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STATISTIC INDICES FOR BOWL-AND DIAPIR-LIKE MORPHOSTRUCTURES IN VERTISOLS OF VORONTSOVKA PADI

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Under description is a profile configuration represented by stratifying the bowl-like morphostructures with the increased thickness of dark-gray humus horizons and diaper-like morphostructures consisted of the olive-brown material ascending from the lower horizons in Vertisols developed on the bottom of a huge closed depression (padi) in Eisk peninsula. Histograms are presented to show statistical distribution and non-parametric statistic indices for morphometric characteristics of the above morphostructures. The statistical relationship between the morphometric indices is estimated. Based upon the results of the statistical analysis the genesis of such morphostructures in Vertisols is discussed as well.

Keywords: dark vertic soils, agro-vertic dark quasi-gley soils, empiric statistic distribution, non-parametric statistic indices.

INTRODUCTION

The soil type including dark compact (vertic) soils (Soil Classification in Russia, 2004, 2008) or Vertisols (WRB, 2014 and Soil Taxonomy, 1999) or Vertosols (Australian Soil Classification. 2008) has a distinctive feature associated with the development of shrink-swell phenomena during wetting and drying cycles in soil and the shearing stress of the soil mass [1, 5–7, 42, 16, 19, 43]. Due to the heavy lateral shearing stress the soil surface is subject to distortion and assumes an undulating microrelief structure, the so-called gilgai [12, 36]. This microrelief structure is represented by convexo-conclave elements with vertical amplitude (10–60 cm, infrequently to 3 m) and the wave length ranging from 3–5 to 10–40 m [1, 6, 7, 12, 36, 43,]. The gilgai microrelief promotes the redistribution of the atmospheric precipitation both liquid and solid ones, differentiated wetting of convex, conclave and intermediate elements in microrelief as well as the development of the soil complex with cyclically varying soil horizons [12, 36, 43, 44, 33, 6, 7, 22, 19]. The similarity between the horizontally oriented changes in soil horizons and diapiric folds occurring due to salt and clay rocks forced out and plastically deformed under the pressure of thick overlaying sedimentary rocks [4, 18] had every reason to use in soil science the term "diapir" to recognize the material ascending from the lower soil horizons up to the surface [2, 36, 11, 42, 43, 6]. Such microrelief structures are also named as mukkara (finger – in Australian language) and chimney [36, 12, 43]. In the other publications the attention is paid to the form of dark-colored surface horizons, which looks like as a bowl, whose thickness is considerably increased under microdepressions [42–44].

The gilgai microrelief is observed in many regions of the world, where Vertisols are widely distributed but this structure is not an obligatory feature for them [5–7, 34, 43]. It is possible to find out the varieties of buried gilgai microrelief in soils of Europe [17, 35]. In Russia the soils with gilgai microrelief are met in the Volga–Akhtuba floodplain [30], in some estuaries of the Pre-Caspian lowland [39, 23], in Yankul depression [8, 22, 28, 29], in the estuary of Manych–Salsk interfluve [27] and within the central part of Chernozem zone [20, 21].

The majority of Vertisols with such a microrelief structure is used as pastures and hay lands. Sometimes they are subject to planation by plowing; however the repeated diversion of these lands for non-agricultural purposes reveals the recovery of the gilgai microrelief after 2–5 years [6, 12, 31, 36,]. This fact serves as evidence that gilgai is formed very quickly, on the one hand, and, on the other hand, the activity of recent processes is capable to provide and restore the gilgai microrelief at the present time.

The given paper focuses on statistical parameters of bowl-and diaper-like morpho-structures in Vertisols that have been found out recently in the Krasnodar region [24].

OBJECTS OF RESEARCH

These studies were carried out in a key area “Vorontsovka”, in one of the great flat depressions (padi) widely spread in the northwestern part of the Kuban-Pre-Azov lowland particularly in Eisk peninsula. This key area is a transect (catena) of about 1800 m in length stretching along the steep coastal line of the Azov Sea. It is located in the northern part of padi near the settlement Vorontsovka in 20 km towards the south-west from Eisk town. The transect embraces the eastern padi board, where the above settlement is located (coordinates of initial point F: 46.654028ºN, 38.071278ºE), the northern part of the padi bottom occupied by arable lands and a ridge-like complex of the western padi board used under crop as well (coordinates of final point G: 46.643889ºN; 38.052139ºE). The parent materials are represented by loess-like clay. 140 soil profiles have been morphologically described, being located along the steep coastal line in interval with the absolute height from 4 to 6–7 m. The soil distribution along the catena is demonstrated in Fig. 1.

The eastern padi board near the settlement Vorontsovka is gently sloping (0.005º). Its upper part within the transect is represented by segregationary deep-quasigleyic medium-thick clay chernozem (Haplic Chernozem (Clayic, Pachic), the profile of which is AU–BCAnc–BCca,q. Downwards the slope at a height of 4.5–5 m – the segregationary deep-quasigleyic deeply vertic chernozem (Bathyvertic Bathystagnic Chernozem (Clayic, Pachic) with the profile AU–BCAnc–BCca,q,v. At a height of 4.2–4.5 m it is followed by the segregationary vertic chernozem (Vertic Bathystagnic Chernozem (Clayic, Pachic) underlying by the clay-illuvial vertic chernozem (Luvic Vertic Bathystagnic Chernozem (Clayic, Pachic) with the profile AU–AUb–AUb,v–B1v,q–BCAnc,v,q–BCca,nc,v,q.

On the bottom of padi near to its eastern board the agro-humus-quasigley vertic residual-segregationary clay soil has been developed (Vertic, Stagnic Phaeozem (Clayic, Pachic), whose profile is AU–AUb–AUb,v–Qv,(ca,nc)–Q/V(ca,nc)–QCv(ca, nc),cs–Cq,v(ca, nc),g. The other part of the padi bottom at a height of 3.9–4.2 m as well as an elevated part (4.2–5.1 m) before the ridge-like complex is occupied by agro-vertic dark-colored quasigley soils (Soil Classification of Russia,

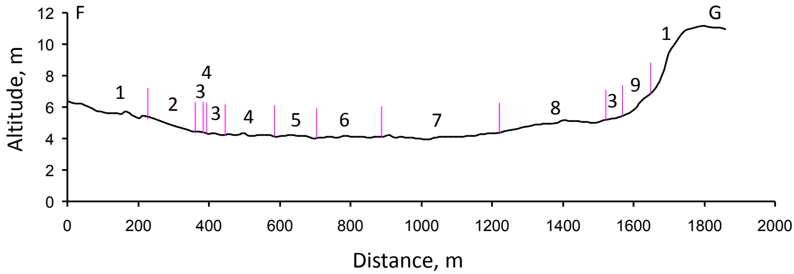

Fig. 1. Distribution of soils along FG catena intersecting the northern part of padi near the settlement Vorontsovka. *Soils according to the Soil Classification of Russia* (all the clay soils on loess-like clays): 1 –segregationary deeply quasi-gleyic medium-thick chernozem; 2 – segregationary deeply vertic deeply quasi-gleyic thick chernozem; 3 – segregationary vertic deeply quasi-gleyic thick chernozem; 4 – clay-illuvial vertic deeply quasi-gleyic thick chernozem; 5 – agro humus-quasigley vertic residual-segregationary medium-thick soil; 6 – agro vertic dark-colored quasigley residual-segregationary medium-thick soil; 7 – a complex of agro vertic dark-colored quasigley highly thick (bowl-like morphostructures) and agro vertic quasigley segregationary shallow soil (diaper-like morphostructures); 8 – agro vertic dark-colored quasigley segregationary medium-thick soil; 9 – clay-illuvial deeply vertic deeply quasigleyic thick agro chernozem. *Soils according to WRB-2014*: 1 – Haplic Chernozem (Clayic, Pachic); 2 – Bathyvertic Bathystagnic Chernozem (Clayic, Pachic); 3 – Vertic Bathystagnic Chernozem (Clayic, Pachic); 4 – Luvic Vertic Bathystagnic Chernozem; 5 – Vertic Stagnic Phaeozem (Clayic, Pachic); 6 – Pellic Vertisol (Aric, Mollic, Hypereutric, Humic, Stagnic); 7 – a complex of Pellic Vertisol (Aric, Mollic, Hyperutric, Humic, Stagnic) (bowl-like morphostructures) and Haplic Vertisol (Aric, Calcaric, Hyperutric, Stagnic) (diaper-like morphostructures); 8 – Pellic Vertisol (Aric, Mollic, Hypeutric, Humic, Stagnic); 9 – Luvic Bathyvertic Chernozem (Clayc, Aric, Pachic).

2004, 2008) or Vertisols (WRD, 2007). In the interval from 880 to 1220 m along the transect Vertisols are represented by stratifying the bowl-like morphostructures of the dark-colored surface horizon and the diaper-like morphostructures comprised the ascending olive-brown horizon with carbonate segregation. It is supposed that the natural state of this territory dispayed the gilgai microrelief which has being changed due to its use under crop for 50 years.

In the eastern part of the ridge-like complex the opposite soil sequence is observed in dependence on the absolute height. The clay-illuvial vertic and deeply vertic and deeply quasigleyic agro-chernozems are developed in the lower part near the bottom (Luvic Vertic and Bathyvertic Chernozem (Clayic, Aric, Pachic); the upper part at a height of more than 7 m is represented by segregationary clay agro-chernozems.

The subject of discussion in the present paper are statistical indices for bowl-and diaper-like morphostructures of Vertisols on the padi bottom dissected by the steep coastal line of the Azov Sea within the interval from 880 m (coordinates: 46.648889ºN, 38.062444ºE) to 1220 m (coordinates: 46.647028ºN, 38.059306ºE).

INVESTIGATION METHODS

The steep coastal line of the Azov Sea occurred as resulted from abrasion proved to a natural model for the vertical section of the soil cover. It allowed measuring a number of morphometric characteristics of bowl-and diaper-like morphostructures in Vertisols. The obtained results were quite sufficient for statistical processing.

The following morphometric characteristics have been determined:

γ – the wave length as a distance between the centers of two adjacent diaper-like morphostructures, m;

Wb – the width of the bowl-like morphostructure in the upper wide part of the dark-gray horizon, m;

T max – the maximal thickness of the dark-gray (humus) horizon in central par of the bowl-like morphostructure, cm;

T min – the minimal thickness of the dark-colored horizon (PU+AU+AUb) in the area of two adjacent bowl-like morphostructures overlying the diapirlike one, cm;

D upper and *D lower* – the depth of upper and lower boundaries of the layer with slickensides located near the coloring boundary between the dark-gray (AUb or AU) and olive-brown (Q/V) horizons in central part of the bowl-like morphostructure, cm;

ΔD – the thickness of the layer with slickensides in central part of the bowl-like morphostructure, cm.

The depth or thickness of horizons was measured by a geodesic rod with the division of 1 cm and telescopic up to 5 m, while the horizontal distances – by geodesic metering bands with the division up to 1 mm.

To describe the morphological properties of Vertisols in bowl- and diaper-like morphostructures more detail, the depth of upper and lower boundaries of soil horizons and subhorizons were measured at a distance of 21.5 m with the step of 25 cm from the centre of the diaper-like morphostructure to central part of the third bowl-like morphostructure.

The soil profiles were morphologically described and supplemented by photos of morphological elements and the whole profile [1, 10]. Special attention was paid to morphological features of vertigenesis including morphometric characteristics of slickensides, the presence of the wedge-shaped structure having a subhorizontal position of the long axis, the penetration depth of fissures filled up by the material from the upper horizons as well as a complex of soil features inherent to the other soil processes (solonetz process, gleying, quasigleying, zooturbation, carbonate accumulation, clay movement, etc.).

The soils were named in field and specified according to the soil classification of the former USSR (1977), Russia (2004, 2008) and WRB-2014 adopted in the 20th International Soil Science Congress held in Korea in 2014.

GPS was used to detect geographical coordinates for all the points of approbation. The particle size distribution was determined by pyrophosphate method, the statistical processing of obtained results in Excel.

RESULTS AND DISCUSSION

The profile configuration of Vertisols with bowl-and diaper-like morphostructures is presented in Fig. 2. The topsoil is an agro-dark-humus (arable) PU horizon which is 27–30 cm thick being decreased to 18–20 cm over some diaper-like morphostructures. Within the bowl-like morphostructures it is free from dispersed carbonates (soil effervescence is absent) and subdivided into three subhorizons including 0–10(12), 10(12)–22 and 22–30 cm in dependence on soil tillage in the fodder and tilled crop rotation. The PU horizon overlying the diaper like

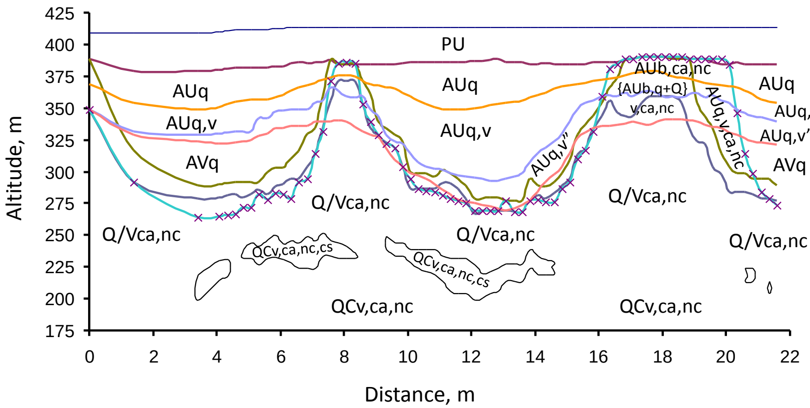

Fig. 2. Morphological configuration of Vertisols with bowl-like morphostructures (distance: 0–7.4; 9–16; 20.5–22 m) and diaper-like morphostructures (distance: 7.5–9 and 16–19 m). Indexation of soil horizons is given according to "Field Determination of Soils in Russia" (2008) and [9]. The line of continuous soil effeverscence is marked by a cross.

morphostructure reveals the soil effervescence at a depth of 10 to 30 cm. In some cases the carbonates can be observed at the soil surface. Downwards the profile is highly changed in horizontal direction and displays undulating changes in the thickness and boundaries of horizons and cyclic alternation of the other horizons.

The dark-gray humus horizons (PU+AU+AUb+AV) form wide bowl-like morphostructures, the latter being very thick in central part. In a distance from the centre the thickness of these horizons becomes decreased. To obtain a regression equation the experimental data about the changes in the thickness of dark-gray horizons were transformed, thus normalizing the distance from central part of the bowl-like morphostructure along the catena. As a result, for the key area presented in Fig. 3 the following regression was compiled as a polynome of the second degree:

$\gamma = 2.696 - 0.0053x + 0.0539x^2$ ($n = 65$; $f_2 = 63$; $R^2 = 0.915$; $F = 338$),

where x – distance from central part of the bowl-like morphostructure, m; γ – height of the lower boundary of the dark-gray horizon, m; n – volume of selected data, f_1, f_2 – numbers of rge degree of freedom, R^2 –

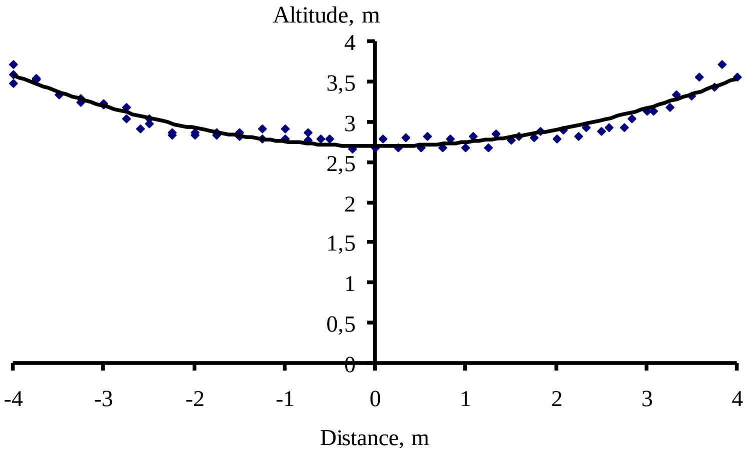

Fig. 3. Experimental points and approximated line of regression reflecting changes in the depth of the lower boundary of the dark-gray horizon in dependence on the distance from the point to central part of bowl-like morphostructure in Vertisol.

determination coefficient, *F* – Fisher criterion. The regression coefficients are valuable at a level of 0.05; regression is also of value with a higher determination coefficient. It means that in the section by vertical plane the thickness of the dark-gray horizon is changed according to a parabolic curve and the bowl-like morphostructure assumes a kind similar to paraboloid of revolution. It is worth of emphasizing that the term "cone of revolution" applied in Wilding's publications (1985, 1988) seems to be unsuccessful because the cone should be provided by a sharp top what is not typical for bowl-like morphostructures.

Within the bowl-like morphostructures the soil profile is the following: PU–AUq–AUq,v–AVq–Q/Vca,nc–QCv,ca,nc,cs–2QCv,ca,nc. Below the plough horizon is the dark-humus AUq horizon with clearly expressed fine ferruginous brown coatings (0.5–1 mm) (q – quasigleyic). At a depth of 50–70 cm (AUq,v horizon) slickensides are observed in the size from 4 to 10–20 cm with the different azimuthally inclined orientation. At a depth of 70–100 cm the soil reveals abundant slickensides and a wedge-like structure. As a result, the lower part of the dark-gray horizon transforms into the dark-vertic AVq horizon with features of quasigleying, they are more black in color as compared to the overlying AUq horizon (2.5Y–2.5/1 or even Gley1 2.5/N, while the AVq and PU horizons are usually 2.5Y 3/1 or 2.5Y 2.5/1. Such a change in color is likely connected with the different duration of redox conditions, the latter being changed very quickly in the upper horizons are accompanied by the formation of abundant ferruginous coatings that make the horizon brown in color to a considerable extent. Probably there are the other reasons which need to be specifically studied. In the lower part the AVq horizon becomes lighter in color (2.5Y 4/1) and forms a transitional stripe 10–15 cm wide. It is locally effervescent but the line of continuous effervescence coincides with the boundary between AVq and Q/Vca,nc horizons fluctuating in several centimeters from it. The AVq horizon is underlying by the Q/Vca.nc one combined diagnostic features of the quasigleyic Q and vertic V horizons. It is olive-brown in color (from 2.5Y 3/2, 2.5Y 4/2 to 2.5Y 5/3), has an abundance of brown ferruginous coatings from 0.5 to 2–4 mm in diameter, prismatic and wedge-like structure with slikensides ranging from 4–7 to 50–100 cm in size. The slikensides of less than 20 cm in size display a chaotic azimuthally inclined orientation. The large slickensides are located along the boundary between AVq and Q/Vca,nc horizons being distributed from the central part of the bowl-like morphostructure and forming diaper-like morphostructures consisting of the material ascending from lower horizons. By this reason the inclination angle of large slikensides is 10º–20º in central part of the bowl-like morphostructure increasing to 40º–60º according to the parabolic curve in the diaper-like morphostructure.

As was mentioned above, the Q/Vca,nc horizon has the continuous but weakly or average expressed effervescence and a great amount of hard carbonate segregations of 5–10 cm in diameter. There are abundant dark-colored mottles and patches consisting of the material from the upper dark-gray horizons penetrated into the earlier open vertical cracks as well as the humus-clayey suspension in subhorizonal frissures along the slickensides. As a result, this horizon can be divided into two subhorizons with a diffusional boundary between them including the upper more dark Q1/Vca,nc (2.5Y 3/3 or 2.5Y 4/2) and the lower more light Q2/Vca,nc (2.5Y 5/3) ones.

At a depth of 160–170 to 180–190 cm in bowl-like morphpstructures the QCv,nc,cs horizon with a network of veins comprising mealy or fine crystalline gypsum is observed. Its thickness doesn't exceed 10–20 cm. As a rule, in horizontal direction this horizon is discontinuous being confined to diaper-like morphpstructures.

At a depth of 250–300 cm the lithological rocks are changed and the lower lying horizon looks like as a buried paleosoil characterized by the presence of well-expressed slikensides, wedge-like structure, marmoreal coloring due to abundant bluish-gray gleyed and rusty-brown and red films of iron oxides on the walls of fissures and cylindrical channels. This layer is dating by specialists of the Institute of Geography now. It is possible to supposed that this horizon derived from mezin soil-loess complex [40].

The soil profile in the diaper-like morphostructure is the following: PU–PUca–b,ca,nc–{AUb+Q}ca,nc,v–Q/Vca,nc–Qv,ca,nc–2QCv,ca,nc,g. The upper part of the profile beneath the PU horizon is divided into (1) the dark-humus AUb horizon which is thick, light-coloring due to dispersed carbonates and carbonate segregations being underlain by a mottled polymorphon {AUb+Q}ca,nc,v, (2) a mottled polymorphon {AUb+Q}ca,nc, the lower part of which reveals slickensides, i.e. {AUb+Q}ca,nc,v. In both variants the carbonates are present in several forms: (1) dispersed carbonates penetrating the soil mass and providing the brown effervescence; (2) compact segregations of the rounded or angular shape of 2–7 mm in size; they are similar to identical segregations in the Q/Vca,nc horizon within the bowl-like morphostructure; (3) friable segregations of 10–15 mm in diameter, sometimes they are hard in central part and look like as white soft spots. The carbonate content is by 2–3 times higher as compared to that in the Q/Vca,nc horizon of the bowl-like morphostructure. There are also many brown ferruginous coatings of 0.5 to 5 mm in diameter. The mottled polymorphon {AUbmq+Q} is represented by alternation of vertically stretched mottles and stripes of varying width. The dark-gray AUb,q fragments are usually wider in the upper part being narrowed downwards. The olive-brown tongues and Q mottles occur in the lower part of the Q/Vca,nc horizon. The mosaic of interpenetrated (AUb) and (Q) tongues and mottles is added by vertical stripes of the dark-gray material from the surface horizon (PU or AUb) that has been put into fissures.

The slickensides appear in diaper-morhostructures at a depth 35–45 cm, what is by 20–50 cm higher as compared to that in bowl-like morphostructures. The mottled polymorphon {AUb,q+Q} at a depth of 50–60 cm reveals wedge-like structural elements. It is underlain by the light-coloring Q2/Vca,nc horizon at a depth of 80–100 cm. The slickensides are smaller in size (40–50 cm), the amount of carbonate segregations is rather low in comparison to the overlaying {AUb,q+Q}ca,nc,v horizon but higher than that in the Q2/Vca,nc horizon under the bowl-like morphostructure.

The QCv,ca,nc,cs horizon is met sometimes under narrow diaper-like morphostructures about 1 m). It is absent in wide diaper-like morphostructures (2–3 m and more). The contact line between bowl- and diaper-like morphostructures is ranging from 20–30 to 100–120 cm in the upper part of the soil profile (Fig. 2). The boundary of the diaper-like morphostructure is usually sharply expressed along tongues of the material ascending from the olive-brown horizon Q. Along this boundary or near it in the range of 2–3 cm the large slickenside is stopped. The boundary of the bowl-like morphostructure coincides with the effervescence line which is sinking downwards from 20–30 to 120–130 cm at a distance of 10–30 cm. In wide contact areas such great morphones are distinguished as AUq,ca,nc; AUq,ca,nc,v; AUb,q,ca,nc; Aub,q,ca,nc,v.

The soils under consideration have the medium-clay coarse-silt-clay particle size (Table 1). The content of particles (<0.01 mm) is 70–80%, clay (<0.001 mm) – from 42.7 to 58.3% and the coarse silt (0.1–0.005 mm) – 13.0–23.7%. It is worthy of note that the clay content in AUq and AUv,q horizons of the bowl-like morphostructure is rather low (42.7–48.7%), whereas in the other horizons of the same profile in the diaper-like morphostructure the clay content becomes higher than 53.5%.

It serves as evidence that the soil mass of surface horizons reveals some redistribution in horizontal direction. One should proposed, that this process has several stages of its development. At the stage of loess-like clay accumulation the proper clay material was probably accumulated, at final stages it became enriched with coarse-silt particles.

Table 1. Particle-size distribution of Vertisols

Horizon	Depth,cm	Content (%) of different-sized fractions (mm)						
		1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01
Diapir-like morphostrcture, pit V-340								
PU	0–15	0.4	1.8	19.7	9.2	12.9	56.0	78.1
AUb,ca,nc,q,v	20–50	0.9	5.1	15.7	8.2	13.7	56.4	78.3
AVca,nc,q	70–100	1.5	2.5	18.0	6.9	12.8	58.3	78.0
V/Qca,nc	130–160	3.8	3.6	16.9	8.4	13.8	53.5	75.7
VCca,nc	180–200	3.2	3.2	21.1	4.3	13.8	54.4	72.5
QCv,(ca,nc),g	200–220	1.1	3.0	17.7	8.0	13.4	56.8	78.2
Bowl-like morphostructure, pit V-341								
PU	0–30	0.3	1.7	20.1	8.3	14.4	55.2	77.9
AUq	30–60	0.3	5.4	23.7	10.8	17.1	42.7	70.6
AUv,q	70–100	0.1	2.3	23.5	9.7	15.7	48.7	74.1
AVq	100–130	0.1	1.0	18.9	8.8	15.5	55.7	80.0
V/Qca,nc	130–160	3.5	5.6	18.6	5.2	13.8	53.3	72.3
V/Qca,nc,cs	180–200	3.6	7.5	13.0	8.7	12.1	55.1	75.9

After compaction and consolidation of the loess-like clay in the course of carbonate leaching under conditions of the closed depression bottom the swelling-sinking and shearing stress processes took place and resulted in undulating soil surface, thus forming the gilgai microrelief. The clay material forced from lower horizons was accompanied by its gradual erosion from concave elements into convex ones. The tongue forms of the olive-brown material ascending from the lower horizons and changed by plowing permit to assume that these tongues reached the surface formerly and pushed aside the soil mass of upper horizons with a lower clay content towards convex elements of relief. This material got intensively mixed by soil mesofauna and in the course of pedoturbation during the swelling-sinking process the stratification traces proved to be disappeared. After plowing and surface planation the material with the increased clay content seemed to be distributed at the surfacef former microdepressions. By this reason, the recent plough horizon PU in the bowl-like morphostructure has the clay composition with relatively higher clay content (more than 53.5%) as identical to that in the soil profile of the diapir-like morphostructure and in lower horizons of soil within the bowl-like morphostructure.

The major part of the bowl-like morphostructure is represented by agro-vertic dark-colored quasigley thick deeply carbonate clay soil or meadow-chernozem leached vertic clay soils (according to Russian soil classification, 2004, 1977) or Pellic Vertisol (Aric, Mollic, Gilgaic, Humic, Stagnic) according to WRB-2014.

The diaper-like morphostructure is represented by agro-vertic shallow clay soil or meadow-chernozem carbonate vertic shallow clay soil (in the soil classification of Russia, 2004, 1977) or Haplic Vertisol (Aric, Mollic, Calcaric, Gilgaic, Humic, Stagnic) according to WRB-2014.

In the contact area (if it is rather wide) the agro-vertic dark carbonate thick clay soil or the meadow-chernozem vertic thick clay soil is recognized (Russian soil classification, 2004, 1977) or Pellic Vertisol (Aric, Mollic, Calcaric, Gilgaic, Stagnic) according to WRB-2014.

Statistical indices for bowl-and diapir-like morphostructures. Fig. 4–10 demonstrate histograms of the empiric statistical distribution of 6 measured indices and a calculated index for the above morphostructures, including 46 bowl-like ones and several diapir-like morphostructures between them.

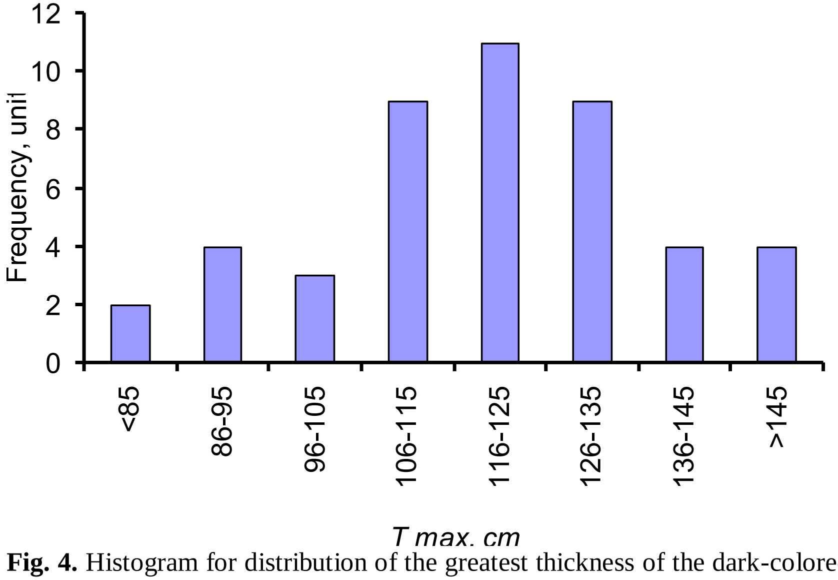

Fig. 4. Histogram for distribution of the greatest thickness of the dark-colored horizon in central part of the bowl-like morphostructure in Vertisol.

Table 2. Statistical indices for bowl-and diaper-like morphostructures in Vertisols

Statistical index	Morphometric index of soils						
	T max	*T min*	*D upper*	*D lower*	Δ*D*	*Wb*	λ
n	44	44	44	44	44	44	43
Minimum	80	25	80	155	30	2.8	4.0
Lower quartile	111	30	110	177	50	4.1	5.2
Median	120	45	120	189	70	5.1	6.2
Upper quartile	130	55	135	204	80	6.9	8.5
Maximum	160	70	153	246	115	8.9	11.3
Amplitude	80	45	73	91	85	6.1	7.3
Average	120	44	121	191	70	5.4	6.8
Standard deviation	19	15	16	22	21	1.7	2.0

Note: *n* –amount of objects; *T max* – the greatest thickness of the dark-colored horizons in central part of the bowl-like morphostructure, cm; *T min* – the minimal thickness of the dark-colored horizon in central part of diaper-like morphostructure, cm; *Dupper and Dlower* – depth of the upper and lower boundaries in the layer with great slikensides in the centre of bowl-like morphostructure, cm; Δ*D* – thickness of the layer with great slikensides, cm; *Wb* – width of the bowl-like morphostructure in its upper part, m; λ – wave length along the distance between central parts in diaper-like morphostructures, m.

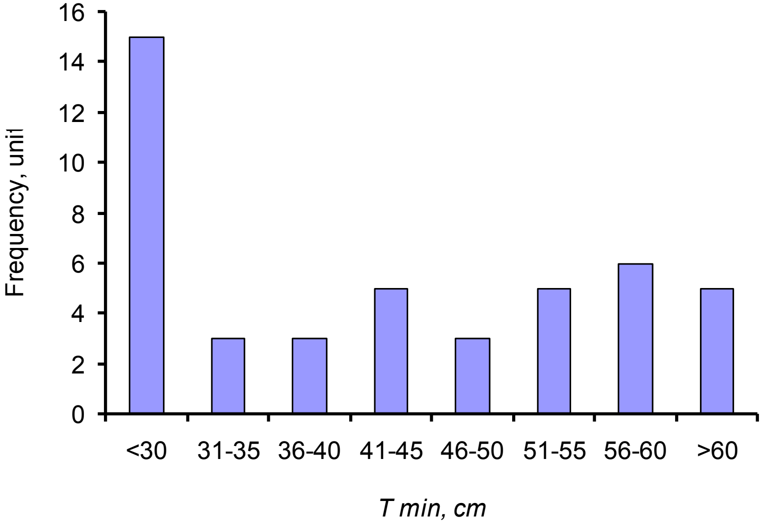

Fig. 5. Histogram for distribution of minimal thickness of the dark-colored horizon in central part of the diaper-like morphostructure.

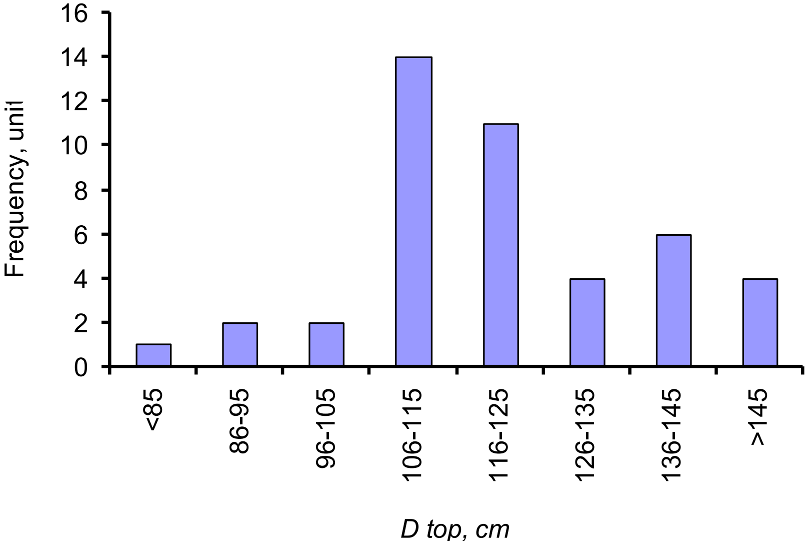

Fig. 6. Histogram for distribution of the upper boundary depth with great slikensides in central part of the bowl-like morphostructure in Vertisol.

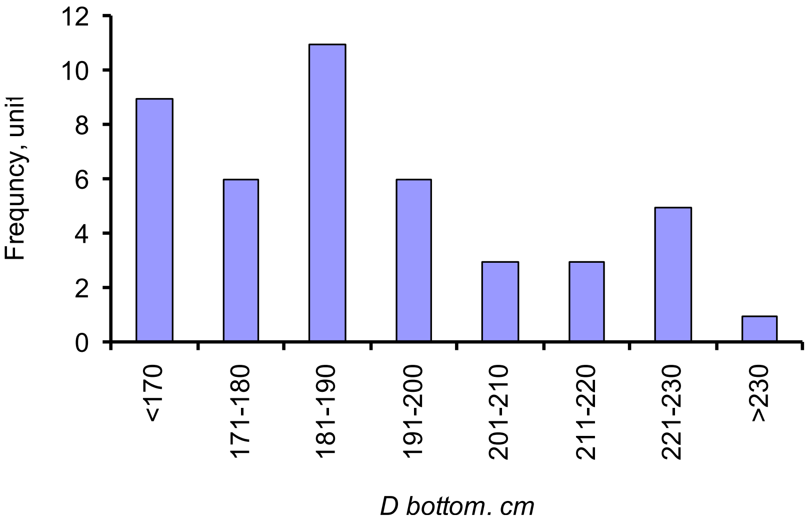

Fig. 7. Histogram for distribution of the lower boundary depth in the layer with great slikensides in central part of the bowl-like morphostructure in Vertisol.

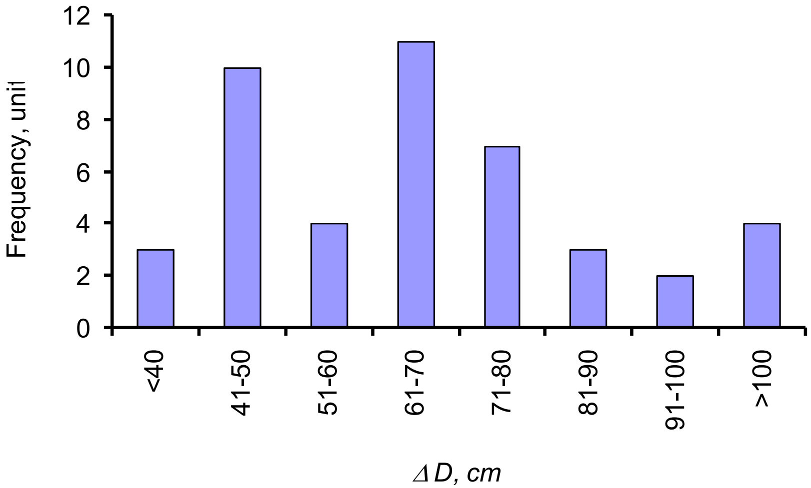

Fig. 8. Histogram for distribution of the layer thickness with great slikensides in central part of the bowl-like morphostructure in Vertisol.

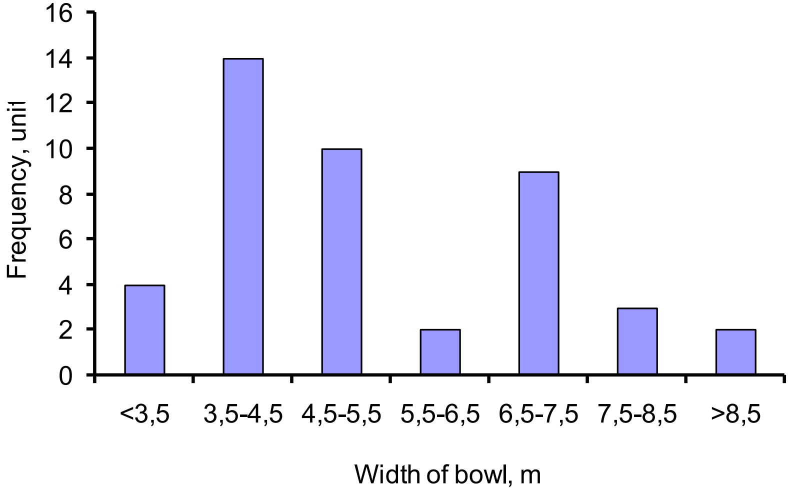

Fig. 9. Histogram for distribution of the bowl-like morphostructure width in its upper part.

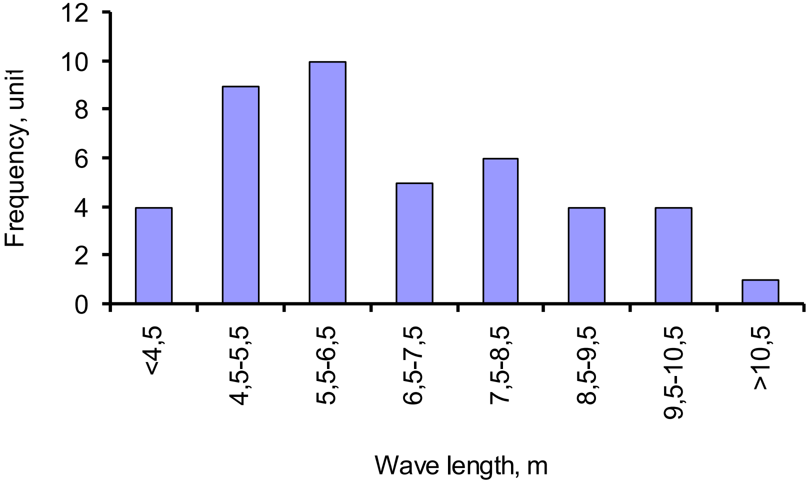

Fig. 10. Histogram for distribution of the wave length according to the distance between centres of diaper-like morphostructures in Vertisol.

The selective statistical distribution of all the morphometric indices differs from normal one according to X^2 criterion. In view of this, Table 2 contains additional values of non-parametric statistical indices.

As a rule, the greatest depth of dark-colored horizons in central part of the bowl-like morphostructure is 105–135 cm varying from 80 to 160 cm. The small depth of these horizons in the diaper-like morphostructure doesn't exceed 55 cm being maximal as 70 cm (Fig. 5). The minimal value of this index equaled to 25 cm is conditioned by annual plowing.

The width of the bowl-like morphostructure displays biomodal distribution in the range of 4–5 and 7–8 m with the variability diapason from 2.8 to 8.9 m.

The upper boundary depth of the layer enriched with large slickensides is asymmetrically distributed towards the highest values (Fig. 6). In most cases (89%) this boundary is at a depth of 105–150 cm being frequently equaled to 105–125 cm. The thickness of the layer containing large slickensides every 8–10 m along the vertical line is varying from 30 to 115 cm (Fig. 8).

The distance between central parts of diaper-like morphostructures (the wave length) varies from 4 to 11.3 m. The distribution is asymmetrically towards the smallest values (Fig. 10). Such a wave length coincides approximately with parameters of gilfai in Yancul depression [22, 21] as well as in many regions of the world [1, 6, 7, 12, 36, 41].

Statistical relationship between morphometric indices. The indices for the depth or thickness of soil horizons are not connected with each other excluding only *Tmax* and *Dlower*. The latter have a close variability diapason (80–160 cm for *Tmax* and 80–153 cm for *Dlower)*and identical median (120 cm). In the equation of linear regression between these morphometric indices the angle coefficient is 0.985. It means that the upper boundary of the layer with large slickensides doesn't statistically differ from the depth of the lower boundary of the dark-gray horizon. Deviation is only ±10 cm. Sometimes the upper boundary of the layer with large slickensides can rise towards the day surface up to 43 cm and sink at a depth of 20 cm relatively the lower boundary of the dark-gray horizon.

A close connection seemed to be expected between the width of the bowl-like morphostructure (*Wb*) and the distance between central parts of diaper-like morphostructures (wave length λ). This connection is approximated by the following equation:

$T\ max = 93.2+4.5\lambda$, $R^2 = 0.250$, $n = 42$, $f_1 = 1$, $f_2 = 40$, $F = 12.2$;

$Dupper = 93.7+4.4\lambda$, $R^2 = 0.286$, $n = 41$, $f_1 = 1$, $f_2 = 39$, $F = 15.6$;

$\Delta T = 35.6+6.5\lambda$, $R^2 = 0.300$, $n = 42$, $f_1 = 1$, $f_2 = 40$, $F = 17.1$.

The coefficients of regression and equation are valuable and have the probability equaled to 0.95.

Having used Maxwell hypothesis (1994, 2013) the above tends permit to propose that the diaper-like morphostructures are alternated when the values of the wave length are rather high at a great depth of the source for the increased lateral pressure in the clay material of the rock or soil in places, where the central part of the bowl-like morphostructure is formed.

CONCLUSIONS

1. In Vertisols developed on the bottom of Vorontsovka padi in Eisk peninsula the changes in the

depth of the lower boundary of the dark-gray horizon in dependence on a horizontal distance from the central part of bowl-like morphostructures have been approximated by the equation of regression as a polynome of the second degree. It allows concluding that the form of bowl-like morphostrctures proves to be similar to the paraboloid of revolution.

2. In central part of the bowl-like morphostructure the depth of the upper boundary of the layer with very large slickensides doesn't statistically differ from the depth of the lower boundary of dark-gray horizons being varied in diapason of ±10 cm with deviation towards the day surface up to 43 cm and down the depth to 20 cm. It serves as evidence that the forms of bowl-like morphostructures and the horizontal shearing of stress in the material of underlying horizons reveal interrelated origin.

3. The maximal thickness of dark-gray horizons and the depth of the upper boundary of the layer with the large slickensides in central part of bowl-like morphostructures have a tend to increasing with increasing the distance between central part of adjacent diaper-like morphostructures (wave length). Based upon Maxwell hypothesis, it is possible to propose that the deep location of the source for lateral pressure in soil promotes the formation of diaper-like morphostructures in a great distance from each other in both sides of the source, where the central part of the bowl-like morphostructure occurs.

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