

Vertic Processes and Specificity of Organic Matter Properties and Distribution in Vertisols¹

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Abstract—Soil organic matter (SOM) was studied in relation to vertic processes (i.e., shrinking/swelling, cracking, vertical turbation, lateral shearing, gilgai formation) in Vertisols and vertic soils of the North Caucasus in Russia, and Texas and Louisiana in the USA. Their impact on SOM properties and distribution was analyzed according to various levels of soil organization, such as soil cover, profile, horizon, and aggregate structure using chemical methods, micromorphology, isotopic analyses, and physical fractionation. The greatest variations both in the distribution and properties of SOM were found in mature Vertisols at the level of soil cover including C_{tot}, organic carbon stocks, stable carbon isotopic composition, and SOM ¹⁴C-age, chemical composition. The distribution of SOM at the profile and horizon levels was related to the functioning of Vertisols during wet-dry cycles. The isotopic and chemical study of densi-granulometric fractions at the aggregate level reflected the minor role of vertic processes.

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INTRODUCTION

Soil organic matter (**SOM**) has been studied in Vertisols by a variety of methods including general characteristics in early studies [13], chemical and physico-chemical methods such as Fourier Transform Infrared (FT-IR) spectrometry, Fluorescence, Electron Spin Resonance (**ESR**) spectroscopy etc. [2, 13–15, 25, 28, 33] and radiocarbon dating [5, 7, 17, 22, 29–31]. Several papers have also presented data on stable isotopic composition [5, 15, 21] and chemical and physical fractions of SOM in Vertisols [9, 10, 23, 27].

The unique properties of Vertisols are related to shrinking-swelling, resulting in vertical mixing (pedoturbation), lateral shearing, and the formation of cracks, slickensides and gilgai. These physical processes result in very specific morphology, properties, functioning and evolution of Vertisols. The best known characteristics of Vertisols include deep homogenous profiles, lateral subsurface cyclic horzonation, formation of gilgai soil complexes, and strong clay-organic matter interactions.

The aim of this paper is to show the specificity of SOM properties and distribution in Vertisols and vertic soils that result from vertic processes including: (i) shrinking and swelling; (ii) vertical turbations when surface mulch and fine aggregates fall down into open

cracks between coarse blocks; (iii) lateral subsurface shearing along slickensides.

An attempt was made to characterize SOM properties and distribution at different levels of organization such as soil cover, soil profile (pedon) and horizon, and the soil aggregate using modern instrumental methods and available data.

MATERIALS AND METHODS

Soils. Two main groups of Vertisols are discussed in the paper. Vertisols and vertic soils from a temperate climate were studied in the southeastern European part of Russia in the North Caucasus. Vertisols were described and sampled in regular soil pits and two trenches 3m-long and 2m-deep with and without microrelief gilgai.

These soils were well studied and the selected data published [15–19].

Vertisols from a subtropical climate were studied in south-central USA, in Texas and Louisiana in trenches 2m-deep and 5m-long across the gilgai microrelief or the subsurface cyclic horizons. Samples were collected along the pedons corresponding to the microhighs (**MH**), microslopes (**MS**) and microlows (**ML**), or at contrasting elements of the subsurface cyclic horzonation.

Microvariability in soil morphological, physical, chemical, and biological attributes was found across the

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Table 1. Location, physiography and list of soils analyses

Location	Soil	Absolute Elevation & geomorphology	Parent material	Vegetation	Analyses
North Caucasus, southern Russia, temperate climate, MAP 500 mm, MAT 9°C					
44°38'N 42°15'E	Vertisol gilgai MH, MS, ML	450 m a.s.l., footslope	Marine clay	Meadow-bog- steppe complex	C_{tot} , stable isotopic composition, ^{14}C , chemical fractionation, physical fractionation, stable isotopic composition of physical fractions, microscopy
44°37'N 42°16'E	Vertisol postgilgai MH, MS, ML	475 m a.s.l., interfluve divide	Marine clay	wheat	C_{tot} , stable isotopic composition, ^{14}C , chemical fractionation, microscopy
45°22'N 41°42'E	Vertic Mollisol	260 m a.s.l., footslope	Marine clay	steppe	C_{tot} , ^{14}C , microscopy
44°40'N 42°44'E	Vertic Mollisol	590 m a.s.l., interfluve divide	Marine clay	corn	C_{tot} , stable isotopic composition of fractions, physical fractionation, C_{fr} , microscopy
	Vertisol	590 m a.s.l., interfluve divide	Marine clay	steppe	C_{tot} , physical fractionation, stable isotopic composition of physical fractions, C_{fr}
Texas and Louisiana, South-central USA, subtropical climate, MAP 850–1500 mm, MAT 18–22°C					
30°29' N.L. 96°28' W.L.	Burleson series. Vertisol gilgai MH, MS, ML	78 m a.s.l., terrace of Brazos river	Red alluvium	prairie	C_{tot} , physical fractionation, stable isotopic composition of fractions, C_{fr}
30°59' N.L. 97°10' W.L.	Houston series. Vertisol gilgai MH, MS, ML	147 m a.s.l., interfluve divide	Clayey marl	prairie	C_{tot}
30°45' N.L. 92°08' W.L.	Lebeau series. Vertisol gilgai MH, ML	12 m a.s.l., Mississippi delta	Red alluvium	trees	C_{tot}

microrelief and/or subsurface cyclic horizons, and the term *gilgai soil complex* was suggested to better describe such a case [37]. Main physiographic information for soils from both groups is presented in Table 1.

Methods. Total organic carbon (C_{tot}) was determined in bulk samples from each horizon by wet combustion with potassium dichromate and concentrated sulfuric acid according to Turin [3]. C_{tot} in specimens from the trenches was determined according to the Soil Survey Staff [34].

Chemical fractionation of SOM was performed on the basis of extractability in NaOH and solubility upon acidification of alkaline extracts into humic acids (HA), fulvic acids (FA) and insoluble humin according to Ponomareva and Plotnikova [26]. As was described [15] three fractions of HAs and FAs were extracted: 1st—free, 2nd—Ca-bound, and 3rd—clay and R_2O_3 —bound.

Radiocarbon dating was performed on humic acids from SOM using liquid scintillation method. Procedures and instrumentation are described in Kovda et al. [17]. The ^{14}C -dates are presented in yr. B.P.

Stable isotopic composition of carbon ($^{13}C/^{12}C$) in SOM was performed on bulk samples of the soil matrix to a depth of 2 m. Analytical procedures, pretreat-

ments and instrumentation for stable isotope analyses were described by Miller [24]. The isotopic ratios of carbon are reported in standard δ -permil notation relative to the international PDB standard.

Thin sections were prepared according to the methods described by Ashley [4] with acetone as a diluting agent. Hardening was initiated using residual gamma radiation from a research nuclear reactor. Blocks were mounted on 50 × 75 mm glass slides and polished to 30 μm thickness. Optical examinations were made under both plane and cross-polarized light modes at magnifications up to 160×.

Soil physical fractionation was performed on samples from the surface 0–10 cm using particle size and density variation of soil components [32]. Additionally, one Mollisol on loess parent material from the East-European Plain (Kamennaya Step', Voronezh region) and one vertic Mollisol from the North Caucasus formed on clayey parent material were fractionated as references. The fractionation scheme is presented in Fig. 1. Particle size-density fractionation was used to separate roots, 3 light fractions, containing mainly free organic matter: $<1.8 \text{ g cm}^{-3} < 50 \mu\text{m}$ (particulate soil organic matter or POM), $<1.8 \text{ g cm}^{-3} > 50 \mu\text{m}$ (weakly transformed organic residues), and $1.8–2.0 \text{ g cm}^{-3}$

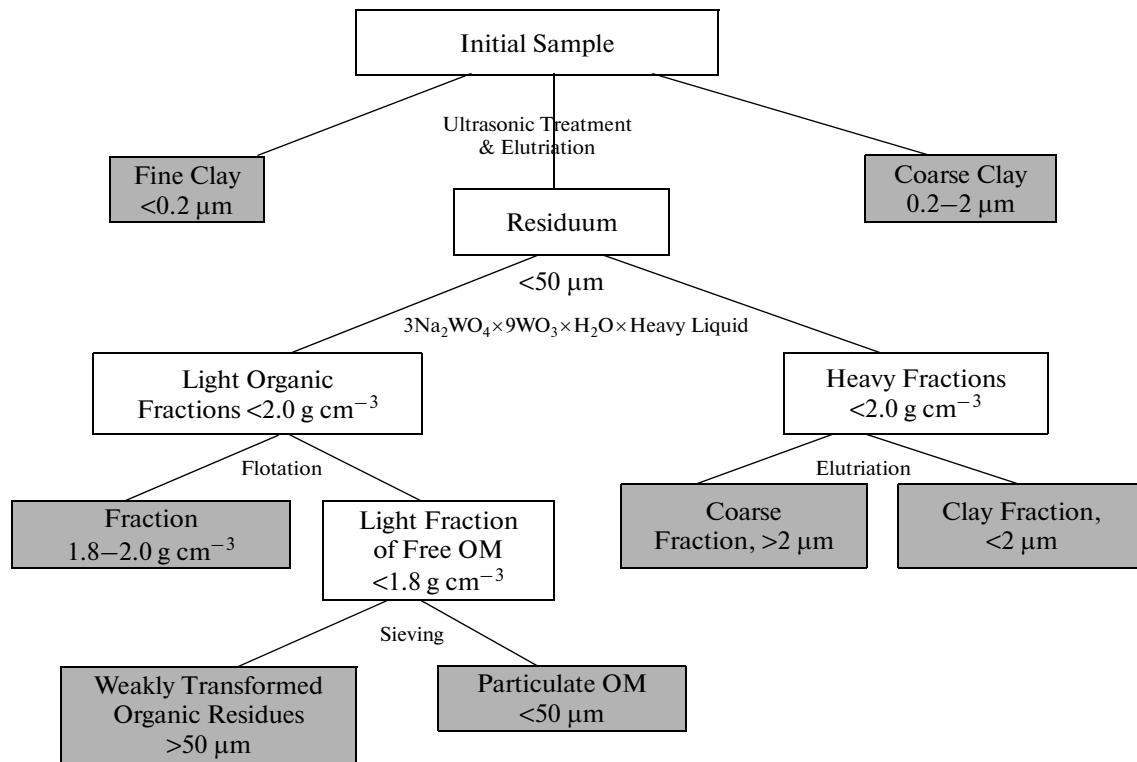


Fig. 1. Scheme of physical fractionation according to the particle size and density.

(organic matter non fixed with mineral matrix and containing biogenic amorphous silica i.e. phytoliths). In addition, 4 fractions of organic matter, associated with mineral compounds: $<0.2 \mu\text{m}$ and $0.2–2 \mu\text{m}$, (fine and coarse clay of unstable organo-mineral aggregates, correspondingly), $>2.0 \text{ g cm}^{-3} < 2 \mu\text{m}$ and $>2 \text{ g cm}^{-3} > 2 \mu\text{m}$ (heavy fraction, composed of the clay and coarse components of stable organo-mineral aggregates, correspondingly) were separated using ultrasonic treatment, sedimentation, and flotation in heavy liquids (Na-polytungstate solutions) for density separations. Organic matter in each fraction was characterized by measuring the concentration (C_{fr} , g kg^{-1} soil) and isotopic composition ($^{13}\text{C } \text{\%}$ vs. PDB) of soil organic carbon using a Carlo Erba EA-1108 elemental analyzer interfaced with a Delta Plus isotope ratio mass spectrometer (ThermoFinnigan, San Jose, CA) operating in continuous flow mode.

RESULTS AND DISCUSSION

Soil Cover Level. Young Vertisols without gilgai have normal vertical distribution of soil characteristics and no specific lateral variation of properties (Fig. 2a). Mature Vertisols with gilgai or with subsurface cyclic horzonation as described by Wilding et al. [36] have complex structure of the soil cover due to water redistribution and complex vegetation pattern according to microrelief [6, 20]. The density of vegetation cover,

variety of species, their stratification, and structure of plant matter were also found to be dependent on microrelief [16]. Soils in depressions are wetter, have more productive vegetation cover, and are subjected to flooding for periods ranging from several days in subtropical climates up to several months after spring snow melting in temperate climate.

This resulted in strong lateral variation of SOM including quantitative and qualitative characteristics. Organic carbon stock varied from 78 T ha^{-1} up to 110 t ha^{-1} in the $0–20 \text{ cm}$ layer along gilgai [15]. The C_{tot} concentrations in surface horizons ranged from 1 to 2.5% with more expressed difference under the temperate climate (Fig. 2b). The calculated difference between C_{tot} in microlows and microhighs is maximal in the upper 20 cm both in the temperate and subtropical environments, staying constantly at least twice

Table 2. The difference in C_{tot} (%) between gilgai microlows and microhighs

Depth, cm	North Caucasus, Russia	Texas, USA*
0–20	2.5	1
40	2	0.8
80	1.6	0.6
100	1.2	0.6

Note: * NRCS data were used for calculations.

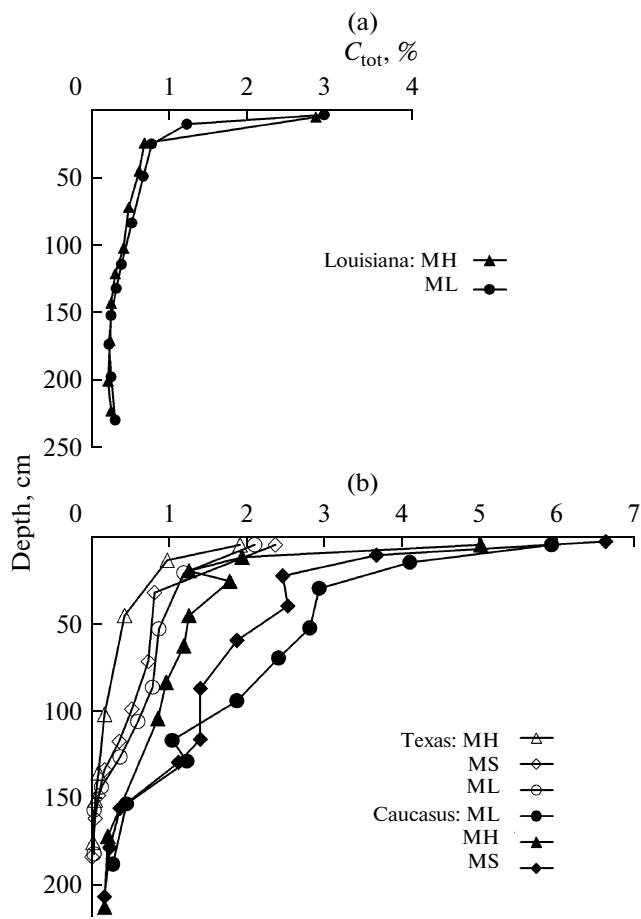


Fig. 2. Lateral and vertical variation of C_{tot} in (a) young Vertisol and (b) mature gilgai complexes. MH—microhigh, MS—microslope, ML—microlow.

larger in the temperate gilgai up to the 100 cm depth (Fig. 2b, Table 2). The lateral variation of C_{tot} disappears below 120–150 cm. Chemical fractionation revealed the drastic increase of the brown humic acids + fulvic acids of the first fraction in the upper part of microslope and microlow positions [15].

The layer $\sim 20 \pm 10$ cm has most expressed variations of all measured characteristics including radiocarbon age, stable isotopic composition, chemical composition, and micro fabric (Table 3). These varia-

Table 3. Variation of the SOM characteristics within 0–20 cm layer along gilgai, North Caucasus

Attribute	Microhigh	Microslope	Microlow
C_{tot} , %	1.9	3.7	4.1
^{14}C -age, years B.P.	1140 ± 30	150 ± 50	70 ± 45
$\text{HA}_1 + \text{FA}_1$, % from C_{tot}	5.1	16.3	52.5
$\delta^{13}\text{C}$, ‰	-25.70	No data	-26.15
Type of humus	Mull	Mull/moder	Moder

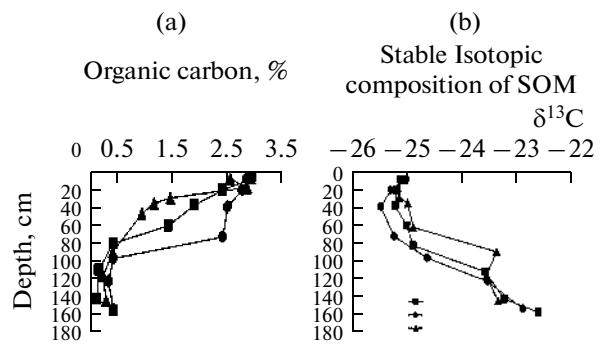


Fig. 3. Differentiation of (a) C_{tot} , % and (b) stable isotopic composition of SOM ($\delta^{13}\text{C}$ ‰ vs. PDB) in cultivated postgilgai site, North Caucasus, Russia.

tions are stable with time and are noticeable even several decades after gilgai were destroyed by natural processes or cultivation. Such examples were studied both in Russia and Texas. Clear lateral differentiation in C_{tot} and stable isotopic composition of carbon was identified at a depth ~ 20 –120 cm with the exception for the upper annually cultivated layer, (Fig. 3a, 3b).

Profile and Horizon levels. Pedoturbation and churning were once believed to be the primary factors responsible for Vertisol morphology [8], but more recent publications have reevaluated the significance of these processes in Vertisols. For example, Wilding and Tessier [35] examined key Vertisol attributes such as horizonation, structure, systematic depth functions of soil properties and concluded that pedoturbations were not as rapid as previously thought. Based on radiocarbon measurements, Yaalon and Kalmar [38] suggested that intrapedon turbations affected the amount, distribution, and dynamics of soil organic matter in Vertisols only slightly.

Despite being overestimated in earlier studies, vertical turbation nonetheless seems to be an important process in Vertisol functioning. We believe that pedoturbation results in the homogenization of the soil when surface mulch falls into cracks and becomes further incorporated into the matrix after local shrink-swell and shearing events. The downward movement of the material prevails upon the reverse direction.

The distribution of SOM at the profile and a horizon levels is related to the functioning of Vertisols during wet-dry cycles. The two most important factors are: (1) the development of large and deep cracks; and (2) specific combinations of structures from loose fine granular surface mulch to large subsurface blocks separated by open cracks, and wedge-shaped aggregates in the bottom. Fine surface aggregates penetrate through the cracks deep into the profile and lead to the mixing of the material. The first stage of this process resulted in strong microzonality. Surface aggregates are distinguished by dark color within the lighter colored matrix deeper in the profile (Fig. 4a). Similarly,

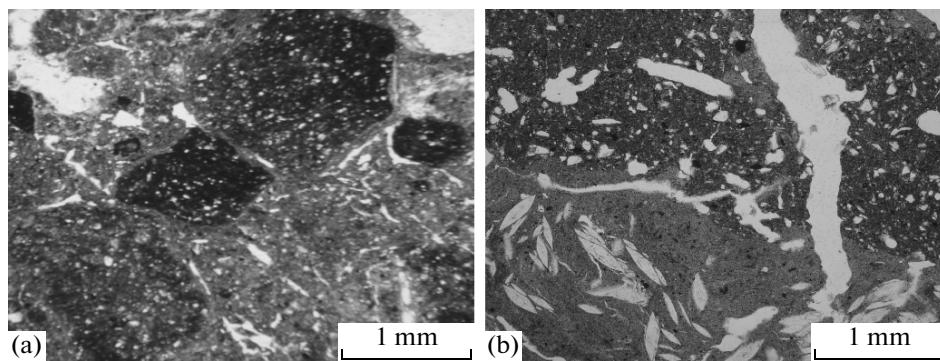


Fig. 4. Microphotographs illustrating the microzonality of Vertic horizons. (a) Dark surface aggregates in the light subsurface matrix; (b) dense matrix with intimate contact of OM rich upper zone and gypsic lower zone. PPL.

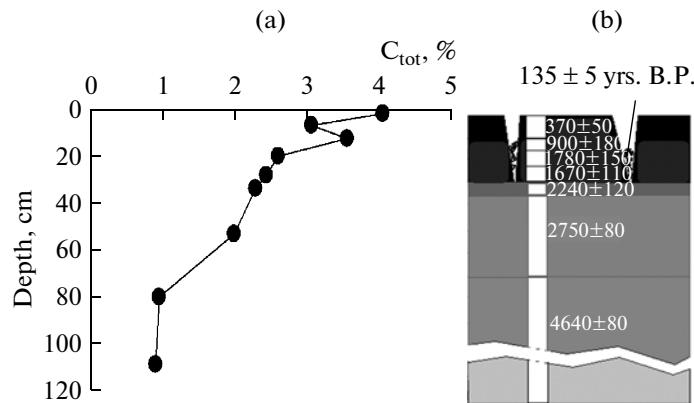


Fig. 5. (a) C_{tot} (%) and (b) ^{14}C -age (years B.P.) distributions in Vertic Mollisol, North Caucasus. White rectangles indicate ^{14}C -sampling.

inclined shearing may lead to rather different soil materials in close proximity within the soil profile (Fig. 4b).

The vertical distribution of C_{tot} in mature Vertisols is shown in Fig. 2b. The mature Vertisols have a well-mixed, dark homogenous profile up to the end of active cracks, and a limited mottled zone below. The end of the mixing zone is usually marked by master slickenside. Where gilgai is present, the organic profile is shallower, more complex and mottled in the microhighs, while in the microlows it is deeper and more homogenous. The inclination of C_{tot} curve is more vertical in microhighs and gentler in microlows corresponding to the morphology and thickness of humus horizons. Radiocarbon age of SOM is younger along the whole profile in the microlow, and is older in the microhigh (Kovda et al., 2002).

We measured the ^{14}C -age and C_{tot} in a Vertic Mollisol (Fig. 5a, 5b). The soil had a black color till ~130 cm. The layer ~3–30 cm consisted of large blocks 30 × 30 cm separated by cracks. Crack width varied from 5 cm at the surface to 1.5–2 cm between the blocks, where they were filled with surface aggregates. C_{tot} decreased

slowly with depth, and was relatively high (0.9% C) even at depths >100 cm. Radiocarbon age had normal increasing with soil depth. However, the incorporation of modern SOM at a certain depth was well marked by modern ^{14}C -age of SOM between the cracks at a depth ~30 cm, while the age of SOM from the adjacent blocks at the same depth was 1780 ± 150 yrs. B.P. The incorporation of fresh SOM is often reflected by the inversions both in C_{tot} and ^{14}C -age curves, as illustrated in this soil at a depth ~15–25 cm (Fig. 6a, 6b). Another possible reason for inversion of SOM properties in Vertisols might be active shearing, leading to the physical displacement of soil older and/or lower in SOM into the upper younger and SOM-rich part of soil. This mechanism is not expected here because of very weak slickensides development.

The relatively slow increase in ^{14}C -age with soil depth suggests that pedoturbations are not very active in this soil, but the whole-soil morphology with very deep black horizons and high C_{tot} concentrations at depth clearly indicate that there has been active mixing of this entire profile in the past.

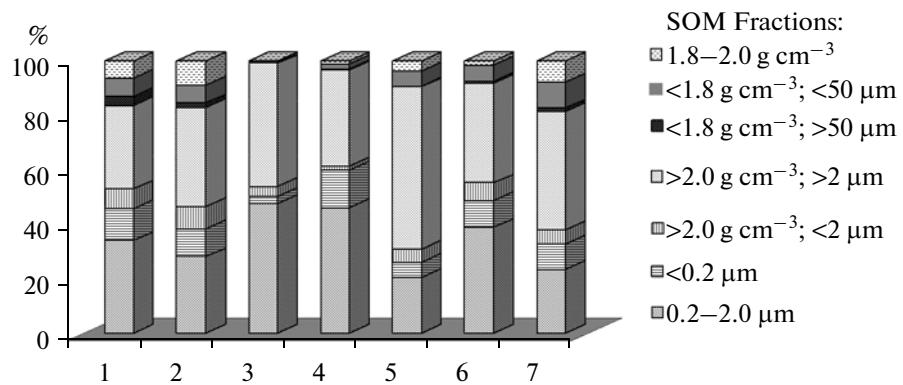


Fig. 6. The relative mass (%) of densi-granulometric fractions of SOM in Vertisols (1–4, 6), a vertic Mollisol (5) and a Mollisol (7).

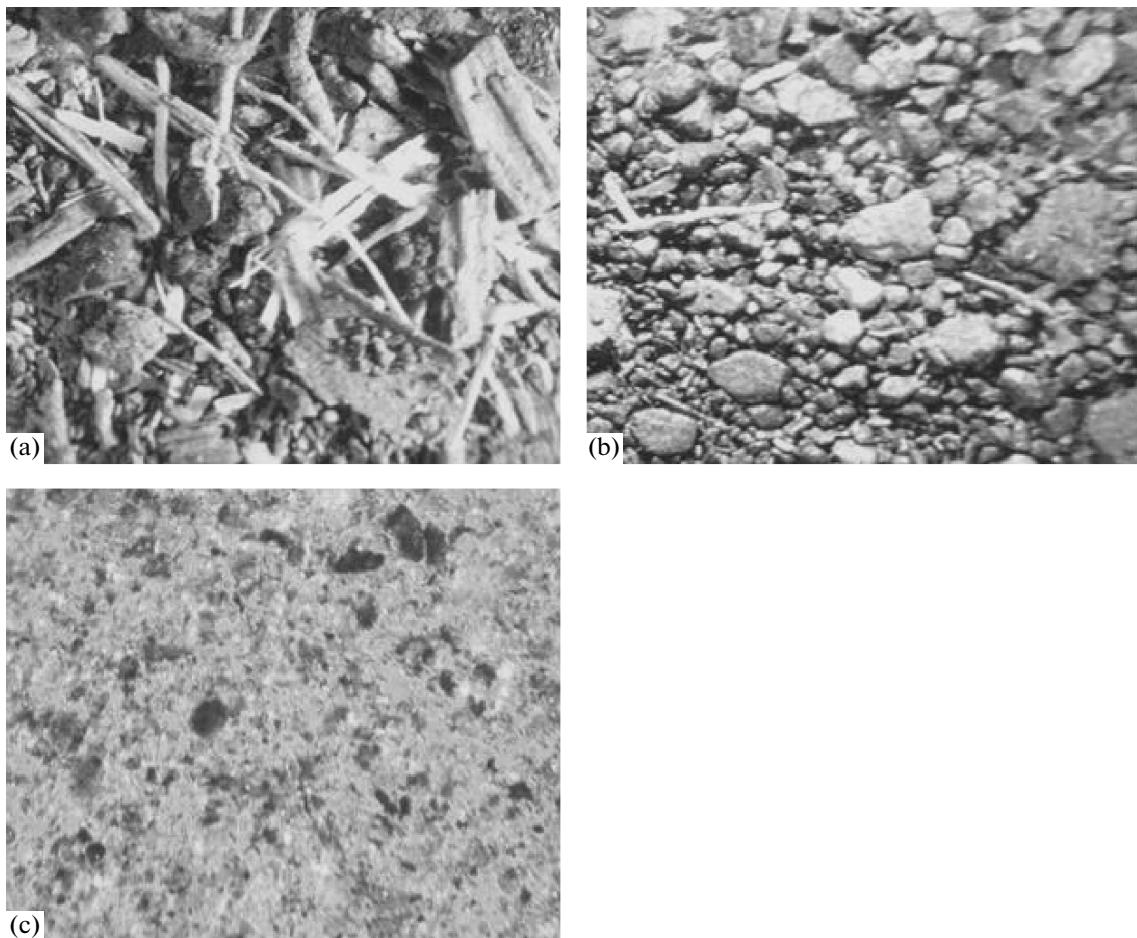


Fig. 7. Microphotographs of selected soil fractions: (a) weakly transformed residues, $\times 25$; (b) unstable light aggregates, both representing the fraction $<1.8 \text{ g}/\text{cm}^3 > 50 \mu\text{m}$, $\times 25$, PPL; and (c) particulate organic matter (POM) or $<1.8 \text{ g}/\text{cm}^3$ and $<50 \mu\text{m}$ fraction, $\times 160$. PPL.

Aggregate level. Results of densi-granulometric fractionation showing the distribution of seven fractions, their C_{fr} and $\delta^{13}\text{C}$ contents are presented (Figs. 6–8).

These samples allow to compare Vertisols with a Vertic intergrade and a reference Mollisol with respect to different vertic processes, climates and parent materials.

We did not find clear relationships between the results of physical fractionations and vertic processes.

Distribution of fractions. The SOM associated with coarse clay ($0.2\text{--}2 \mu\text{m}$) and coarse heavy organo-mineral fractions ($>2.0 \text{ g cm}^{-3}$; $>2 \mu\text{m}$) dominated with 20–47% and 30–59%, respectively (Fig. 6). In contrast, the particulate organic matter or POM ($<1.8 \text{ g cm}^{-1}$; $<50 \mu\text{m}$) and stable organomineral aggregate ($>2.0 \text{ g cm}^{-3}$; $<2 \mu\text{m}$) fractions represented the smallest components of total soil organic matter at ~0–10% and ~2 to 8%, respectively (Fig. 6). Microphotographs of some of these size/density fractions (Fig. 7) show their morphological diversity even within the similar fractions.

We did not find clear differences in the characteristics of size/density fractions in Vertisols vs. the Mollisol. However, some trends do seem to reflect the role of climate (temperate vs. subtropical), texture (parent material) and pedogenesis (vertic, mollic) in the formation of SOM fractions (Fig. 8a, 8b).

Stable isotopic composition and carbon content of fractions. Each densi-granulometric fraction occupies relatively limited and well identified areas in C_{fr} versus $\delta^{13}\text{C}$ coordinates (Fig. 9). The broadest area is characteristic for the fraction of weakly transformed residues ($<1.8 \text{ g cm}^{-3}$; $>50 \mu\text{m}$) reflecting the mixture of vegetation of both C_3 and C_4 types. Stable isotopic composition of carbon in fractions varies from ~−27 to −18‰, with the values ~−26.79 to −23.55‰ for Caucasus soils, and −23.17 to −18.19‰ for Texas Vertisols, reflecting the importance of C_4 plants in this subtropical region. Similarly, slightly heavier stable isotopic compositions are typical for any fractions separated from drier gilgai microhighs comparing to wetter microlows both in Texas and Caucasus. This could be due to the fact that C_3 plants generally have higher $\delta^{13}\text{C}$ values on drier portions of the landscape [1, 11]. This mechanism resulting in ^{13}C -enriched organic matter inputs on microhighs is probably more important in the Caucasus where C_4 plants are not abundant. Alternatively, higher $\delta^{13}\text{C}$ values in soil fractions from microhighs could be due to greater dominance of ^{13}C -enriched C_4 plant species on this drier portion of the landscape. This mechanism is probably more important in Texas/Louisiana where C_4 grasses are relatively common components of the flora.

Slight tendency for lighter isotopic composition was found for free SOM (phytolith and unstable aggregates fraction $1.8\text{--}2.0 \text{ g cm}^{-3}$) and POM ($<1.8 \text{ g cm}^{-1}$; $<50 \mu\text{m}$) fractions i.e. for fractions reflecting the humification process. These two fractions are also the most rich in C_{fr} , which increases in Caucasian Vertisols up to ~25%. To note, that the initial C_{tot} content of whole specimens was different in Vertisols from Texas and Caucasus (~2% versus ~6% respectively), the C_{fr} in POM fraction has similar trend with 20 and 26%. The similar allocation of fractions with similar

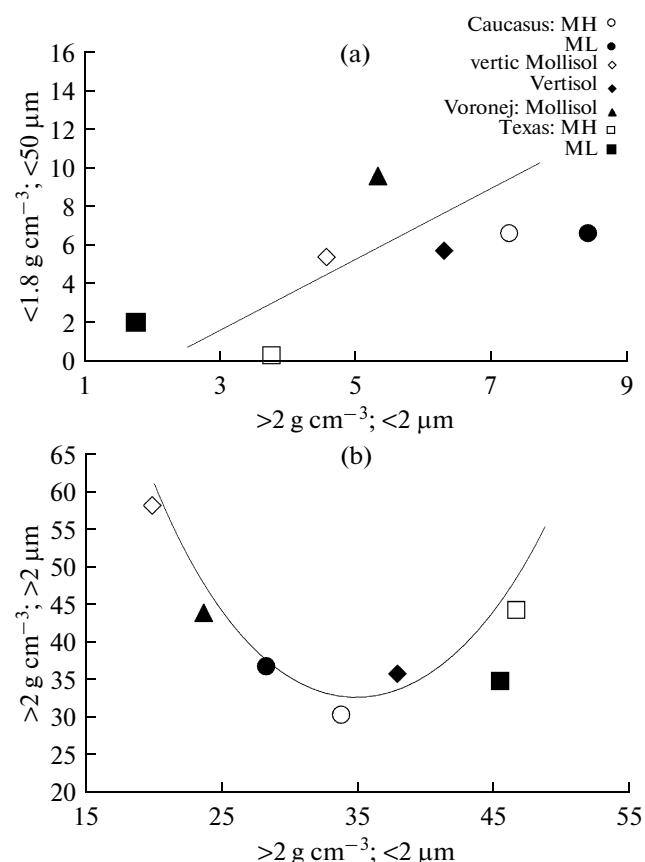


Fig. 8. The trends indicated by (a) minor fractions and (b) major fractions distribution.

tendencies for C_{fr} and $\delta^{13}\text{C}$ increasing suppose that the mechanism and processes of aggregation are similar and universal despite the climate, and soil type.

The minimal C_{fr} content in all investigated soils was found in coarse fraction i.e. associated with silt and sand. Note that C_{fr} content in stable organomineral aggregates ($>2.0 \text{ g cm}^{-3}$; $<2 \mu\text{m}$ fraction) was generally higher than in fine clay fraction ($<0.2 \mu\text{m}$). The correlation seems to exist between C_{fr} increasing and smaller isotopic variation of carbon, especially for temperate climate soils.

Role of fractions in SOM pool. To better understand the ecological role of densi-granulometric fractions we analyzed the distribution of fractions and C_{fr} content not independently, but estimated the input of each fraction into the SOM pool i.e. the stock of SOM with respect to the fractions. Thus, the fraction leading in content may be poor in carbon, like it is for the coarse heavy fraction for example. Table 4 shows the portion (%) of C_{fr} from C_{tot} which allows to find the most important fractions for carbon sequestration. Such a major fraction in subtropical Vertisols is $0.2\text{--}2 \mu\text{m}$ clay fraction, which contains about 52% of carbon from C_{tot} (Table 4). This means that in the subtropical

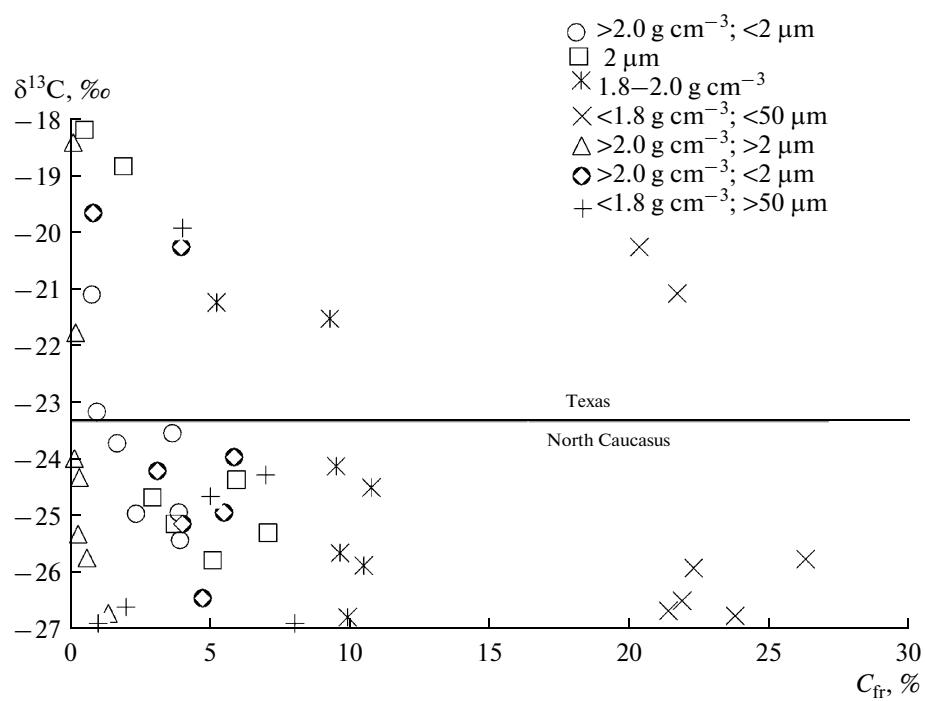


Fig. 9. Stable isotopic composition ($\delta^{13}\text{C}$ vs. PDB) versus carbon content (C_{fr} , %) of densi-granulometric fractions.

environment the organic matter is mostly associated with clay minerals. Vertisols and Mollisol from temperate climate have two fractions with similar highest carbon content: 0.2–2 μm fraction as in subtropical Vertisols, and POM fraction ($<1.8 \text{ g cm}^{-3}$ and $<50 \mu\text{m}$). This suggests that in hot subtropical environment POM is less stable.

The input or % from C_{tot} of other fractions is variable depending the specificity of pedoenvironment with some increasing of phytolith fraction ($1.8\text{--}2.0 \text{ g cm}^{-3}$) in

soils under natural grasses, and coarse heavy fraction ($>2 \text{ g cm}^{-3}; >2 \mu\text{m}$) in clay depleted horizons.

CONCLUSIONS

Vertic process consisting of shrinking/swelling, lateral shearing and vertical turbation affects the vertical and lateral distribution of SOM, its chemical and isotopic characteristics. We analyzed such influence at various organizational or hierarchical levels including soil cover, profile and horizon, and aggregate.

Table 4. The input of densi-granulometric fractions (%) into the C_{tot} content

Soil	SOM associated with mineral mass				Free SOM		
	coarse fraction	organo-mineral aggregates	fine clay	coarse clay	POM	residues	phytolith
	$>2 \text{ g cm}^{-3}; >2 \mu\text{m}$	$>2 \text{ g cm}^{-3}; <2 \mu\text{m}$	$<0.2 \mu\text{m}$	$0.2\text{--}2.0 \mu\text{m}$	$<1.8 \text{ g cm}^{-3}; <50 \mu\text{m}$	$<1.8 \text{ g cm}^{-3}; >50 \mu\text{m}$	$1.8\text{--}2.0 \text{ g cm}^{-3}$
Caucasus, MH	4.0	6.5	6.0	28.0	31.3	9.8	14.5
Caucasus, ML	9.3	7.4	7.5	26.7	29.0	3.6	16.5
Caucasus, Vertisol	3.5	6.3	5.0	34.6	40.3	5.3	5.0
Caucasus vertic	2.3	7.6	5.6	33.3	40.1	0.8	10.2
Mollisol							
Voronezh Mollisol	2.3	5.2	6.6	30.1	37.6	4.5	13.8
Texas, MH	10.8	6.7	5.3	52.9	13.2	4.5	6.5
Texas, ML	3.8	4.2	6.3	52.0	24.2	3.3	6.0

The influence of vertic process on specific features of SOM seems to decrease from soil cover to the aggregate level. The drastic variations were found for SOM chemistry, isotopic and morphological properties along gilgai or subsurface cyclic horizonation due to lateral shearing. The layer ~ 10–30 cm has most expressed variations of all measured characteristics including radiocarbon age, stable isotopic composition, chemical composition, microfabric.

Initial microzonality and following homogeneity reflect influence of vertical churning and turbations to SOM distribution. Rejuvenation of ^{14}C -age occurs through the surface aggregates falling into the cracks.

Densi-granulometric fractionation shows weak specificity of SOM at the aggregate level in Vertisol comparing with Mollisol. Coarse clay (0.2–2 μm) and coarse heavy organomineral fraction ($>2.0 \text{ g cm}^{-1}$; $>2 \mu\text{m}$) prevails in all soils. Tendencies for POM and fraction of stable organomineral aggregates increasing under temperate climate were found. Similar trends for $\delta^{13}\text{C}$ and carbon content in fractions suggest the universal mechanism of aggregation despite the type of pedogenesis, parent material and climate. Climate factor seems to be the most important for the aggregate attributes (content and composition) in soils. The only attribute related to vertic process at aggregate level is the high content of fraction associated with the mineral matrix.

Summarizing, two groups of vertic features were identified according to their influence on SOM. The first group includes vertical cracks and the specific combination of soil structures from surface mulch to large blocks. Small aggregates fall down into cracks and determine the deep and homogenous distribution of SOM, the rejuvenation of ^{14}C -age, and high rate of C cycling at a depth. These features are most important during intraseasonal shrinking-swelling events when cracks open and close. The second group of vertic features consists of slickensides, gilgai and subsurface cycling horizonation. Through lateral redistribution of liquid phase and solid material they determine the complex vegetation cover and complex structure of soil cover, the differentiation of SOM quality, the formation and disposition of zones of SOM rejuvenation and conservation i.e. of maximal and minimal rates of C exchange. The impact of these features accumulates multiseasonally and is more profound influencing the chemical and isotopic SOM compositions.

The specificity of SOM properties and distribution should be taken into account in land use and management plans in regions where Vertisols are present.

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