3. Soil Salinization and Alkalization Processes

3.1. Saline and alkali soils

It is generally accepted that water soluble salts, particularly the sodium salts, are responsible for the low fertility of salt affected soils. Saline or alkali soils are soils in which the content of salts (or their ions) interferes with the growth of the majority of crops.

Two main groups of these soils may be distinguished:

1. Soils affected by neutral sodium salts (mainly sodium chloride and sodium sulphate);

2. Soils affected by sodium salts capable of alkaline hydrolysis (mainly $NaHCO_3$, Na_2CO_3 and Na_2SiO_3).

In the course of the development of soil science and soil classification, two main groups of these soils have been distinguished: soils belonging to the first group have mainly been named saline, and those of the second group, alkali soils. These two main types differ not only in their chemical character but also in their geographical and geochemical distribution, as well as in their physical, chemical, physico-chemical and biological properties. The methods used for their reclamation and agricultural utilization are also different.

Although it is evident that in Nature the various sodium salts do not occur absolutely separately in soils, in most cases either the neutral sodium salts or those capable of alkaline hydrolysis exercise a dominating influence on soil forming processes and soil properties.

On different continents, under the very wide range of environmental conditions, the general levels of the salinity and alkalinity of parent materials and ground waters may differ sharply. The salinity or alkalinity tolerance of local crops also varies widely.

The potential salinity or alkalinity of an area depends to a considerable extent on the cropping system used in that particular area.

It is more than obvious that in all these respects only very vague limit values may be given on a world-wide scale. Therefore, it is necessary that, while keeping the basic principles in mind, a certain flexibility be displayed in the definition of the salinity and/or alkalinity limit values characterizing the salt affected soils of a given territory, that is, the local conditions should also be taken into consideration.

Table 3.1, compiled by R. Dudal and I. Szabolcs [In: Szabolcs 1974], demonstrates the correlation between the classification system elaborated by the Subcommission on Salt Affected Soils of the International Society of Soil Science and other, widely used classification systems of salt affected soils.

Table 3.1

Tentative Correlation of the Most Widely Used Classification Systems of Salt Affected Soils

Subcommission on Salt Affected Soils Classification			Soil Map of the World (Soil Map of Europe) FAO/UNESCO Project (ECA Working Party) Classification	Australian Classification 1968	Canadian Classification 1965	French Classification 1967	USDA Classification 1967	USSR Classification 1967
Basic Grouping 1967	In the legend of the Map of European Salt Affected Soils 1968	In the legend of the Saline and Sodic Soils Map of Australia 1971						
Saline Soils	*Saline Soils*	*Saline Soils*	*Solonchak* Orthic solonchak Mollic solonchak	Solonchak	Saline sub-groups (pp)	Sols salins (excepté sousgroupe acidifié) Sols salins à alcalins Sols à gley salés	Salorthids Salorthidic Calciustolls Salorthidic Haplustolls	Fluffy solonchak (non steppic) Crust solonchak Soda solonchak (non steppic) Fluffy solonchak (steppic) Soda solonchak (steppic) Takyrs Meadow solonchak
Alkali Soils without structural B horizon	*Alkali Soils* without structural B horizon	*Alkaline Sodic Soils* AS1 AS2 AS3	Takyric solonchak Gleyic solonchak				Halaquepts (pp)	
Alkali Soils with structural B horizon	*Alkali Soils* with structural B horizon	*Non-Alkaline Sodic Soils* NS1 NS2	*Solonetz*	Solonetz and solonized solonetz		Sols sodiques à horizon B et solonetz solodises		
	Solonchak-solonetz and calcareous solonetz						Nadurargids Natrargids Natriboralfs Natrudalfs Natrustalfs Natrixeralfs	Desert-steppe and Desert solonetz
	Non-calcareous solonetz with A horizon < 15 cm		Orthic solonetz		Brown solonetz (pp) and alkali solonetz			
	Solodized and/or deeply leached solonetz		Mollic solonetz		Black, grey and brown solonetz (pp)		Natralbolls Natriborolls Natrustolls Natrixerolls	Steppe solonetz
	Solonized and slightly salt affected soils with minor structure formation		Gleyic solonetz Solodic planosols	Solod and solodic groups (pp)	Gleyed solonetz Solod and solodiced sub-groups (pp)		Natraquolls Natraqualfs Argiabolls (pp)	Meadow solonetz Solod
	Deeply leached solodized soils and solods							

pp = in parts

3.2. World extension of salt affected soils

There are vast areas in all continents covered by salt affected soils. We still do not have an accurate cadaster on the exact territory and distribution of salt affected soils, due to the fact that in some countries they have been studied in more detail and in other countries only moderately, while in many areas the existence of these soils was only recognized due to the up-to-date surveys or the pressing demand for the agricultural utilization of the territory.

However, thanks to the FAO/UNESCO Soil Map of the World (on a scale 1 : 5 000 000), and to the maps of salt affected soils of various continents prepared by the Subcommission on Salt Affected Soils of the ISSS, as well as other numerous international and national efforts, we are now in possession of a good estimation of the world extension of salt affected soils. In Table 3.2 data are given on the distribution of salinity and alkalinity in the countries mainly affected, as compiled by F. Massoud and based on the FAO/UNESCO Soil Map of the World (on a 1 : 5 000 000 scale).

In Table 3.2, in accordance with the legend of the Soil Map of the World, saline soils are indicated as solonchak, or as saline phase, while alkalis soils are indicated as solonetz or alkaline phase. The data show that the rough estimation of the territory of salt affected soils is as follows:

	Thousand ha
North America	15 755
Mexico and Central America	1 965
South America	129 163
Africa	80 538
South Asia	87 608
North and Central Asia	211 686
South East Asia	19 983
Australasia	357 330
Europe	50 804
Total:	954 832

A more detailed estimation of the extension of salt affected soils was prepared for Europe. Table 3.3 gives data on the distribution and extent of salt affected soils in Europe [In: Szabolcs 1974].

The total area covered by salt affected soils in Europe is 50 804 000 ha.

3.3. Effects of salinity on the soils of arid and semi-arid regions

Kovda [1947] delineates the following three effects of salinity on the soils of arid and semi-arid regions:

a) Effect of the climate. The sparse rainfall leads to insufficient humidity and irregularity, so consequently, the soil forming processes are only fairly intensive in certain periods, while in others they practically cease. The climate governs the dynamics and migration of both mineral and organic elements in the soils. The weathering processes are limited by the shortage of water, which also prevents the leaching and transport of the weathering products. In dry periods the soluble substances form efflorescence in patches on the soil surface.

Table 3.2

Distribution of salinity and alkalinity in countries mainly affected (areas in 1000 ha)

Country	Solonchaks	Saline phase	Solonetz	Alkaline phase	Total
North America					
Canada		264	6 974		7 238
USA		5 927	2 590		8 517
Mexico and Central America					
Cuba		316			316
Mexico	242	1 407			1 649
South America					
Argentina	1 905	30 568	11 818	41 321	85 612
Bolivia		5 233	716		5 949
Brazil	4 141		362		4 503
Chile	1 860	3 140		3 642	8 642
Columbia	907				907
Equador	387				387
Paraguay		20 008	1 894		21 902
Peru	21				21
Venezuela	1 240				1 240
Africa					
Afars and Issas Territory	59	1 682			1 741
Algeria	1 132	1 889		129	3 150
Angola	126	314	86		526
Botswana	1 131	3 878		670	5 679
Chad	2 417		3 728	2 122	8 267
Cameroons				671	671
Egypt	3 283	4 077			7 360
Ethiopia	319	10 289		425	11 033
Gambia		150			150
Ghana	200			118	318
Guinea		525			525
Kenya	3 501	909		448	4 858
Liberia		362	44		406
Libya	905	1 552			2 457
Madagascar	37			1 287	1 324
Mali		2 770			2 770
Mauritania	150	490			640
Morocco	42	1 106			1 148
Niger			111	1 378	1 489
Nigeria	455	210		5 837	6 502
Portuguese Guinea		194			194
Rhodesia				26	26
Senegal	141	624			765
Sierra Leone		307			307
Somalia	1 043	526	3 754	279	5 602
South West Africa	562		1 751		2 313
Sudan		2 138		2 736	4 874
Tanzania		2 954		583	3 537
Tunisia	990				990
Zaire		53			53
Zambia				863	863

Table 3.2 continued

Country	Solonchaks	Saline phase	Solonetz	Alkaline phase	Total
South Asia					
Afganistan	2 924	177			3 101
Bangladesh		2 479		583	3 017
Burma	634				634
India	2 979	20 243		574	23 796
Iran	24 817	1 582		686	27 085
Iraq	6 679	47			6 726
Israel	28				28
Jordan	74	106			180
Kuwait	209				209
Muscat and Oman	290				290
Pakistan	1 103	9 353			10 456
Quatar	225				225
Sarawak		1 538			1 538
Saudi Arabia	6 002				6 002
Sri Lanka	180	20			200
Syria		532			532
Trucial States	1 089				1 089
Turkey					2 500
North and Central Asia	7 307	28 914		437	36 658
China	3 728	342			4 070
Mongolia		238			238
Solomon Island	11 430	39 662	30 062	89 566	170 720
USSR					
South East Asia		13 213			13 213
Indonesia		1 291			1 291
Khmer Republic		3 040			3 040
Malaysia		1 456			1 456
Thailand		983			983
Viet Nam					
Australasia	16 567	702	38 111	301 860	357 240
Australia		90			90
Fiji					

In cases where the soils are not enriched even secondarily with sodium compounds and Ca and Mg dominate among the cations (gypsiferous soils, magnesium soils, etc.) the dry climate leads to certain geochemical processes which affect the accumulation of soluble products both in the soils and waters of these regions.

b) Kovda [1947] and others [Polynov 1930; Szabolcs 1961] also called attention to the action of the ground water in the soil forming processes of arid and semi-arid regions. A large part of the soils in semi-arid and arid regions have either been exposed to hydromorphic influence in the past, or they are under such influence at the present time. Even in zones where the soil does not, in the course of time, pass through this kind of cycle, the presence of ground waters, either at the base of or within its profile, has a remarkable effect on its properties and its evolution.

The ground water is always mineralized to some degree. In an arid climate, the soluble elements it contains rise upwards through the soil as

Table 3.3

Distribution and extent of salt affected soils in Europe

Countries and originators	Mapping units: area in 1000 ha/area in percentage of the total salt affected area					Total area in 1000 ha
	Saline soil	Alkali soil: without structural B horizon	Alkali soil: with structural B horizon, non calc.	Alkali soil: with structural B horizon, calc.	Potential salt affected soil	
Austria J. Fink O. Nestory	0.5 / 25.0	— / —	— / —	— / —	2.5 / 75.0	3.0
Bulgaria L. P. Raikov H. Trashliev	5.0 / 20.0	— / —	20.0 / 80.0	— / —	— / —	25.0
Czechoslovakia J. Hrasko	6.2 / 5.8	7.5 / 7.1	2.7 / 2.5	4.3 / 4.1	85.0 / 80.5	105.7
France E. Servat J. Servant	175.0 / 70.0	— / —	75.0 / 30.0	— / —	— / —	250.0
Greece E. P. Papanicolaou						3.5
Hungary I. Szabolcs G. Várallyay J. Mélyvölgyi	1.6 / 0.1	58.6 / 4.7	294.0 / 23.1	31.9 / 2.5	885.5 / 69.6	1 271.6
Italy O. T. Rotini L. Carloni	50.0 / 20.0	— / —	— / —	— / —	400.0 / 80.0	450.0
Portugal J. Carvalho Cardoso M. Branco Marado						25.0
Rumania N. Florea J. Munteanu	40.0 / 16.0	100.0 / 40.0	110.0 / 44.0 (non calc. and calc.)		— / —	250.0
Spain P. Grajera Torrez R. Grande Covian J. Bardaji Cando J. M. Ontanon						840.0
USSR V. V. Egorov N. I. Bazilevich E. I. Pankova	7 546.0 / 16.0	1 616.0 / 3.4	20 382.0 / 43.1	— / —	17 781.0 / 37.5	47 325.0
Yugoslavia N. Miljkovic G. Filipovski N. Plamenac P. Blaskovic	20.0 / 7.8	50.0 / 19.6	110.0 / 43.1	75.0 / 29.5	— / —	255.0

a result of capillary action and enrich the soil surface, forming efflorescences, which are grey or white in colour when there is an accumulation of sodium chloride or sodium sulphate, or of salts of magnesium or calcium, and black or dark brown when formed from sodium carbonate coloured by dissolved humus in the top soil horizons. These efflorescences appear either right on the soil surface or in the upper part of the fissures, or else, in the case of highly saline alkali soils, just below the powdery horizon. They may also form lower down, however, in grooves, root-holes, etc. in the form of pseudomycelium.

This phenomenon operates whenever a deep horizon rich in salts becomes water-logged even only temporarily. It is greatly accentuated when it is due to a real water table.

It is, however, only after a certain "critical depth", varying according to the texture, structure and other factors of the soil, that efflorescences may, subject to the salt content of the ground water, make their appearance. This is vitally important for all irrigation and drainage operations in arid zones. The critical depth depends on numerous environmental and even technicoeconomical factors, but in general a good relation exists between the total salt content of the ground water and the so-called critical depth. This relation is demonstrated in Figure 3.1 [after KOVDA; In: International Source Book 1967] which shows that the higher the degree of mineralization, the greater the depth to which the ground waters can salinize the soil and thereby destroy crops.

c) The direct effect of salts on soils and soil forming processes. Many arid soils are rich in soluble salts [as indicated in a) and b)]. The origin of these salts varies widely. In some cases they were either present in the parent rock or produced as a result of the weathering of these rocks, and the insufficiency of precipitation prevented them from being removed to a distance. In other places they originate from sea-spray or from efflorescences on the denuded surface of other saline soils, blown by the wind, or again they are contained in irrigation or flood waters and have, as a result of a climate with a strong power of evaporation, been leached far away from the surface. Frequently, the salts rise up through the profile by capillary action, from mineralized ground waters [as indicated in b)].

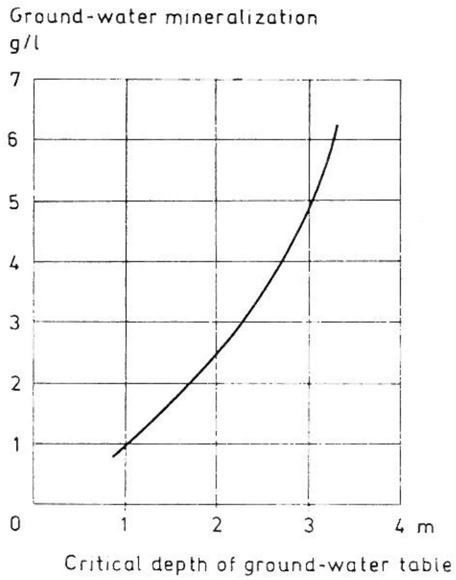

Fig. 3.1.
Relationship between ground water salt content and the "critical ground water level"

These salts may simply accumulate in the soil, affecting the flocculation of the clay-humus complex and the development of the vegetation and microflora of the soil.

Table 3.4

Content of the most common elements of the earth's crust in %
[CLARK In: International Source-Book 1967]

Name of element	%	Name of element	%
Oxygen*	49.13	Potassium*	2.35
Silicon	26.00	Hydrogen*	1.00
Aluminium	7.45	Titanium	0.61
Iron	4.20	Carbon*	0.35
Calcium*	3.25	Chlorine*	0.20
Sodium	2.40	Phosphor	0.12
Magnesium*	2.35	Sulphur*	0.10
		Manganese	0.10

The asterisk denotes the elements which participate in the formation of the easily soluble salts leading to soil salinity.

More frequently the presence of sodium salts leads to the dispersion of soil colloids and creates a very compact and diffused structure.

When the salts simply accumulate in the soil, the phenomenon is closely related to saline soil formation, while the dispersive and colloid chemical effects of salts are closely associated with the formation of alkali soils. In this case the dispersed clay is easily carried away in pseudo-solution either laterally, on the surface of the soil which is eroded by sheet erosion, or vertically, in which case the sodic clay carried away is deposited at a certain depth of the soil profile where it accumulates as a result either of the effect of an extremely impermeable horizon or because of limited penetration of the sparse rainfall.

3.4. Main soluble salts in salt affected soils and waters, and their origin

From the numerous salt compounds which are found in various quantities in different soils we shall take a look at the main types of salts which lead to the formation of saline and alkali soils.

The main elements, combinations of which give rise to the formation of saline soils, are Ca, Mg, Na, K, Cl, S, C, N and B. Apart from these, Cu, Zn and I often accumulate, in micro quantities, in saline soils.

Elements from which soluble salts can be formed are some of the most common found in the earth's crust; they are, in fact, among the first fifteen elements (Table 3.4).

During the geological period, the continuing magma-forming processes and the volcanic and post-volcanic phenomena occurring in the earth's crust facilitated the accumulation of vast quantities of chlorides, sulphates and borates, both in the solutions circulating on the earth and in the oceans and in continental and marine deposits.

The weathering of the crystalline rocks forming the continents was considered, at one time, as the main source of the easily soluble salts found in natural waters, sediments and soils. GLINKA [1914], GEDROITZ [1917], POLYNOV [1956], and FERSMAN [In: International Source Book 1967] in the USSR and HILGARD [1910], HARRIS [1920] and KELLEY [1948] in the USA took the

Table 3.5

Sequence of ion-extraction during weathering [according to FERSMAN In: International Source Book 1967]

Sequence of extraction	I		II		III		IV	
	Ions	C.E.	Ions	C.E.	Ions	C.E.	Ions	C.E.
Ions	Cl, Br	0.23	Na	0.45	SiO_3	2.75	Fe	5.15
	NO_3	0.18	K	0.36			Al	4.25
	SO_4	0.66	Ca	1.75				
	CO_3	0.78	Mg	2.10				

C.E. = coefficient of energy

view that weathering processes were mainly responsible for the appearance and accumulation of these salts in natural waters, deposits and soils on the continents.

The chemical composition of the salt solutions formed by the weathering of igneous rocks depends to a very large extent on the mineral composition of the rocks.

The sequence of extraction of the ions during weathering, their speed of migration and the ability of the ions to accumulate in inland depressions in the form of salt masses are proportional to the ionic radius, the valency and the stability of the crystal network of the compound (Table 3.5).

POLYNOV [1956] and KOVDA [In: International Source Book 1967] divided the elements into five categories according to their mobility during weathering and their migration capacity. The migration categories of the elements are as follows:

1. Virtually non-leachable	Si in quartz
2. Slightly leachable	Fe, Al, Si
3. Leachable	Si, P, Mn
4. Highly leachable	Ca, Na, K, Mg, Cu, Co, Zn
5. Very highly leachable	Cl, Br, I, S, C, B.

Both the absolute and relative participation of different elements in the formation of saline soils and natural waters will be greater, the higher the migration category of the element.

Elements of the 4th and 5th migration categories will constitute the main compounds contributing to contemporary salt accumulation: NaCl, Na_2SO_4, $MgCl_2$, $MgSO_4$, $CaSO_4$, Na_2CO_3, $NaHCO_2$, $CaCO_3$ and $MgCO_3$. In inland depressions, arid regions, marine deltas and in the oceans, the elements of the 4th and 5th categories are certain to accumulate in the largest quantities. The presence of soluble salts in the different geological layers in the sediments and in the parent materials always means that there is a risk that salt affected soils will form, but it does not always lead to the full development of this process.

The distribution of soluble salts and the processes of salt accumulation are connected with definite types of relief and with certain geomorphological and hydrogeological conditions. From the point of view of soil chemistry, the

Table 3.6

Characteristics of accumulation processes in Eurasia, in relation to natural conditions

Conditions	Residual salinization of sedimentary rocks	Maximum mineralization of waters, g/l			Max. quantity of soluble salts in top horizons of solonchaks %	Typical compounds
		river	ground	lake		
Desert	common	20—90	200—350	350—400	25—75	NaCl KNO_3 $NaNO_3$ $MgCl_2$ $MgSO_4$ $CaSO_4$ $CaCl_2$
Semi-desert	frequent	10—30	100—150	300—350	5—8	NaCl Na_2SO_4 $CaSO_4$ $MgSO_4$
Steppe	rare	3—7	50—100	100—250	2—3	Na_2SO_4 NaCl Na_2CO_3 $NaHCO_3$
Forest steppe	none	0.5—1.0	1—3	10—100	0.5—1.0	$NaHCO_3$ Na_2CO_3 Na_2SO_4 Na_2SiO_3
Forest	none	0.1—0.2	0—1	none	none	R_2O_3 SiO_2

solubility of salts is one of the most important properties characterizing the mobility of salts in soils and this property is the one which influences the degree of salinization and the distribution of salts with different chemical compositions.

When a dry soil becomes wet, different compounds become soluble. If sufficient quantities of solid salts are present, a saturated solution may be obtained.

According to KOVDA [1947, 1954] the main types of salts which lead to the formation of salt affected soils are the following:

(i) *Carbonates.* — Salts of carbonic acid are widely found in soils, subsoils and ground waters of deserts, semi-deserts, steppes and even forest steppes. The role of these salts depends on the character of the carbonate-containing compound, on the amount of salts accumulated, on their solubility, on their toxic effect on plants and on their effect on the colloidical and water-physical properties of the soils.

(ii) *Sulphates.* — Sulphuric acid salts are found in varying quantities in almost all types of soils. In the soils and ground waters of steppes and deserts, sulphates accumulate in very considerable amounts.

(iii) *Chlorides.* — High solubility and, consequently, high toxicity are characteristic for all chlorides. The chlorides, together with sulphates, are the main compounds responsible for the formation of saline soils.

The leaching of saline soils containing sodium chloride and calcium sulphate is very easy. If the soil does not contain calcium sulphate, the leaching out of sodium chloride solonchaks can lead to the formation of alkaline soils.

(iv) *Borates.* — The salts of boric acid rarely occur in excess in soils. When this happens, it is usually connected with specific geological conditions.

In nature few processes are one-way processes. In the case of soil salinity, the processes of salinization often alternate with periods of desalinization. The alternate processes of salinization and desalinization are called the salt regime of the soil.

The salt regime of the soil is determined by the climatic, geomorphological, hydrological and hydrogeological factors of the area under natural conditions, and as a result, salts accumulating during the dry period of the year can move downwards during the rainy period according to their solubility. If the salt accumulation prevails over the leaching processes, salinization of the soil takes place. The dominating direction of salt movement is reflected in the distribution of salts with different solubilities. If salt accumulation is the dominating process, the accumulation of readily soluble salts will be nearer to the surface than the accumulation horizon of the less soluble salts. If the leaching processes prevail, the maximum of the easily soluble salts will occur in the same horizon or even deeper than the accumulation of the less soluble salts.

The degree and type of salinity of ground waters and soils are closely related to the hydrochemistry of the rivers and lakes of the given area, as well as to that of underground layers.

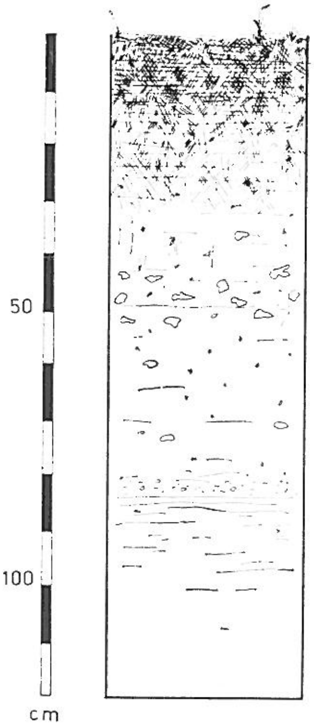

Fig. 3.2
Schematic profile of a saline soil

In Table 3.6 the characteristics of accumulation processes in different natural conditions are given for typical districts of Eurasia.

3.5. Saline soils

In arid regions, deserts and semi-deserts, the most strongly saline soils (having several per cent of water soluble salts in their profile and millimhos values higher than 10) contain mainly NaCl and Na_2SO_4. In Russian literature this group of soils is denominated as chloride and/or sulphate solonchak. Saline soils mainly belong to this group. As a rule, these soils occur under dry conditions in large arid and semi-arid regions in Eurasia, North Africa, in the western part of North and South America, and in the central part of Australia.

The accumulation of NaCl and Na_2SO_4 takes place in varying degrees in the soil profile. In many cases the salinization process is so intensive that a thinner or thicker salt crust has formed on the soil surface and the concentration of salts in the various horizons of the soil profile may amount to several percent. When referring to saline deserts, it is hardly possible to speak of "soils" at all, because the strongly saline formations are completely devoid of the most essential property of soils, that is, fertility.

It is evident that all the properties of saline soils are conditioned by the high salt content.

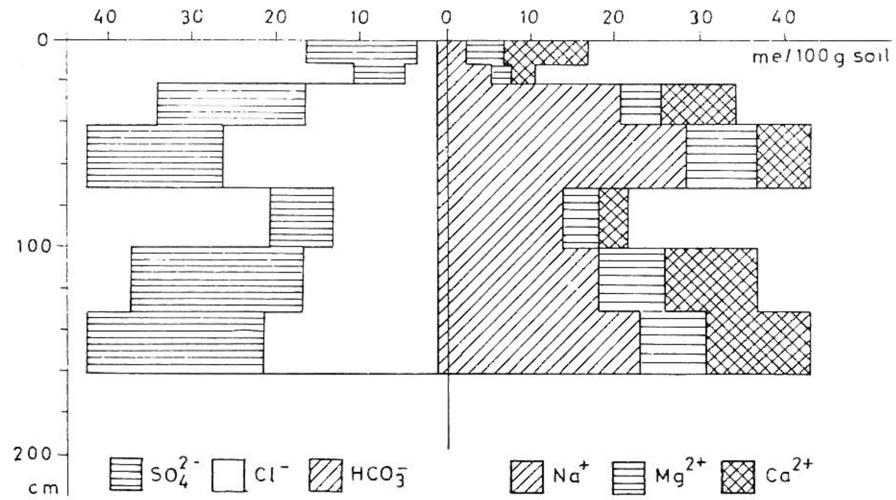

Fig. 3.3
Salt profile of a saline soil from the Caspian Lowland (chloride sulphate solonchak)

Figure 3.2 demonstrates the schematic profile of a saline soil.

The basic morphological precondition for saline soils is the lack of a structural B horizon (see Fig. 3.2). Although several morphological systems use the letter "B", in those cases it never signifies a horizon distinguishable from the A horizon by its well-developed structural formation. Consequently, the profiles of saline soils are rather monotonous, from the surface down to the parent material. In a few cases, when saline soils have formed under bog conditions, the top layers are humus, but usually, when they have developed under arid conditions, these soils are very poor in humus substances and their humus content is lower than 1%. The low plant nutrient content (mainly N and P_2O_5) is also characteristic of most saline soils.

The high salinity determines practically all the physical and chemical properties of saline soils; consequently, when these properties are evaluated, primarily the salt content of the soils and its influence should be taken into consideration.

Many classification systems employ the term "chloride and/or sulphate solonchak" for saline soils.

Figure 3.3 demonstrates the salt profile of a saline soil (chloride-sulphate-solonchak) from the Caspian Lowland, USSR.

The diversity of the shape of the salt profile in solonchak soils can be observed, if, besides the above indicated salt profiles, we take a look at the salt profile of a saline soil from the Guadalquivir River Delta (Spain) (Fig. 3.4).

The description of a saline soil of Marismas is as follows:

A_{11}	0–5 cm	Dark greyish-brown (10YR 4/2), calcareous fine clay, medium moderate laminar structure, abundant roots, slightly organic, moderately moist, very sticky and very plastic, abrupt smooth boundary.
A_{12}	5–25 cm	Dark greyish-brown (10YR 4/2), calcareous fine clay, coarse moderate granular structure, abundant roots, very slightly organic, moist, very sticky and very plastic, gradual smooth boundary.
AC	25–29 cm	Dark brown (10YR 4/3), calcareous fine clay, few roots, very coarse moderate prismatic structure, presence of slickensides, moist, very sticky and very plastic, common fine faint mottles about 5%, very dark grey (5YR 3/1) and dark reddish-grey (5YR 4/2), diffuse and smooth boundary.
Cy	95–135 cm	Similar to the overlying layer but saturated with water; coarse yellowish-red patches, about 30% (5YR 5/8). Very few roots.
CG	135 cm	Gley, greenish-grey (5GY 5/1). Water appears. No roots.
Elevation:		5 m above sea level.
Water table:		140 cm.
Slope:		0%.

3.6. Alkali soils

While the effect of neutral sodium salts on soils is mainly associated with arid or semi-arid regions, the occurrence of alkali soils formed under the influence of sodium salts capable of alkaline hydrolysis may be found not only in arid and semi-arid regions, but also in areas with a moderate or even semi-humid or humid climate [Szabolcs 1970].

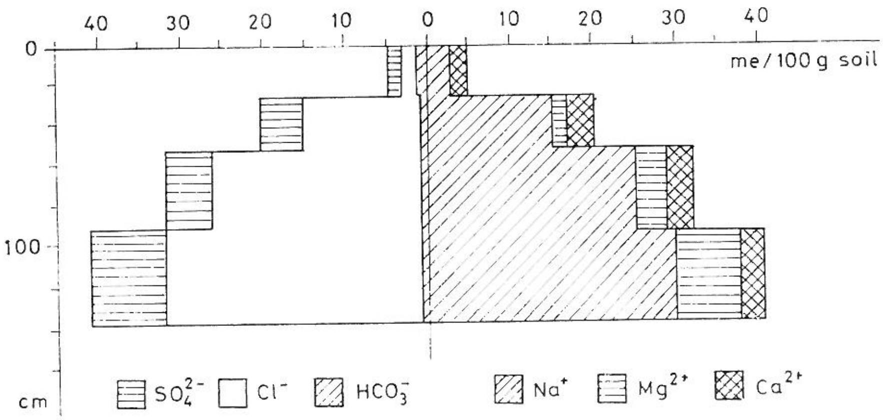

Fig. 3.4

Salt profile of a saline soil (sulphate-chloride-solonchak) of Marismas, Spain

When sodium salts capable of alkaline hydrolysis are discussed, both in the literature and in practice, the effect of sodium carbonate or bicarbonate is usually emphasized. However, we must not focus our attention solely on the effect of these compounds when striving to elucidate the soil processes. It is fairly evident that in addition to Na_2CO_3 and $NaHCO_3$, other compounds capable of alkaline hydrolysis also play an important role in the formation of alkali soils.

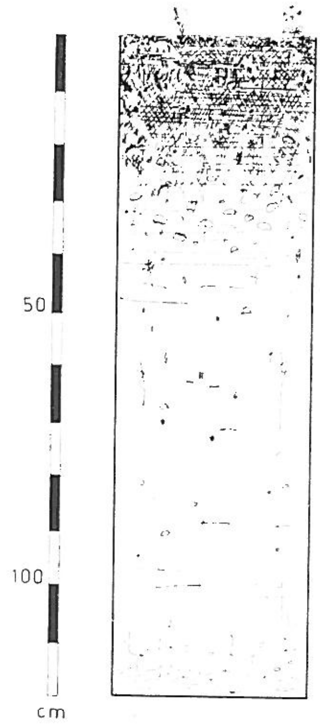

Fig. 3.5
Schematic profile of an alkali soil without structural B horizon

In alkali soils, the presence of Na-salts capable of alkaline hydrolysis determines the soil properties [Gedroitz 1928; Szabolcs 1969]. Due to their effect, either the high alkalinity of the soil solution hinders plant growth, or the alkalinity renders the physical soil properties disadvantageous for the water supply of the plants. Evidently, these processes often exert their harmful influence together, though in alkali soils without structural B horizons the former, and in alkali soils with structural B horizons the latter dominates.

As a rule, in the case of soils belonging to subclass a) (alkali soils without structural B horizons) quite a high concentration of water-soluble sodium salts capable of alkaline hydrolysis can be found even in the top layers. In subclass b) (alkali soils with structural B horizons) the concentration of water-soluble salts is often very low, and, except in the B horizon, the alkalinity may also be quite moderate. Owing to the considerable differences between the properties of soils belonging to sub-class a) and b), their characteristics and definitions should be discussed separately.

3.6.1. Formation of alkali soils under the influence of a comparatively high concentration of sodium compounds capable of alkaline hydrolysis. Alkali soils without structural B horizons.

If the concentration of sodium carbonate, affecting soil formation processes in the upper horizon of the soil profile, is high, soils without structural B horizons develop. These soils display many similarities to saline soils formed under the influence of neutral sodium salts, i.e. they have no readily-distinguishable horizons separated by abrupt boundaries. On this basis – in the Russian literature, as well as in several other classification systems – these soils are also named solonchak soils, or rather, sodium carbonate solonchak to distinguish them from the sulphate or chloride solonchaks developed due to the effect of neutral sodium salts. It is quite evident, that, in spite of the similarities, these soils differ in many of their properties. The most important difference is that the soil reaction of sodium carbonate solonchaks is strongly alkaline, while in the others it is nearly neutral.

Figure 3.5 demonstrates the schematic profile of an alkali soil without a structural B horizon.

Due to the high alkalinity of these soils, the top layers are fairly compact, structureless, and their extremely low water permeability, or virtual impermeability is a very important factor from the point of view of drainage or chemical reclamation.

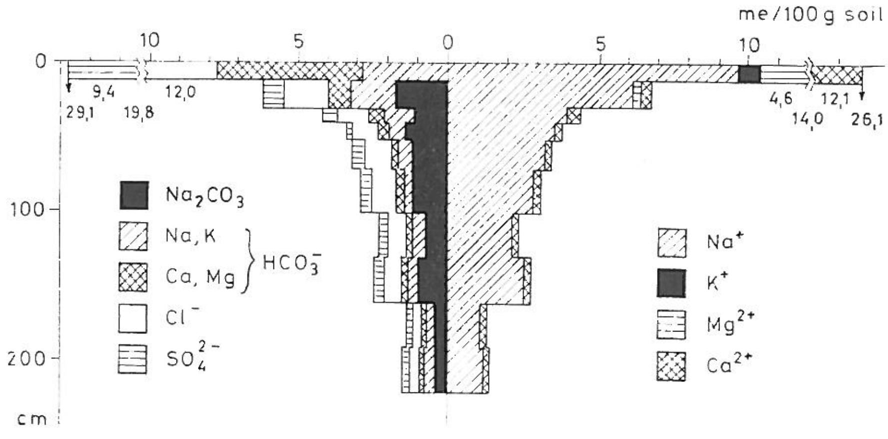

Fig. 3.6
Salt profile of an alkali soil without structural B horizon from the Hungarian Danube Valley, Apaj-4

Because high alkalinity is accompanied by high salinity, the former governs not only the chemical, but also the physico-chemical processes in these soils. Consequently, the determination of exchangeable cations is not always necessary, and quite often it may even prove to be analytically difficult during the survey and routine analysis of alkali soils without a structural B horizon.

If the concentration of sodium salts capable of alkaline hydrolysis decreases, transitional types between alkali soils with and without structural B horizons may develop. This transitional form is known in several classification systems as "solonchak-solonetz" or "solonetz-solonchak". A similar soil type may develop during the desalinization of saline soils.

Figure 3.6 demonstrates the salt profile of an alkali soil without structural B horizon from the Hungarian Danube Valley, Apaj-4.

Figure 3.7 shows the chemical composition of the ground water, obviously corresponding to the salt composition of an alkali soil without a structural B horizon from the Hungarian Danube Valley.

3.6.2. Formation of alkali soils with structural B horizons under the influence of a comparatively low concentration of sodium compounds capable of alkaline hydrolysis. Alkali soils with structural B horizons.

The definition of these soils is based on the prismatic or columnar structure of the B horizon, which is accompanied by a high percentage of exchangeable sodium ions (ESP < 15).

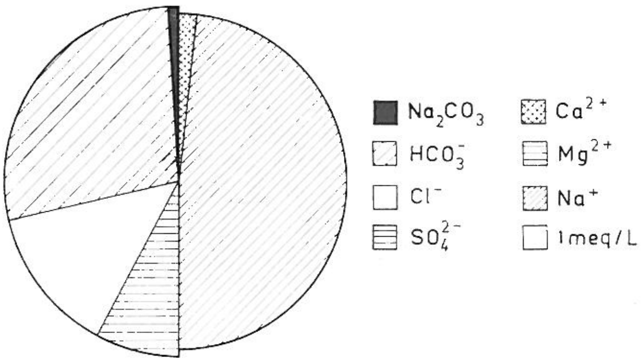

Fig. 3.7
Chemical composition of the ground water at Profile Apaj-4, Hungary

This horizon always has well-developed structure elements, mainly columns. It can be easily distinguished from the horizon above it, which is less compact, and the structure of which is less developed. This B horizon determines the genetic type of these soils, their main physical, chemical, physico-chemical and biological properties and their fertility as well as the possibilities of their agricultural utilization. These soils are called solonetz soils in the Russian literature, and this denomination has been generally accepted. As regards their development, solonetz forming and solod forming processes can be distinguished. Solod formation will be discussed later.

In Figure 3.8 schematic profiles of alkali soils with structural B horizons (solonetz) are shown.

The structural B horizon is situated at various depths, depending on the local circumstances. In some cases it is on the surface (the A horizon is completely lacking).

The structural B horizon always markedly differs from the A horizon, not only in morphology, colour and structure, but also in its physical, chemical, physico-chemical and biological properties. Figure 3.9 schematically represents some of the chemical, physical and physico-chemical properties of a solonetz soil (adapted in a modified form from Kovda [In: Szabolcs 1971]).

The figure demonstrates that at a given depth below the surface (in this case about 30 cm) an illuvial or accumulation horizon may be found. This is named the B or B_1 horizon. In this horizon the accumulation of clay particles and sesquioxides may be observed and both the water soluble organic matter content and the ESP value reach a maximum, while the ratio of $SiO_2 : R_2O_3$ is the lowest there, signifying that there is a comparatively low quantity of silicon compounds. In Figure 3.9 this horizon is found at 20 – 30 cm, as is often the case in Nature, but it frequently occurs at depths other than this. Naturally in those cases the respective maximum and minimum values are to be found at the depth at which the B horizon has developed.

It may be seen in Figure 3.9 that as far as the movement and accumulation of materials is concerned, the situation in the A horizon is just the opposite. The A horizon is called the elluvial horizon.

In the B horizon the sodium ions are mainly in an exchangeable form, adsorbed on the soil colloids, which are also at a maximum there. These exchangeable sodium ions, depending on the equilibrium conditions between the solid and liquid phases, are capable of alkaline hydrolysis. This phenomenon is influenced by the CEC and ESP values, by the chemical composition and concentration of the soil solution, especially by the CO_2 tension, and by many other factors. Because of this, the alkaline hydrolysis of the soil colloids, saturated with sodium to a greater or lesser degree, results in more or less alkaline conditions in this horizon. It is evident that, in solonetz soils affected by strongly developed solod forming processes, in the B horizon, where sodium compounds capable of alkaline hydrolysis play a dominant role, alkaline hydrolysis usually takes place, due to the interaction of the solid and liquid phases of the soil.

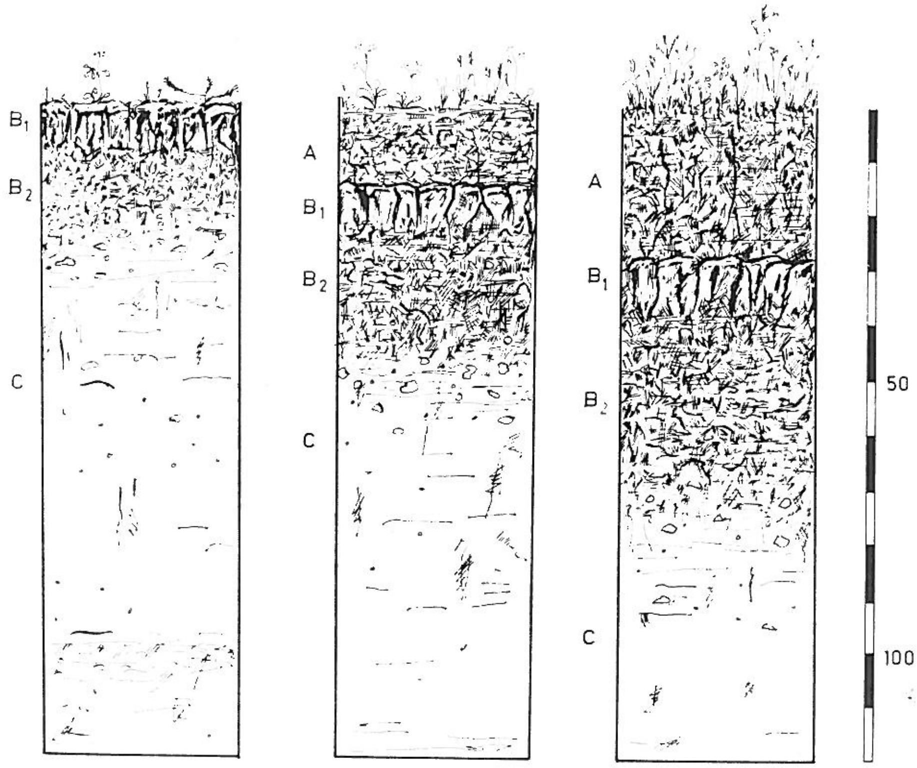

Fig. 3.8
Schematic profiles of alkali soils with structural B horizons (solonetz)

As regards the source of the sodium salts of relatively low concentration which cause the formation of solonetz soils, essentially two cases may be distinguished:

1. The soil profile and the top layers are capillarily linked with the mineralized ground water.

KOVDA [1937] states that in this case, solonetz formation is intertwined with solonchak formation because sometimes (for instance, if the water table rises) salt accumulation in the soil layers from the ground water may be considerable and then a solonchak soil develops. In these soils it is the fluctuation of the water table that determines the upward and downward migration of sodium salt solutions, which, as described earlier, is one of the most important conditions for solonetz formation.

In Russian literature this type of solonetz soil is named meadow solonetz, indicating that it is permanently affected by the ground water.

Naturally, apart from the ground water, precipitation also influences the migration of the solutions in the soil. Figure 3.10 demonstrates the ground

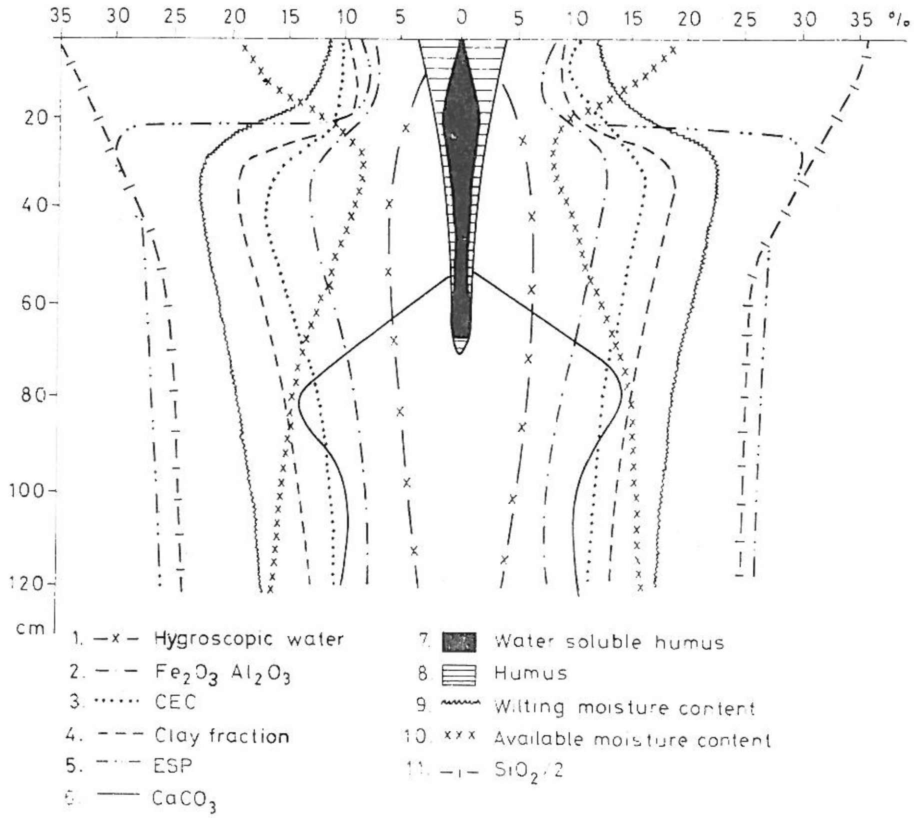

Fig. 3.9

Schematic representation of some of the physical, chemical and physico-chemical properties of an alkali soil with structural B horizon (solonetz) [after KOVDA, in modified form] water and precipitation conditions in a solonetz area of the Hungarian Lowland during a six-year period [MADOS 1940]. It may be seen that in most years the precipitation water penetrating the soil meets the capillary ground water at certain times. The accumulation horizon of soluble salts may usually be found at the depth where the upward and downward currents of the solutions meet. KOVDA [1937], ANTIPOV-KARATAEV [1958], and DARAB and FERENCZ [1969] point out that the distribution of the accumulation of soluble salts within the profile depends on whether the upward or downward solution

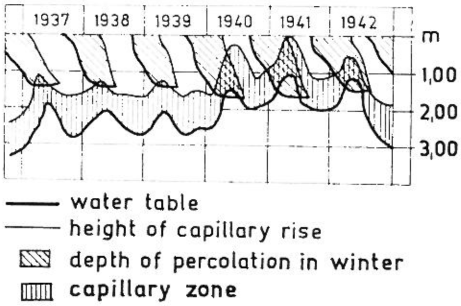

Fig. 3.10
The ground water and precipitation conditions in the solonetz area in Hortobágy (Hungary) in six years [after MADOS 1940]

movements are dominant. For instance, it is clearly indicated by the accumulation horizons of Na_2SO_4, $CaSO_4$ and $CaCO_3$ in the profiles.

Figure 3.11 demonstrates the water soluble salt content in a 1 : 5 aqueous extract of a solonetz profile developed under the influence of the ground water.

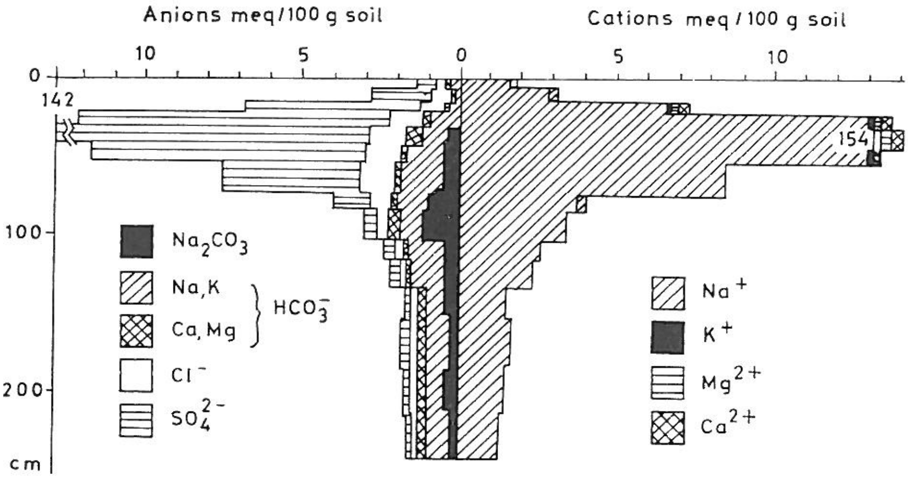

Fig. 3.11
Water soluble salt content of the 1 : 5 aqueous extract of a shallow meadow solonetz soil (Hortobágy, Hungary)

In Figure 3.12 the composition of the ground water is represented. The close relation between the chemical composition of the soil profile and the ground water is quite obvious. The sodium carbonate content is considerable

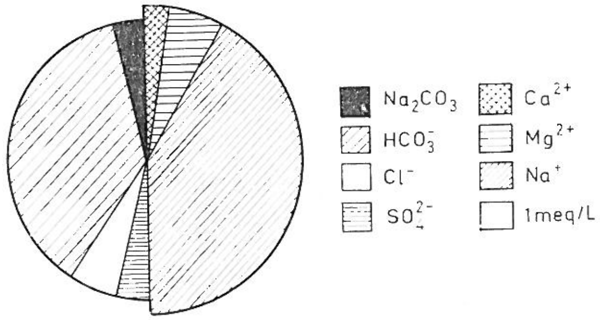

Fig. 3.12
Chemical composition of the ground water under a shallow meadow solonetz soil (Hortobágy, Hungary)

in both the soil and the ground water. It must be added that the depth at which sodium carbonate appears may change within the same profile depending on the seasonal dynamics of the soluble salts.

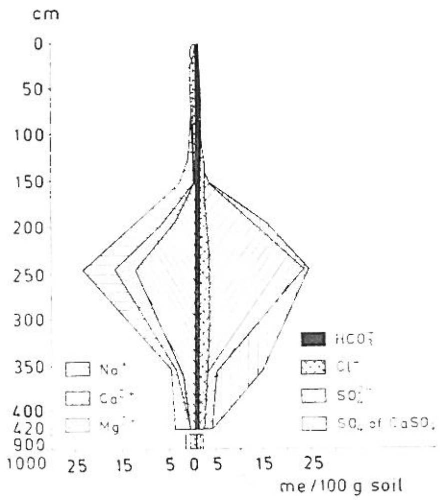

Fig. 3.13
Salt profile of a steppe solonetz soil from the USSR [after KOVDA 1937]

In most of these soils the B horizon is situated near the surface, consequently the A horizon is relatively shallow, or, in certain cases, where the B horizon is at the surface, it is completely missing.

The great majority of sodium carbonate containing solonetz soils have developed through the above described processes, under the influence of mineralized ground waters. They often occur on territories where the climatic conditions are far from being arid, for instance in tropical Africa, some states in the USA, Argentina, Canada, Victoria (Australia), the Hungarian Lowland, etc.

2. In another group of solonetz soils, the mineralized ground water is at such a great depth (more than 6, 8 or 10 metres) that it exerts practically no influence on soil formation processes. The sodium salt solutions affecting solonetz forming processes enter the soil profile from other sources, in another way. Under arid or semi-arid conditions, the weathering of minerals and the decomposition of organic and inorganic compounds or the transport of water soluble salts by the surface waters may constitute such sources. Depending mainly on the climatic conditions, the repeated downward and upward migrations of the sodium salt solutions form the profiles of these soils which, although they have all the features characteristic of solonetzes, differ noticeably from those developed under the influence of ground waters.

Figure 3.13 shows the salt profile of this soil, named steppe solonetz in the Russian literature. It is common in the Ukrainian SSR, in the Trans-Volga region, in the Kazakh SSR, in China, Australia and in many places in semi-arid countries.

3.7. Secondary salinization and alkalization of soils

Secondary saline or alkali soils are those which have not been affected or only slightly destroyed by salinity or alkalinity before human management (mainly irrigation), but after a certain period of irrigation they became salinized or alkalized.

It is wellknown that the majority of the irrigated territories existing in the world are exposed to the hazard of secondary salinization, alkalization and water-logging.

Theoretically, there are many factors influencing salt affected soils; however, in practice it is irrigation which leads to the formation of many million hectares of saline and/or alkali soils in different parts of the world. Often paradoxical things happen in irrigation systems even when they are established by thorough work and expensive planning and construction, when the soils, instead of increasing in their fertility, transform into poor saline land. This process is known as secondary salinization and/or alkalization, which is as old as irrigated agriculture.

Many thousands of square kilometres of fertile irrigated lands have been transformed into saline and alkali deserts during the history of mankind, under the influence of improper irrigation. Unfortunately, this happened not only in the past. The secondary salinization and/or alkalization process is showing a disastrous increase, parallel with the construction of new irrigation systems in many countries all over the world, particularly in arid and semi-arid regions, or in regions with mineralized ground waters near to the surface of the soil.

The extension of irrigation, in accordance with the demand for an increase in food production, makes it imperative to pay due attention to potential salinization and/or alkalization, in order to study and characterize this process, as well as to predict and prevent it everywhere, if possible.

According to an estimation made by the UN affiliated organizations

(FAO, UNESCO) more than 50 per cent of all irrigated lands in the world have been damaged by secondary salinization and/or alkalization and waterlogging. According to the same estimation, many millions of hectares in irrigation systems have to be abandoned from production yearly as a consequence of this process.

Secondary salinization and alkalization processes may take place mainly in the following situations:

1. Accumulation of salts from irrigation water of poor quality.

2. Salt accumulation as a result of the increase in the level of the ground water.

a) The salt content of the ground water accumulates in the affected layers;

b) the rising ground water transports the salts from the deeper soil layers to the surface or surface layers, or

c) the rising water table limits natural drainage and hinders the leaching of salts.

The possible hazard of salinization and/or alkalization in irrigated areas or areas to be irrigated may be determined by the following factors [Szabolcs, Várallyay and Darab 1976].

1. Climatic factors, such as temperature, rainfall, humidity, vapour pressure, evaporation and their fluctuation and dynamics;

2. Geological, geomorphological, geochemical, hydrological, hydrogeological and hydrochemical factors, such as natural drainage, the depth and fluctuation of the water table, the direction and velocity of horizontal ground water flow, salt content and composition of the ground water, etc.

3. Soil factors, such as soil profile, texture, structure, saturated and unsaturated water conductivity, soluble salt content, salt composition and salt profiles, exchangeable cations, pH, etc.

4. Agrotechnics, such as land use, crops, cultivation methods, etc.

5. Irrigation practices, such as the amount of irrigation water, method, frequency and intensity of irrigation; salt content and composition of irrigation water; natural and artificial drainage, etc.

The above mentioned factors determine the aims and methods of the preliminary survey of soils in order to define the degree to which potential salinity and/or alkalinity exists.

Evidently, both the environmental conditions and the methods of utilization of the territory in question should be taken into consideration when an area is evaluated in this respect. Consequently, different limit values and different methods, based on uniform principles, should be selected in the course of this procedure. For example, in arid regions, particularly outside Europe, in deserts and semi-deserts, practically all irrigated areas are potentially salt affected, owing to the arid climate as well as to the high accumulation of salts in the soils and waters of these areas.

In moderate or humid climates, the problems of potential salt affected soils are not the same as those encountered in arid zones, due to the different climatic, geochemical and farming conditions [Szabolcs 1971a, b].

In these areas the basic aims of the survey and study of potentially saline or alkali soils are to predict the harmful processes and to elaborate, whenever possible, methods suitable for preventing the occurrence of secondary salinization and/or alkalization.