CHANGES IN MICROMORPHOMETRIC PARAMETERS OF VOIDS ALONGTHE PROFILE OF ZONAL SOILS IN EUROPEAN RUSSIA

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The soils are distinguished by the presence and the profile distribution pattern of such pedogenic parameters as the organic matter content, available pedofeatures, structural state of the soil mass, etc. They differ in the organization of the pore space throughout the soil profile as well. Under discussion are results of computer micromorphometric analysis of fine macropores d = 0.2–2.0 mm in thin sections of vertical orientation from samples taken in genetic horizons of podzolic, soddy podzolic, gray forest soils and chernozems at the territory of European Russia. The profile changes in voids were analyzed using the most informative morphometric parameters such as the total area of the studied voids in thin sections, the content of fissure-like voids and those of vertical and/or horizontal orientation. The soil types under study showed differences in profile distribution of the above parameters. By analogy with the profile of carbonates, salts, organic matter it is proposed to recognize diagnostic profiles of the pore space represented as a system of voids in genetic horizons of the soil profile. Empiric profiles of the pore space reveal a great diversity. The most complicated organization of the pore space is inherent to soddy podzolic soils, the most simple "smoothed" profiles are characteristic of typical chernozems. The expert qualitative typification showed that the eluvial-illuvial and accumulative-eluvial-illuvial types are dominant among the studied empiric profiles of the pore space (42 and 30% respectively), what is explained by prevailing texture-differentiated soils. On the other hand, it makes possible to use the profile of the pore space as a diagnostic parameter of soils and soil formation processes.

Keywords: the pore space, micromorphometry, computer analysis, soil profile.

INTRODUCTION

It is common knowledge that the soils reveal differences from their parent material, being distinguished by the presence and profile distribution pattern of such pedogenic features as the organic matter content, available pedofeatures, structural state of the soil mass, etc. They are also quite different in organization of the pore space. Among various characteristics of the pore space in soil (total and differentiated volume of voids, capillary models) the morphological (morphometric) parameters seem to be genetically specific. Just they create a morphological-genetic image of the pore space in soil [9–12].

It has been earlier established that the morphometric parameters for the shape and orientation of fine macropores d = 0.2–2.0 mm in thin sections of vertical orientation enable to reflect morphological differences between the main structures of loamy soils including crumby, granular, nutty, platy, prismatic ones [5, 6]. It should be supposed that the given parameters can be used to compare the pore space along the profile of zonal soils at the territory of European Russia.

The present studies are aimed at determining micromorphometric peculiar features of voids along the profile of soils in European Russia. From this the following objectives have been derived:

1. Computer image analysis of the area, shape and orientation of fine macropores d = 0.2–2.0 mm in thin sections of vertical orientation prepared from samples taken in genetic horizons of zonal soils at the territory of European Russia.

2. Identification of the area, shape and orientation of the above macropores distributed throughout the profile of these soils.

3. Qualitative expert typification of the obtained profile distribution.

4. Consideration of the main principles for the morphometric profile of the pore space in soil.

OBJECTS AND METHODS

The objects of research were podzolic, soddy-podzolic, gray forest soils and chernozems on mantle carbonate-free loam and loess-like loam with different carbonate content. The soils under study represent a zonal sequence of soil types in forest, forest-steppe and steppe landscapes at the territory of European Russia. By today, the morphological, physical and chemical properties of these soils have been studied in detail. They are characterized by a great diversity of the soil structure at aggregate and profile level.

The podzolic soils were studied in autonomous geomorphological positions confined to carbonate-free mantle loams under the long-lived spruce forest in the Republic of Komi [2]. According to V.Tonkonogov (1985) the podzolic part of these soils displays an Al-Fe-humus "subprofile", being regarded to the subtype of texture-podzolic illuvial-iron soils. The soddy-podzolic soils were studied in autonomous geomorphological positions under sub-radical 90-100-aged spruce forests in the north-eastern part of the Moscow region [3], whereas the gray forest soils under the canopy of broad-leaved forests in the Tula region [2]. The studied virgin chernozem was exemplified by a typical thick high-humic heavy loamy chernozem on carbonate loess-like loam in Central-Chernozem reservation at the territory of Streletskaya steppe [4, 8].

To study the pore space in the above soils, the thin sections were prepared from soil samples taken in the main genetic horizons in 3–10 replications (Fig. 1). The computer image analysis of every thin section (2×2 cm) permitted to determine the visible morphometric parameters of fine macropores d = 0.2–2.0 mm, the amount of which was varying from 50-100 in the C horizon to 200–500 in the AY and AU horizons. Each void was measured to detect its area (S), perimeter (P), long (L) and diametrical (D) size; the shape index $F = (4\pi S/P^2 + D/L)/2$ was calculated to determine the orientation index (deviation angle of long axis from vertical direction of the void in the thin section). Based upon the obtained data the average arithmetical values of the main morphometric parameters have been calculated for every thin section. The latter was also characterized by empiric distribution of voids according to 5 classes of their shape (Table 1) and 3 classes of orientation including vertical and subvertical (deviation from the vertical line 0°–33º), inclined (deviation 33°–66º), horizontal and subhorizontal (deviation 66°–90º).

The previously conducted measurements showed that 5 classes of void shape and 3 classes of orientation are quite sufficient to characterize and diagnose the different types of the pore space in soil. The greater is the amount of classes, the higher is the uncertainty associated with a great diversity of void shapes and orientation [6]. As a result of measurements and calculations a set of morphometric data has been obtained to give a comparative assessment of the size, shape and orientation of voids along the profile of the studied soils (Tables 2 and 3).

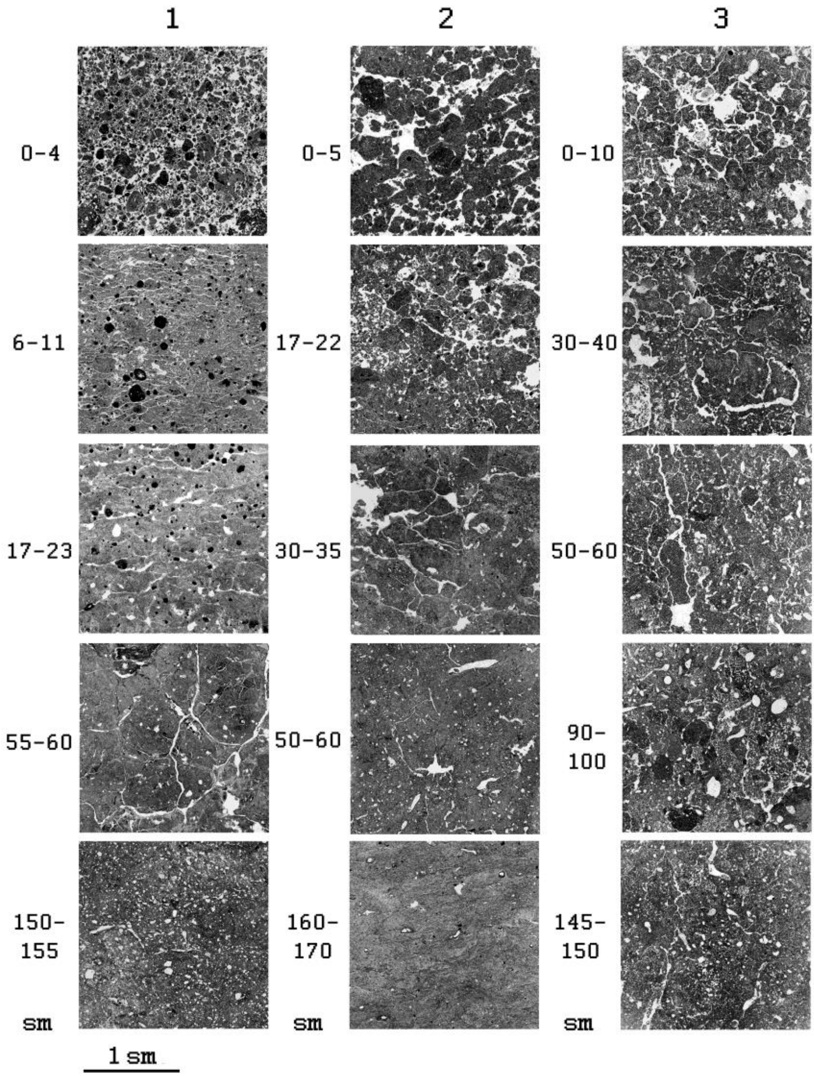

Fig. 1. Vetical thin sections from profiles of soddy-podzolic soil (1), gray forest soil (2) and typical chernozem (3). Voids are white in color.

Table 1. Grouping of voids in thin sections according to the *F* factor

F factor value	Shape of voids	Description of voids
<0.2	Fissured	Transaggregate fissures, fissured packing voids in angular-blocky and platy aggregates
0.21–0.4	Stretched broken	Packing voids in crumbly-granular aggregates and blocks composing of them, the other stretched and broken voids in aggregated and non-aggregated soil
0.41–0.6	Isometric broken	Packing voids in rounded-crumbly aggregates, void-vagi in the slightly aggregated soil
0.61–0.8	Isometric slightlybroken	Channels in section, slightly broken voids in the non-aggregated soils
0.81–1.0	Rounded and closed to rounded	Channels in section, bubbles

The most informative morphometric parameters were used to analyze changes in voids throughout the soil profile including the total area of the studied voids in thin sections (in per cent from the field of vision). In thin sections the total area of voids d = 0.2–2.0 mm reflecting the visible soil porosity serves as evidence of packing density of soil aggregates. Apart from the void area the content of fissured macropores with $F < 0.2$ is of great diagnostic importance. Their percentage is small in underlying bedrocks but in soils they can make up 20-30% from the total amount of macropores in field of vision. As a rule, the platy, prismatic, nutty and granular structures reveal a higher content of fissured macropores in soil. The soils under study are different in such structures and their distribution along the profile. Consequently, the differences in the profile distribution of macropores with $F < 0.2$ should be expected in the studied soils. By analogy with this fact the presence of anisometric structures in the soil profile can be diagnosed by the content of voids of horizontal and subhorizontal orientation in vertical thin sections.

A comprehensive analysis of the most informative parameters allowed specifying the pore space in profiles of the soils at the territory of European Russia.

Table 2. Morphometric parameters of voids in thin sections from soils of European Russia

Horizon	Amount of thin sections	Statistic data	Total area, %	Specific amount, pieces/mm^2	Average arithmetic value in thin section: area, mm^2	perimeter, mm	size: length, mm	width, mm
Texture-podzolic illuvial-iron soils								
EL	7	*M*	4.53	0.22	0.20	3.07	1.33	0.36
		s	2.40	0.12	0.06	0.40	0.20	0.05
		V	53	54	29	13	15	13
BHF	3	*M*	6.95	0.24	0.27	3.42	1.30	0.49
		s	4.68	0.14	0.08	0.38	0.03	0.09
		V	67	59	29	11	2	17
ELf	3	*M*	12.47	0.50	0.21	3.00	1.18	0.43
		s	1.99	0.11	0.02	0.43	0.17	0.04
		V	16	21	10	14	14	9
BT	7	*M*	8.96	0.24	0.35	3.61	1.52	0.44
		s	3.78	0.05	0.13	0.59	0.22	0.09
		V	42	20	36	16	14	21
C	10	*M*	4.98	0.19	0.23	2.39	1.01	0.35
		s	1.91	0.07	0.10	0.71	0.29	0.08
		V	38	38	44	29	29	22
Soddy-podzolic soils								
AY	10	*M*	16.00	0.33	0.46	3.55	1.13	0.56
		s	7.81	0.12	0.20	0.82	0.18	0.12
		V	49	35	44	24	16	22
AEL	10	*M*	13.90	0.30	0.43	3.44	1.19	0.54
		s	5.96	0.08	0.24	0.80	0.22	0.10
		V	43	27	54	23	18	18
EL	5	*M*	8.36	0.25	0.34	3.42	1.36	0.48
		s	1.98	0.03	0.09	0.86	0.36	0.05
		V	24	13	26	25	27	11
BEL	10	*M*	9.55	0.29	0.33	3.44	1.37	0.47
		s	2.78	0.08	0.09	0.72	0.31	0.05
		V	29	27	26	21	23	12
BT1	8	*M*	9.75	0.30	0.36	3.62	1.38	0.51
		s	4.96	0.06	0.16	1.06	0.29	0.14
		V	51	21	45	29	21	27
BT2	8	*M*	7.96	0.32	0.21	2.25	0.93	0.35
		s	1.84	0.07	0.05	0.45	0.20	0.03
		V	23	21	23	20	21	9
BT3	12	*M*	6.34	0.27	0.20	2.08	0.87	0.33
		s	1.48	0.05	0.06	0.50	0.22	0.04
		V	23	20	29	24	25	12

Horizon	Amount of thin sections	Statistic data	Total area, %	Specific amount, pieces/mm^2	Average arithmetic value in thin section			
					area, mm^2	perimeter, mm	size	
							length, mm	width, mm
BC	6	*M*	6.42	0.30	0.21	1.74	0.72	0.26
		s	1.91	0.04	0.07	0.31	0.12	0.09
		V	30	12	33	18	16	36
Gray forest soils								
AY	3	*M*	13.22	0.41	0.30	3.01	1.15	0.46
		s	1.15	0.05	0.03	0.21	0.07	0.05
		V	9	11	10	7	6	11
AEL	3	*M*	12.86	0.40	0.31	3.57	1.44	0.46
		s	3.42	0.02	0.11	0.42	0.21	0.08
		V	27	4	34	12	15	18
BEL	5	*M*	11.51	0.26	0.43	4.48	1.86	0.49
		t	3.62	0.05	0.09	0.38	0.13	0.05
		V	31	19	21	8	7	11
BT1	5	*M*	11.36	0.30	0.37	3.46	1.43	0.43
		s	1.76	0.03	0.09	0.54	0.21	0.05
		V	15	10	25	16	15	12
BT2	6	*M*	12.25	0.26	0.43	3.82	1.58	0.46
		s	3.41	0.11	0.11	0.65	0.30	0.04
		V	28	41	25	17	19	9
BC	8	*M*	11.05	0.23	0.41	3.53	1.45	0.45
		s	3.42	0.05	0.16	0.81	0.32	0.06
		V	31	22	35	23	22	13
Typical chernozem								
AU	10	*M*	18.04	0.48	0.38	3.68	1.28	0.55
		s	2.09	0.08	0.10	0.58	0.13	0.08
		V	12	17	25	16	10	15
AB	6	*M*	17.49	0.55	0.30	2.79	1.00	0.46
		s	3.84	0.06	0.06	0.28	0.10	0.03
		V	22	11	19	10	9	6
BCA	7	*M*	11.57	0.43	0.21	2.15	0.83	0.37
		s	1.99	0.11	0.05	0.32	0.11	0.05
		V	17	25	22	15	14	12
BCca, Cca	5	*M*	7.20	0.27	0.23	2.27	0.93	0.36
		s	1.61	0.05	0.06	0.37	0.15	0.02
		V	22	19	24	16	16	6

Note: Symbolic of horizons is given according “Soil Classification of Russia”, 2004. M – average arithmetic value; s – average standard deviation; V – coefficient of variation.

Table 3.The pore space in thin sections of soils at the territory of European Russia

Horizon	Amount of thin sections	Statistic data	Content of voids, %							
			shape factor *F*					orientation		
			<0.2	0.21–0.4	0.41–0.6	0.61–0.8	0.81–1.0	vertical	inclined	horizontal
Texture-podzolic illuvial-iron soils										
EL	7	*M*	35	29	20	12	4	14	19	67
		s	8.4	5.1		5.6	1.2		4.6	5.5
		V	24	18		45	3.5	26	24	8
BHF	3	*M*	17	43	26	13	1	25	27	48
		s	9.0	8.1	3.1	3.1	2.3	8.2	4.4	10.4
		V	52	19	14	24	173	33	16	22
ELf	3	*M*	18	33	29	16	4	22	31	47
		s	6.7	2.1	4.0	1.0	1.2	5.7	4.7	10.0
		V	36	6	14	6	27	26	15	21
BT	7	*M*	30	29	21	14	6	31	27	42
		s	10.1	5.6	4.7	3.2	2.9	9.8	5.4	12.4
		V	33	19	23	23	51	31	20	30
C	10	*M*	11	19	26	29	15	31	31	38
		s	9.7	7.4	6.0	7.2	5.8	8.5	6.4	10.3
		V	87	39	23	25	38	28	20	27
Soddy-podzolic soils										
AY	10	*M*	4	25	43	22	6	35	34	31
		s	4.4	6.7	4.8	4.6	2.3	3.9	3.1	4.1
		V	117	26	11	21	41	11	9	14
AEL	10	*M*	10	24	36	22	8	36	33	31
		s	8.3	7.7	8.5	7.8	3.0	6.1	4.5	4.1
		V	84	32	24	35	40	17	14	13
EL	5	*M*	24	17	26	21	12	20	24	56
		s	13.8	5.6	5.6	9.4	5.8	3.8	4.9	4.0
		V	58	34	21	44	47	19	20	7
BEL	10	*M*	24	22	26	19	9	34	30	36
		s	9.9	5.6	5.1	6.6	4.7	5.7	4.4	7.7
		V	41	26	19	35	51	17	15	21
BT1	8	*M*	19	25	27	19	10	30	34	36
		s	8.3	7.4	5.3	6.2	5.3	8.8	4.6	9.0
		V	43	30	19	33	51	30	13	25
BT2	8	*M*	9	15	31	27	18	32	34	34
		s	8.0	6.6	5.5	4.6	8.2	3.7	3.8	3.7
		V	93	43	18	17	44	12	11	11
BT	12	*M*	6	18	30	29	17	32	32	36

Horizon	Amount of thin sections	Statistic data	Content of voids, %							
			shape factor *F*					orientation		
			<0.2	0.21–0.4	0.41–0.6	0.61–0.8	0.81–1.0	vertical	inclined	horizontal
3		*s*	5.8	6.7	3.0	5.6	5.2	6.0	3.9	4.7
		V	96	37	10	19	30	19	12	13
BC	6	*M*	2	15	30	32	21	33	33	34
		s	2.2	4.9	3.9	3.6	7.2	3.6	9.9	8.1
		V	93	33	13	11	35	11	30	24
Gray forest soils										
AY	3	*M*	16	23	28	24	9	33	33	34
		s	2.5	3.6	4.0	3.1	3.8	1.5	1.0	1.5
		V	15	16	14	13	44	5	3	5
AEL	3	*M*	29	25	22	17	7	31	26	43
		s	17.2	8.2	9.5	3.5	2.5	6.1	8.1	13.0
		V	58	33	45	20	34	20	31	30
BEL	5	*M*	36	27	17	12	8	35	30	35
		s	3.1	6.8	5.4	4.4	4.0	4.3	6.2	3.1
		V	9	25	30	35	51	12	21	9
BT1	5	*M*	21	19	19	25	16	34	33	33
		s	8.4	6.1	5.7	9.5	4.8	8.4	7.6	4.7
		V	40	33	30	38	29	24	23	14
BT2	6	*M*	23	20	24	20	13	38	19	33
		s	6.4	5.3	5.3	3.8	2.2	5.0	2.3	5.2
		V	28	26	22	19	17	13	8	16
BC	8	*M*	17	19	25	24	15	34	32	35
		s	8.2	6.8	4.3	6.9	5.9	4.1	4.0	4.0
		V	49	36	18	29	38	12	13	12
Чернозем типичный										
AU	10	*M*	14	35	31	15	5	38	33	29
		s	2.5	5.0	3.3	2.9	2.4	4.2	2.8	4.1
		V	19	14	11	19	50	11	8	14
AB	6	*M*	5	22	35	26	12	39	34	27
		s	2.3	4.6	3.6	4.6	3.1	8.7	4.7	4.9
		V	41	21	10	18	25	22	14	18
BCA	7	*M*	3	17	36	28	16	40	34	26
		s	3.7	4.7	6.0	4.8	3.2	6.2	5.4	6.9
		V	117	28	17	17	19	16	16	27
BCca, Cca	5	*M*	7	20	31	26	16	44	31	25
		s	5.1	5.6	3.5	5.8	5.2	6.4	3.0	4.6
		V	69	27	11	22	33	15	9	19

Note: Interpretation of F shape factor in Table 1.

DISCUSSION

The studied soils are distinguished according to the profile distribution of the total area of macropores (visible macroporosity) in thin sections. The obtained data indicate that the texture-podzolic illuvial-iron soils display the macroporosity along the whole profile to a lesser extent with the exception of the lower podzolic part represented by the Elf horizon as a Al–Fe-humus subprofile (Fig. 2, I). The increase in visible macroporosity in this horizon is conditioned by a friable packing of platy and rounded large-sized soil aggregates. In the soddy-podzolic soils the macroporosity is constantly decreasing from the humus horizon to the underlying bedrock and the area of macropores is sharply declined in the EL horizon. The gray forest soils reveal the increased area of macropores throughout the profile due to their high content in packing of nutty and fine prismatic aggregates. It is possible to observe decreasing the visible macroporosity in the profile of typical chernozem that is ranged from 18% in the AU horizon to 7% in the BC horizon.

The soils under consideration are also differed by presence and profile distribution of aggregates with flat edges. In these soils there are differences in profile distribution of macropores with $F < 0.2$ as well. Fig. 2, II demonstrates the main distribution types. The podzolic soils are characteristic of distribution with two maxima in the EL horizon characterizing by platy structure and in the BT horizon with the prismatic structure. The soddy-podzolic soils reveal a clearly expressed maximum corresponding to adjacent EL and BEL horizons. The gray forest soils have the increased content of fissured macropores along the whole profile with maximum in the BEL horizon characterizing by the nutty structure. In chernozem the content of fissured macropores is decreased throughout the whole profile although their amount in the humus horizon is rather high.

In assessing the changes in orientation of the pore space along the soil profile one should notice the ratio between macropores of vertical and horizontal orientation (Fig. 2, III). In podzolic soils the macropores of horizontal orientation prevail. In soddy-podzolic soils this regularity is disturbed indicating a higher content of vertical macropores due to biogenic treatment as compared to those with horizontal orientation. The gray forest soils reveal isometric pore space

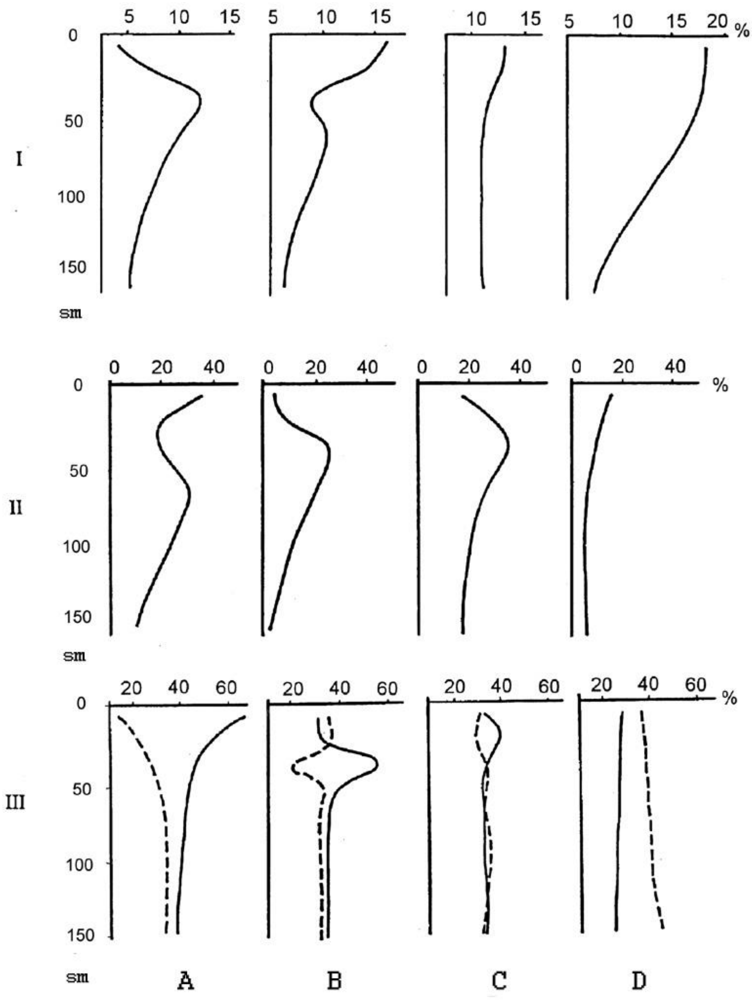

Fig. 2. Profile of the pore space (d = 0.2–2.0 mm) in virgin loamy soils: (A) – podzolic soil; (B) – soddy-podzolic soil; (C) – gray forest soil and (D) – typical chernozem. Morphometric parameters: I – total area of macropores, % from field of vision; II – content of fissured macropores; III – horizontal (right line) and vertical (dotted line) macropores in thin sections, % from the total amount of voids in field of vision.

with the similar content of vertical and horizontal macropores (exception in the AEL horizon). Vertical macropores are dominant along the profile of typical chernozem.

An expert method of profile typification was employed to describe the obtained empiric data. At present, 12 distribution types of such substances as humus, clay particles, carbonates, gypsum, water-soluble salts, R_2O_3, silica, secondary minerals and pedofeatures have been described in detail in different soils. The image and names of such profiles are given in Fig. 3. The type names reflect the pattern of the soil formation processes and how they are confined to some profile parts. The image of such profiles is formalized and permits to use this method for describing changes in different soil properties throughout the profile. The given method is also applicable for describing the voids in soil; it allows emphasizing the genetically valuable peculiarities in the pore space of soils.

The visual comparison showed that the empiric profiles of morphometric parameters for soil voids may be referred to types presented in Fig. 3 (Table 4). So, the parameters of the most complicated accumulative-eluvial-illuvial profile (Fig. 3, 4b) are characteristic for profile changes in the total area of voids in soddy-podzolic soils (Fig. 2, IB); the amount of fissured voids – for texture-podzolic illuvial-iron soils (Fig. 2, IIA) and the content of vertical voids in soddy-podzolic and partially gray forest soils (Fig. 2, IIIБ and IIIВ). The most simple profile distribution is inherent to the content of vertical and horizontal voids in typical chernozem (Fig. 3).

CONCLUSION

The obtained data show that the studied soil types reveal quite different profile distribution of the main morphometric parameters for the pore space in these soils. Thus, by analogy to carbonate and salt profiles it is possible to distinguish diagnostic "profiles of the pore space" that represent a system of voids distributed in soil horizons down the profile. Such profiles of the pore space may be characterized by separate morphometric parameters as well as by a complex of these parameters. Empiric profiles of the pore space reveal a great diversity. The most complicated organization is typical for soddy-podzolic soils, whereas typical chernozem displays a very simple "smoothed" profile.

Table 4. Expert typification of profile distribution of empiric morphometric indices for voids in virgin loamy soils

Profile type (according to Rozanov, 2004)	Corresponding empiric profile distribution of morphometric indices
1a – regressive-accumulative	The total area of voids in gray forest soils (Fig. 2, I B) The content of fissure-like voids in typical chernozem (Fig. 2, II D) The content of horizontal voids in texture-podzolic illuvial-iron soils (Fig. 2, III A)
1б – progressive-accumulative	The total area of voids in typical chernozem (Fig. 2, II)
2б – progressive-eluvial	The content of vertical voids in texture-podzolic illuvial-iron soils (Fig. 2, III A)
4a – eluvial-illuvial	The total area of voids in texture-podzolic illuvial-iron soils (Fig. 2, I A) The content of fissure-like voids in soddy-podzolic and gray forest soils (Fig. 2, II B and II C) The content of horizontal voids in soddy-podzolic and gray forest soils (Fig. 2, III B and III C)
4б – accumulative-eluvial-illuvial	The total area of voids in soddy-podzolic soils (Fig. 2, I B) The content of fissure-like voids in texture-podzolic illvial-iron soils (Fig. 2, II A) The content of vertical voids in soddy-podzolic and gray forest soils (Fig. 2, III B and III C)
5 – undifferentiated	The content of vertical and horizontal voids in typical chernozem (Fig. 2, III D)

The qualitative expert typification showed that eluvial-illuvial and accumulative-eluvial-illuvial types are widespread among empiric profiles of the pore space in the studied soils (42 and 30% respectively). This is connected by prevailing the texture-differentiated soils; on the other hand, it reflects possibilities to use the profile of the pore space as a diagnostic parameter for soils and soil-forming processes.

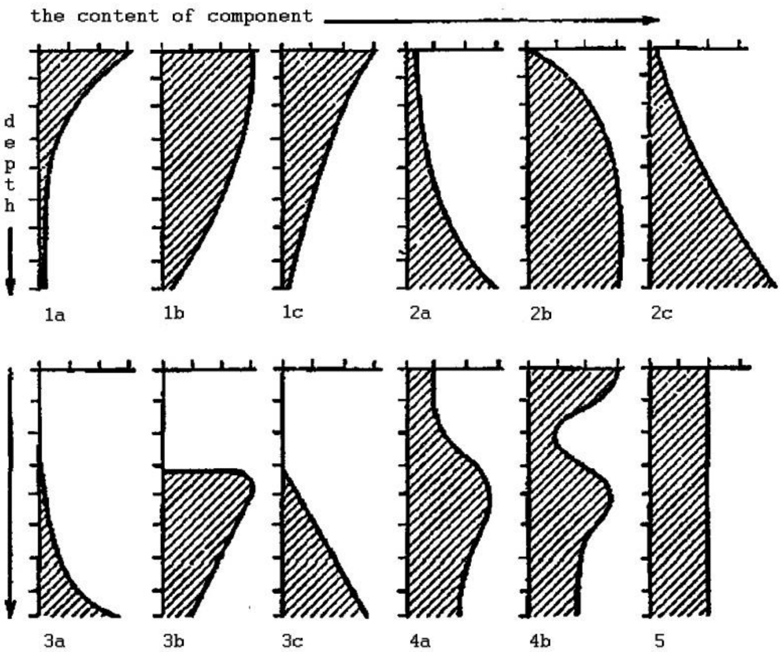

Fig. 3. Distribution types of substances in the soil profile: 1a – regressive-accumulative; 1b – progressive-accumulative; 1c – evenly-accumulative; 2a – regressive-eluvial; 2b -progressive-eluvial; 2b – evenly-eluvial; 3a – regressive-ground-accumulative; 3b – progressive-ground-accumulative; 3b – evenly-ground-accumulative; 4a – eluvial-illuvial; 4b – accumulative-eluvial-illuvial; 5 – undifferentiated.

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