occur as a result of leaching and desalinization of sodium gypsum-free saline soils with formation of solonetz.

The soda salinity has acquired a catastrophic character in the Indus Valley and Delta (Punjab, West Pakistan); it is observed in Iran, Egypt, Kenia, Argentina, Syria, China, in some regions of the USA, Canada, Hungary, Roumania, Bulgaria, etc.

The above reasons have put the problem of the origin and amelioration of soda-saline soils among the most important problems of to-day.

Up to the present time, many investigators consider the soda salinity to be characteristic only of steppe and forest-steppe zones and representing the most northern variant of salt accumulation processes. The formation of

soda-saline soils in other natural zones is explained by the soda inflow from the outside (BAZILEVICH [1]).

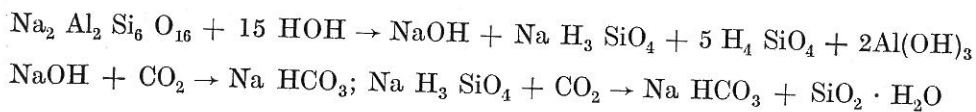
But it became evident long ago that alkaline soils affected by soda salinity are widely spread all over the land surface and in different climatic conditions (KOVDA [18]), although the estimated areas with soda soils occurrence are relatively small. These soils reach the Polar Circle in North America. In Asia, Africa and South America they approach the equator and sometimes go further, up to 40° s. l. They may be found in quite different bioclimatic environments except the purely humid localities, where the accumulation of soluble salts is impossible. However, they occupy large territories on the lowlands even in the monsoon tropics of India (the Ganges terraces, vicinities of Bombay, Calcutta, etc.). Most frequently, soils with soda salinity are associated with black humic soils of various climatic belts: with chernozems, meadow-chernozems, meadow soils, brunizems, vertisols, regurs, grumosols, planosols and other soils.

Soda-saline soils are confined, as a rule, to the hydromorphic sites, their formation being related to the high level (1–3 m below the soil surface) of weakly mineralized alkaline ground waters. When the ground water ceases to influence the soil formation, soils lose very soon their soda and high alkalinity, but other indices of soda salinity — compactness, montmorillonitic composition of the clay fraction — remain for a long time. We can judge by these indications, observed in soils of neo-automorphic landscapes, about the old hydromorphic stage in the evolution of these soils, about their alkaline paleohydromorphism.

Soils with soda salinity being formed in the accumulative conditions of topography, are restricted to ancient alluvial or deltaic plains with an impeded drainage, to lake and river terraces or to foothill and fan plains, where they are connected with zones of ground water exposure and with "dry" deltas.

The soda salinity is caused by ground waters with a mineralization approximating to 0.5–5 g per litre. KOVDA was the first to show [14, 15, 16] that just by that very concentration, the composition of soil solutions and ground waters is usually sodium hydrocarbonatic-calcic; it was later proved by numerous investigations.

Diluted waters, with HCO_3^- -ions prevailing, are formed in the process of weathering of igneous rocks. The chemical alteration of aluminosilicates is accompanied by the formation of very diluted solutions of alkaline and alkaline earthcarbonates and bicarbonates and of ionic and colloidal forms of silica and aluminium hydroxides. This process is continuously going on all over the land surface, and in all the climatic zones it follows the scheme:



The cationic composition of waters is determined by the composition of minerals. The alteration of sodic feldspars, refelines, sienites, etc. results in a predominant formation of soda. The formation of sodium hydrocarbonate waters is especially peculiar for the water-collecting basins, consisting of

young volcanic rocks: basalts, lavas, ashes and tuffs. The products of their weathering have very frequently strongly alkaline reaction. The soda accumulations in the East African Rift, Chile, Argentina and the Transcaucasia have developed under the influence of waters fed by the runoff in the areas of recent volcanic deposits.

The important role in the soda formation is also played by acid igneous and sedimentary rocks, rich in sodium feldspars (ORLOVSKY [24], EGOROV [6]).

The composition of natural waters acts as a function of their mineralization (KOVDA [14]). So, waters with the lowest mineralization (100 mg/l) prove to be the silicate ones, with the strong domination of SiO_2 in relation to total salt amount; the cationic composition may be different.

The silicate-hydrocarbonate, mainly calcic, waters have a mineralization of 100–500 mg/l, the sodium hydrocarbonate alkaline waters are characterized by a mineralization of 500–2000 mg/l, while the soda-sulphate waters contain about 2–5 g/l of salts, etc. The relative amount of silica acid decreases sharply.

These general regularities of salt accumulation were stated in various bioclimatic conditions. CHEVERRY [4] in particular, had found in the soils of polders on the shore of Lake Chad the following regular changes in the ground-water composition connected with the changes in their mineralization: with the amount of soluble salts below 0.5 g/l the waters had a calcium-hydrocarbonate composition; if it ranged between 0.5–3 g/l the waters were sodium-hydrocarbonate; if it was 3–5 g/l the waters were soda-sulphate; at a salt content ranging from 5 to 20 g/l the sulphate-soda waters were observed (Fig. 1).

The limits of mineralization, characteristic of each phase of salt accumulation change to a certain extent in different bioclimatic and lithological conditions (Fig. 1).

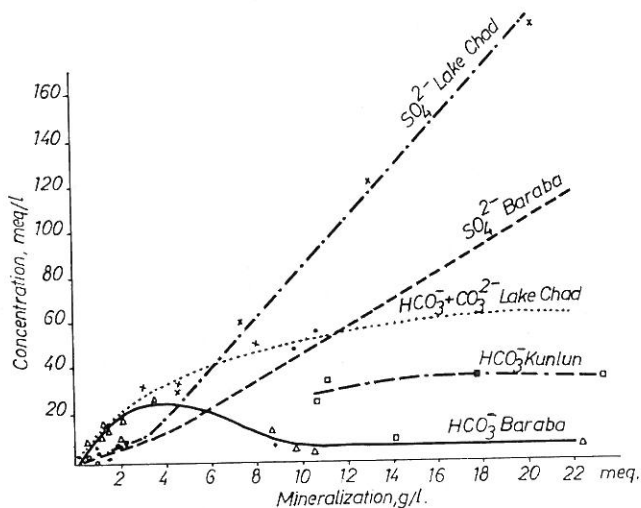


Fig. 1

Dependence of CO_3^{2-} and HCO_3^- content on mineralization of ground waters. The graph has been constructed basing on the data of BAZILEVICH [1], EGOROV [6], CHEVERRY [4]

The evaporation and concentration of primarily fresh natural waters during their movement to the regions of salt accumulation or the capillary rise bring the changes in their chemism and mineralization degree. The silicate waters are transformed into the silicate-hydrocarbonate ones, then into the soda, sulphate-soda, chloride-sulphate and, at last, the chloride waters. This process is a reversible one. The mineralized waters may acquire a sodium-hydrocarbonate composition due to their dilution, for example, in the process of drainage and irrigation.

A curve, reflecting an increase in HCO_3^- content in the process of dilution and desalting of ground waters repeats the curve, demonstrating a decrease in the hydrocarbonate ions' content accompanied by an increase in mineralization of ground waters.

A series of soda-producing processes is now known. First of all, it is alteration of rocks, containing sodium aluminosilicates, with the formation of silicates, aluminates and, at last, carbonates of sodium in the ground and soil waters. Soda may appear as a result of the reactions of substitution of calcium in the carbonates of rocks and soils by the sodium of chlorides and sulphates of the ground waters (HILGARD's reaction) and also as a result of exchange reactions between the sodium-saturated soil and the hydrogen of carbonic acid or calcium of carbonates (GEDROITZ's reaction). Soda may be formed in the process of decomposition of plants with sodium among the ash-elements and in the process of sulphate-reduction in a waterlogged soil as well. The possibility of soda formation in all these processes is demonstrated by many observations, but the quantitative regularities of soda formation are not yet known. Even all these facts and considerations taken together can not give a sufficient explication to the presence of soda in a landscape.

In the last years a more close attention is paid to the possible role played by the ascending artesian waters in the process of soda penetration into the soils. If such waters contain sodium hydrocarbonate, they may become a powerful source of soda in the landscapes by outpouring to the surface and into the subsurface horizons, by capillary movement or rise along the pores and fissures up to the horizon of soil and ground waters.

In such geological structures as crystalline shields or platforms, outpourings of pressing waters are comparatively rare. But in the areas of regional faults and geosynclines, along the periphery of mountainous folded districts, in the zones with tectonical fractures the inflow of deep pressure waters may be very considerable and may determine many soil-geochemical peculiarities of the territory. It may be especially well pronounced in the arid climate, due to an intensive evaporation favouring the formation and accumulation of salt minerals from the solutions brought by deep waters, and also due to an arid climate, helping to conserve those minerals in soils and in the crusts of weathering.

Under the cold and humid climatic conditions the pressing underground waters facilitate the extramoistening and formation of waterlogged soils. At the same time they deliver valuable elements of plants' mineral nutrition to the soil.

The weakly mineralized alkaline thermal pressing waters are widely spread in the areas with neo-tectonics and high seismicity, where they rise to the surface along the fracture fissures (BARABANOV and DISLER [2]). Outflows of such waters are known in Iceland, the Pyrenees, the Alps, the Car-

pathians, the Caucasus, the Copet-Dag, the Pamirs, the Altai, in the Sayan-Baikal region, in the Republic Tuva, in Kamchatka — i.e. along the whole zone of recent mountain formation in Eurasia. The same phenomena are typical for the large areas of the Great African Rift and Pacific Coast of America.

Patches with soda salinity which are sure to be linked with the alkaline pressing waters, are also known in the valleys of many rivers: Chu, Ili, Samarka, Dnieper and its tributaries. Especially large regions of soda salinity are confined to the terraces of the Danube and its tributaries, the terraces of the Dnieper, the Desna and of other rivers, whose channels are deeply incised in the bed-rocks and drain the alkaline fresh waters (mineralization 0.2—1.2 g/l). On the contact with the ground waters these deep interbedded waters enrich the first ones with soda (GRIN [11]).

Among the deep sodium-hydrocarbonate waters a special role is played by the reduced, desulfurized solutions paragenetically connected with the oil and gas deposits (SULIN [27]); KOVDA [20]). Such waters are known to occur in the West-Siberian Lowland, in Transvolga areas, on the northern Caspian Lowland, in southern Tadjikistan.

The above mentioned areas of influence of pressing soda waters may be regarded as comparatively rare, extraordinary. Now, however, data permitting to consider the connection between the soda saline soils and artesian waters as a regular and constant one, are collected. A strict correlation is observed between the localization of soda saline soils and the chemistry of the artesian basins in the USSR. According to the recent hydrogeological investigations (ZAITSEV and TOLSTIKHIN [29]), the artesian basins in the USSR may be subdivided into two belts: the northern and the southern. The northern one is located in the Russian, West-Siberian and East-Siberian Lowlands (with the basins: Baltic, Moscow, Volga-Kama, Sura-Khoper, Dnieper, Donetz etc.). Its continuation in the East are the basins on the Okhotskoe Sea coast and the North-American ones: the Dakota and Wisconsin basins.

The southern, or Mediterranean belt of artesian basins includes the coast of the Black Sea, Caspian and Aral regions (the Lvov, Black Sea, Azov and other basins). In the west the southern belt is continued by the Paris basin, in the east — by the middle and coastal basins of China and Mexican Gulf coast.

A peculiar feature of the northern belt artesian basins is a clear vertical zonality of artesian waters — their upper horizon being represented by fresh often weakly alkaline interbedded waters occurring at the depths, varying from tens to hundreds meters. The rate of mineralization increase with depth is also different, and the highest concentrations of salts in the lowest horizons range from weakly saline to strongly saline brines.

Waters of the fresh layer are calcium-bicarbonate, rare sodium-bicarbonate (Hydrogeology of the USSR, v. I, III, [12]; GRIN [11], DUBYANSKY [5], BAZILEVICH [1]). Data on the silica content in these waters are very scarce. We can approximately estimate it, according to fragmentary information, equal to 10—20 mg/l.

In the basins of the southern or Mediterranean belt the vertical zonality of waters is weakly expressed. Many basins are situated along the periphery of the platforms, areas of their feeding are in the mountains, that is why horizons of fresh and saline waters alternate in accordance with the com-

position of rocks. The upper horizon is not always represented by fresh or weakly mineralized waters. When the basins are formed in the depth of salt-containing sediments (the Caspian Lowland), they prove to be strongly mineralized in the upper horizon too, while fresh waters are found sporadically as lenses on the surface of saline waters. Similar differences exist between the artesian waters of the folded regions in the northern and southern belts. Mountains in the northern zone are characterized by the presence of deep layers of fresh waters, giving place to the saline ones at greater depths. Folded areas of the southern zone from Carpathians and the Caucasus to the Tian-Shan have waters with varying composition and mineralization.

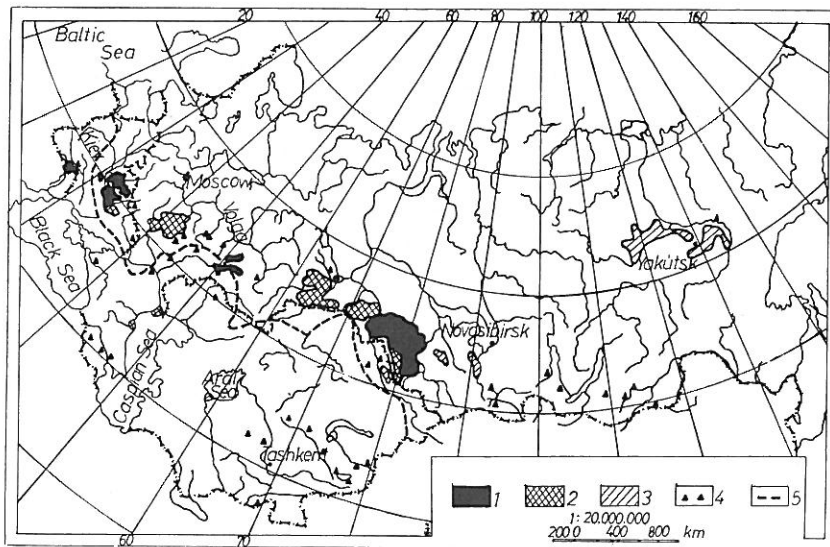


Fig. 2

Schematic Map of Saline-Sodic Soils Distribution in the USSR Territory
(KONDORSKAYA [21])

The schematic distribution of these zones is shown on the map (Fig. 2). By comparing this scheme and the map of soda salinity, one can see a striking coincidence between the areas with an all-round distribution of soda soils and the boreal belt of artesian waters having fresh, frequently weakly alkaline waters in the upper horizon between the areas with local or sporadic occurrence of sodic soils and the southern belt of artesian basins also with sporadic fresh waters in the upper horizon. Besides, more intimate differences in the artesian waters composition and distribution of sodic soils coincide. The most clearly expressed soda salinity and the largest areas of soda-saline soils in our country are found in the Baraba and Kulunda Lowlands. Western Siberia has also the greatest volume of fresh and weakly mineralized alkaline artesian waters — up to 500 m thick (on the Russian platform they are 100—200 m deep). Consequently, the regionally most clearly expressed soda salinity is related to the largest underground reserve of soda. It seems difficult to imagine, that this correlation

between the chemistry of artesian and soil waters should be causal. How can we decipher it? It is known that the upper zone of waters of the artesian basins and its composition are to a certain extent determined by the composition of surface waters infiltrating in the recharge area. In the area of discharge and evaporation of artesian waters the inverse relation must acquire greater importance: the influence of deep ground waters on the superficial ones.

Waters of the upper layers of the artesian basins are frequently calcium-bicarbonate. But during their ascent, evaporation and concentration their composition must change from calcium-bicarbonate to alkaline sodium-bicarbonate if there is present at least a small quantity of soda. Consequently, the fresh deep ground waters enrich the soil waters with soda.

Besides outflows as sources in large fractures and fissures, artesian waters are discharged in descending lowlands, like the Tambov and Dnieper—Donetz depressions, incised ancient and modern river valleys, intramountainous depressions, where the pressing waters mix with the surface and ground waters and are involved into the soil formation. The movement of pressing waters from depth to the surface is realized in different ways. One of them may be represented by their movement with capillary and film moisture. They may also rise along the series of small fractures in rocks due to disjunctive dislocations of the lower strata. The interbedded waters may be hydraulically connected with the ground waters in places of aquifuge ruptures. Mixing of the ground and interbedded waters frequently takes place in deep river valleys.

Our amount of knowledge on deep pressing water is yet extremely insufficient. It is obvious, however, that the underestimation of this factor makes the understanding of the main peculiarities of the soil cover more difficult. We mean the territories situated in the areas of discharge of artesian waters: zones of marginal flexures along the periphery of folded mountains, the foothill and intermountain depressions, the sinking areas, territories with tectonical disjunctions and fractures, the deeply incised valleys of large rivers and their tributaries. It is especially important to take all this into account while considering the problems of soil amelioration by changing the water and soil regimes (drainage, irrigation, leaching, construction of dams and reservoirs).

Having appeared in the superficial horizons, soda may accumulate only in quite definite hydrogeological and climatic conditions with an evaporative type of ground water balance. In purely humid areas with a clearly pronounced permacid regime soda, as other soluble substances, does not accumulate. Accumulation is possible only following the evaporation or if at least a periodical desiccation of soils occurs, f.i. in the monsoon tropics or in regions with winter freezing of the soil. The latter phenomenon is accompanied by an increase in the moisture content of the frozen layer at the account of water of the lower layers. If the frozen layers are situated in the zone of capillary fringe, the water deficit in the lower layer is made up at the expense of capillary ascension, and the ground water is spent in the process of further freezing. Together with waters, the dissolved salts are moving to the upper horizons. The winter salt accumulation plays a significant role in the salt balance of soils and waters in the West-Siberian Lowland (ORLOVSKY [24]), Yakutia (ELOVSKAYA [8]) and in other regions with a prolonged frost period.

So, the general annual duration and the seasonal rhythm of salt accu-

mulation are different in various regions. These differences are schematically reflected in Fig. 3.

Originating continuously in the crust of weathering from the aluminosilicates' hydrolysis and from other processes, soda has limited possibilities of distribution and accumulation. The possibility of stable existence of alkaline carbonates and bicarbonates in the solutions is limited by the presence of such soluble salts as gypsum and calcium chloride. Their interaction with sodium carbonate and bicarbonate is accompanied by the formation of CaCO_3 ,

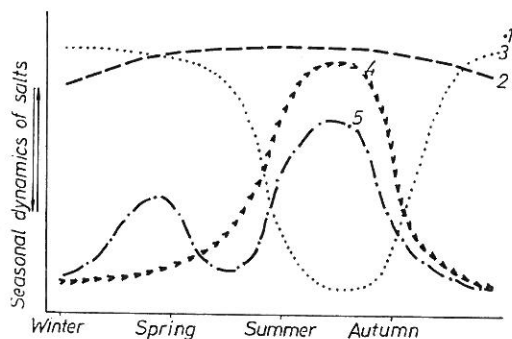


Fig. 3

Seasonal dynamics of salts in the soils depending on the type of climate: 1. Continental-tropical; 2. Continental subtropical; 3. Monsoon tropical and subtropical; 4. Mediterranean and continental subboreal with a mild winter; 5. Continental boreal and subboreal with a frosty winter

quite insoluble in alkaline medium, as well as of sodium chloride and sulphate. The same is going on by the interaction of soda solutions and exchangeable calcium. Theoretically, the free soda and sodium bicarbonate may accumulate in more or less considerable amounts only after transformation on the whole territory of all the exchangeable sulphate and chloride calcium into the calcium carbonate. It is just the presence of calcium sulphate in the water-collecting basins of Central Asia, with gypsum always present in Tertiary and Quaternary sediments and in the soils, that excludes the possibility of considerable soda accumulation on this territory.

However, there are some cases of high alkalinity and presence of soda in the gypsum-containing horizons of the hydromorphic soils in Yakutia (ELOVSKAYA [8]), in the solonetz of the southern Dnieper basin (MOZHEIKO [23]). The Ukrainian pedologists explain it by the "passivity" of gypsum owing to the formation of organic, or silica, or CaCO_3 films on the surface of crystals.

A serious factor, hindering soda accumulation in the landscape, is the high clay content of sediments. By percolation of soda waters through calcium-saturated clays, Na of soda enters the absorption complex by way of exchange reactions, thus reducing migration and accumulation of soda in the landscape.

A peculiar feature of alkaline soils of soda salinity is the predominance of montmorillonitic minerals in the clay fraction of these soils. It is precisely the montmorillonite which accounts for many physical-chemical properties of soda-saline soils: their high absorption capacity, water retaining capacity,

impermeability, swelling by moistening and high contraction with formation of large and deep fractures by desiccation, so peculiar for alkaline soils. There are certain grounds to suppose that the mineralogical composition of soda-saline soils is stipulated by their ancient or modern hydromorphism.

As it was already stated, the alkaline soils with soda salinity prove to be hydromorphic and develop under the influence of ground waters in the accumulative or transit-accumulative landscapes. All the dissolved substances come to the hydromorphic soil with the capillary fringe from the ground water; during desiccation or freezing of the soil they accumulate and consolidate in the profile. The balance of substances in a hydromorphic soil tends, on the whole, to be an accumulative one due to the coincidence of the positive signs of tendencies of the biological and geochemical cycle.

This type of balance may be expressed as follows:

$$S = f(P + A^b + Agch) T,$$

where:

S — soil; T — time of soil formation; P — parent rock, A^b — biological accumulation, Agch — geochemical accumulation.

Besides the soluble salts, the soluble silica and compounds of Fe and Al come to the horizons of alkaline soils.

In the ground waters of the soda-saline soils in the boreal and subtropical belts the SiO_2 concentration is usually equal to 10–20–30 mg/l, but sometimes, if the pH surpasses 9, the SiO_2 content approximates to 50–60 mg/l. The tropical sodic soils have ground waters with higher silica amounts. At these concentrations silica is supposed to be in the form of molecular solution of H_4SiO_4 (BOGOMOLOV et al. [3]). Iron and aluminium concentrations in the same waters are considerably lower and, as a rule, do not surpass 1 mg/l. Aluminium may migrate also in the form of aluminates. Neither iron, nor aluminium was found in the ionic form in the sodic soils of the boreal and subtropical belts. The greatest part of both elements is connected with the organic matter.

So, the Si/Al ratio in the ground waters of soda-saline soils is of the order of 100. In the process of concentration of the evaporating soil-ground waters a mutual precipitation of SiO_2 and of sesquioxides is quite possible. Because of a considerable prevalence of Si over Al, further crystallization of the allophanes leads to accumulation in the soils of such clay minerals as illite, interstratified minerals and, at last, of montmorillonite with the largest Si/Al ratio (2 : 1).

The second way of enrichment of the soda-saline soils with montmorillonite is the metamorphism of clay minerals in the alkaline medium, with silica present in the soil-ground waters. Minerals with a relatively low silica content are subjected to silication under these conditions. So the kaolinite or illite are transformed into the vermiculite or into montmorillonite. The possibility of such transformation was experimentally proved by JACKSON [13], who had observed this process in the calcareous humic gley soils in particular. KORNBLJUM [22] obtained reliable proofs of transformation of kaolinite-illite into the illite-vermiculite-montmorillonite in the soils of the Volga-Akhtuba flood plain. This transformation is realized through losses of potassium by the illite layers, through hydratation, silication and, to a lesser extent,

ferritization. Basing on the analogy with this case, it seems possible to regard the transformation of kaolinite into the montmorillonite with the help of an additional layer of silica-oxygen tetrahedrons combining with the two layers of kaolinite as a quite possible way of montmorillonitization.

Concepts on the genetic interrelations of clay minerals in watershed soils and in those of subdued depressions, developed by JACKSON, are of great interest. In all the climatic belts, according to JACKSON's, as well as POLYNOV's [25] notions, the most peculiar feature in weathering and soil formation on watersheds is the desilication leading to the allitization of eluvium. The liberated sesquioxides remain in situ, while silica is leached partially to the illuvial horizons, partially to depressions with the ground water flow. In

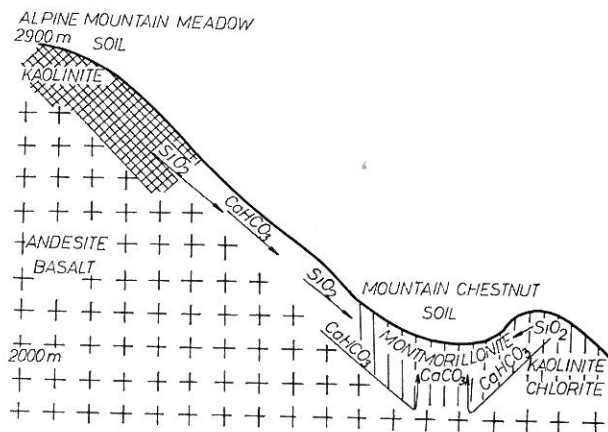


Fig. 4

Scheme of soil clay fraction montmorillonitization in the accumulative mountain landscapes

depressions, where micas kaolinite or Al oxides were primarily present, the silica interaction with these minerals leads to the montmorillonite formation. A similar process is suggested by JACKSON for the soil illuvial horizons. The montmorillonitization of soils on the periferies of slopes and depressions was stated by EDELMAN for the Indonesian ash soils already in the forties.

Correlations in the mineralogical composition of watershed weakly podzolic soils and of alkaline meadow solonetzic soils in Hungary were disclosed by GEREI with colleagues (GEREI, BIDLÓ and SZÉKELY [9]). The aluminium content in the clay fraction of podzolic soils is considerably higher than that in the meadow ones. It is interesting to note that the soil salt composition is reflected in the chemical composition of montmorillonite: the Na-montmorillonite predominates in the meadow solonetzic soil, NH_4 - and Mg-montmorillonite — in the forest soils, and Ca-montmorillonite in the carbonate horizon of meadow soil.

A connection between the processes of mineral formation in the eluvial and transit-accumulative landscapes is convincingly proved by the mineralogical investigations of mountainous soils. In particular, such investigations were carried out in Armenia, on the eastern slope of the Gegam Upland in

the Kamo district (RODE and MYAGKOVA [26]). Two soil profiles on the same parent rock — andesite-basalt — were studied those of a meadow alpine soil at an altitude of 2900 m in eluvial conditions and of a mountainous-chestnut soil (2000 m a. s. l.), developing under the influence of a pronounced deluvial hydromorphism (Fig. 4).

The synthesis of secondary minerals is quite different in these soils. In the alpine soil with its permacid regime and leaching of bases and silica acid, the main clay mineral is kaolinite. In the mountainous chestnut soil, receiving large amounts of silica acid and calcium bicarbonate with the deluvial solid and liquid flows, montmorillonite prevails. The received substances form a cemented carbonate horizon. It is peculiar that in a truncated chestnut soil, developed at the same altitude — 2100 m and in the same bioclimatic zone, but in eluvial conditions — on the summit of a sinter fan, neither carbonization, nor montmorillonite synthesis take place; kaolinite and chlorite predominate among the clay minerals.

The interrelation of processes of mineral formation in the eluvial, transit and accumulative landscapes, may be broadly outlined in the following way. In the crust of weathering the process of aluminosiliceous minerals destruction is going on continuously and everywhere. As a result of hydrolytical alterations silicate, alkaline and alkaline earth bicarbonate solutions are continuously being formed, as well as various iron and aluminium compounds whose mobility, despite the ability to form soluble compounds with the organic matter, is lower in all the landscapes in comparison with that of silica. The silica leaching is especially great in the tropical eluvial landscapes. Products of eluvial weathering, impoverished by silica are brought to the rivers, lakes and seas and deposited as deluvial, alluvial and proluvial sediments.

Under the influence of silica-enriched ground waters the soils of slopes and depressions detain part of the migrating silica acid. One of the main forms of detention and accumulation is the silication of such clay minerals as hydrargillite, boehmite, kaolinite, halloisite, illite that are transformed into minerals of the montmorillonite group. As it was already stated, the possibility of silication processes is especially great in the alkaline soils, where the SiO_2 concentration in the solutions can be very high.

Such are the reasons for the prevalence of montmorillonitic minerals in the soda-saline soils.

A vivid example of correlated minerals formation in the genetically connected landscapes is a catena of landscapes of tropical savannas, very typical for the monsoon tropics and subtropics of Africa, Asia and Australia. Allitization of the red crusts of weathering on watersheds supplies the accumulative and transit-accumulative landscapes with huge amounts of silica. On the summits and upper parts of slopes red allitic soils rich in boehmite, gibbsite, goethite and kaolinite are formed. Compact, black montmorillonitic, frequently soda-saline soils with calcium carbonate layers occur in the depressions and on deluvial slopes. Large areas of such soils may be traced in the East-African Rift, on Western Australian plains and in Southern India (Fig. 5).

Summarizing we can emphasize that soils of soda salinity are characterized by very intensive processes of modern mineral formation. Synthesis of minerals of the montmorillonitic group is active here, it is favoured by the accumulative balance of soil formation, as well as hydromorphism and alkalinity of these soils. The resilication of the secondary minerals in the

upper part of the soil profile takes place owing to the seasonal concentration of soda and silica containing solutions ascending with the capillary fringe and sharp changes in the redox and temperature conditions.

In conclusion we should like to discuss some examples relating to the soda-saline soils, occurring in patches under quite different climatic conditions, in different geological structures and having different history of development: the Tambow Lowland on the Russian Plain, the Ararat Valley in the Transcaucasia and the Nile Delta.

The Tambow Lowland is a typical accumulative plain in the centre of the Oka—Don Lowland in the forest-steppe and, partially, in the steppe zone. Composition and fabric of the sediments, relief and soil properties prove the

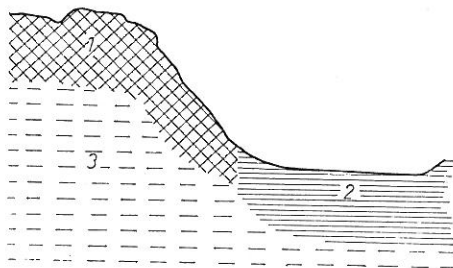


Fig. 5

Sodic salinization of soils in the tropics. 1. Allitized red crusts of weathering with kaolinite, gibbsite and hydrargillite. 2. Montmorillonitic argillaceous soils with features of sodic salinity and with accumulation of CaCO_3 . 3. Basalts, lavas, ashes

fluvio-glacial origin of the upper deposits. Alongside with sedimentation, the formation of primary soils proceeded under the hydrophilous vegetation. With the natural draining of the lowland, soils passed from the hydroaccumulative phase to the hydromorphous one with an intensive accumulation of the chemical substances from the high ground waters and a subsequent development of the fertile meadow, rich in humus soils. Following the regularities of chemical differentiation of substances in the geochemical flow, the Tambow Lowland proved to be a part of the belt of calcium, magnesium and sodium carbonate accumulation (KOVDA and SAMOILOVA [19]) which, to a certain extent, can be attributed to the effect of fresh pressing artesian waters discharging into this sinking lowland, surrounded by the uplands.

Until the landscapes of the lowland were influenced by ground waters, soda accumulation proceeded. It was gradually stopped when the soils and rocks became less hydromorphic. Nowadays the most elevated regions do not have any connections with the ground waters. Deep typical chernozems, doubtless paleohydromorphic, develop here now. But the greatest part of the Tambow Lowland is up till now in the hydromorphic conditions that force the development of chernozemic-meadow, frequently solonchakous soils, meadow chernozems, soda solonetz, solonchaks and solods. The development of the meadow complex is especially typical for the flat part of the lowland with weakly drained watersheds spotted by numerous depressions. The high complexity of the soil cover in such regions is due to stagnation and diversity of ground waters, changing their composition in accordance with micro- and

mesorelief. Depending on the increasing mineralization, the soil- and ground water composition changes from the calcium-hydrocarbonate with soda traces (1) to the sodium-magnesium-hydrocarbonate (2) then to the sodium-hydrocarbonate (3) and, at last, to the soda-sodium-sulfate (4). The minimal mineralization of ground waters in this series is equal to 0.5 g/l, the maximal one to 3.2 g/l. Waters of the 1st type are typical for the chernozemic-meadow non saline soils, of the 2nd for the solonchakous meadow soils, of the 3d for soda solonetz and of the 4th for solonchaks.

All the soda-saline soils display a high humus accumulation in these meadow conditions. In the chernozemic-meadow soils the humus content may reach 17%, and even in solonchaks it is about 3%. The discrepancy between the high humus content and the vegetation on modern solonchaks and solonetz makes it possible to suppose the origin of saline soils to be related to salinization of primarily weakly saline chernozemic-meadow soils. In the clay fraction of the meadow soils, solonetz and solods montmorillonite and illite prevail. The montmorillonite content increase with the depth, that may be explained by its synthesis under the influence of inflow of silica and aluminium with the capillary fringe.

The soil reaction is alkaline: pH 8.0—8.5 in the upper horizons, and up to 9—10 in the lower ones. All the soils of the solonetzic complex have a certain amount of absorbed Na, in the subsolonetzic horizons its content reaches 60% from the total sum of exchangeable cations.

The peculiar property of soils is a high carbonate content throughout the profile. The CaCO_3 and MgCO_3 deposition is especially strong owing to a sharp increase in alkalinity of the solonetz soils. The stock of these (2) salts in the stratum of 0—2 meters of a sodic solonetz reaches 4,000 t/ha.

The Ararat Valley of Armenia is an intermountain accumulative plain surrounded by volcanic massifs of Aragats, Ararat, and Gegam mountains in the Transcaucasia.

The Ararat Valley is situated in the zone of dry subtropics, its soils are represented by brown semidesertic soils, frequently with patches of saline soils. One of the biggest patches with soda salinity is the Arazdayan steppe situated on the Arax terrace.

The Arazdayan steppe serves as a water-collecting basin for the surrounding mountainous systems. It is very poorly drained, the depth of ground waters is about 0.5—2.5 m, evaporation exceeds the rainfall twofold. All those factors promote salt accumulation. The ground waters are of soda-sodium-chloride and soda-sodium-sulphate types.

The titrating alkalinity is high, the content of normal soda is equal to 0.025—0.476 g/l of CO_3^{2-} . The sources of soda in ground waters are the altering volcanic rocks of the surrounding ridges together with alkaline pressing artesian waters, discharging into the plain. A certain amount of soda might result from biochemical reduction of sulphates.

Formerly meadow soils of the Arazdayan steppe have now entered the phase of an intensive salinization. The titrating alkalinity reaches 3.6% of HCO_3^- , the soil reaction is strongly alkaline throughout the profile: pH 9.4—10.1. The exchangeable sodium is dominating in the absorption complex. The high calcium carbonate content is typical and is explained by the precipitation of calcium bicarbonates, coming from the mountains with the underground flow. Calcium carbonate total reserves in the one-meter thick

layer are equal to 1700–2000 to/ha. The calcium carbonate is accumulated diffusely, in the microcrystalline form.

The humus content is extremely low, only 0.7% in the upper horizon.

In the profiles of solonetz-solonchak soils processes of transformation of clay minerals are intensive. Only the particles of chlorite are brought from the mountains to the valley. In the profile of a soda-saline soil the silication of this mineral with illite formation takes place. The interstratified layer-lattice minerals are prevailing, newly formed illite layers are stratified with chlorite layers. A mineral of the montmorillonite group representing a further stage of chlorite silication has been found.

The delta of the great African river Nile is situated in the zone of tropical deserts. It is a flat monotonous plain, consisting of alluvium, brought and deposited by numerous tributaries. The source of soda salinity is the Nile water, feeding the delta and used for irrigation. It has a low mineralization (100–300 mg/l) and throughout the year a small amount of soda is always present. The HCO_3^- ion content may be equal to 40% of the total soluble salts. Rather high is the silica content: mean values are 15–25 mg/l of SiO_2 , but in certain periods they may rise up to 40–60 mg/l of SiO_2 . The composition of the Nile water, according to long-term observations (1906–1936), is given in Table 1.

Table 1

The Nile water composition, meq/l
(according to WARREN et al. [30])

	HCO_3^-	CO_3^{2-}	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+
in the flood	1.44	0.23	0.16	0.14	0.64	0.57	0.50
in low water	3.03	1.44	0.23	0.46	0.87	0.72	2.04

The annual amount of salts coming to the delta with the river waters reaches 10.7 mln tons, including 1.7 mln tn of Na_2CO_3 and 0.5 mln tn of K_2CO_3 ; 1.7 mln tn of Ca_2SiO_4 , 0.9 mln tn of SiO_2 (ELGABALY [7]).

The high content of soda and silica is due to the formation of the Nile's upper flow in the volcanic Abyssinian plateau and Victoria Lake supplying the alkaline products of weathering of granites and volcanic material to the Nile's waters. In the Nile's upper flow the processes of desilication are developed, liberating large amounts of silica acid and alkalis. The ground waters are not very saline (1–2 g/l) but they contain soda.

The modern irrigation system is not provided with a sufficient drainage, the ground-water level is rather high and the extraordinarily strong evaporation, characteristic of deserts, causes a progressive soda salinization of the soils. With a further increase in salt concentration up to 4 g/l the main role is played by the SO_4^{2-} ion, at 11 g/l NaCl becomes predominant (KOVDAT [17]).

The soda-saline soils in the Nile delta have a very high alkalinity (pH 9–10.5) and a constant presence of sodium in the absorbing complex. In some cases it may be equal to 70% of the absorbing capacity. A strong accumulation of CaCO_3 and Mg silicates is also peculiar (GRACIE et al. [10]). The high exchange capacity (50 meq/100 g) on the background of low humus content

(0.5—2%) allows to suppose the predominantly montmorillonite composition of the clay fraction. Among the soda saline soils a group of black alkaline and of gypsum-containing soils is distinguished.

The examples, discussed in the previous pages, confirm the fact that the phenomena of soda salinity and soil montmorillonitization prove to be a planetary pedo-geochemical process, characteristic of the hydromorphic landscapes with an accumulative balance of substances.

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