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CENTRAL IMAGE OF VERTISOLS: EVOLUTION OF CONCEPTS OF THEIR MORPHOLOGY AND GENESIS

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This paper discuss the changes in understanding of the central image of Vertisols and leading processes of their formation. The early concept described Vertisols as black or dark clayey soils with homogenous undifferentiated profile resulted basically of pedoturbation. The further studies discovered vertical differentiation of Vertisol attributes. The application of trench method discovered spatial heterogeneity of Vertisols with alternation of bowl and diapiric structures. Such spatial complex subsurface pattern seems to be rather common and can be found even in the absence of gilgai microrelief. A new central image of a mature Vertisol is a combination of two structural types, one being homogenous and monotonous, generally corresponding to the initial central image, and the other – heterogeneous profile with fragmented horizons. A leading process forming the new central image of Vertisols was defined as lateral shearing or plastic deformations, i.e., plastic movements and gradual upward pushing of moist material (analogy of defluction process). Pedoturbation or more exactly the vertical falling of surface material into the cracks results in the vertical mixing rather than in deformations. Micromorphological features typical of Vertisols and associated with shrink-swell phenomena, cracking, mixing and lateral shearing that are reflected in the central image of Vertisols are summarized in the paper and illustrated by microphotographs.

Key words: Vertisols, vertic (compact) soils, central image, morphology, microstructure, age, evolution.

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INTRODUCTION

The recent Classification and Diagnostic System of Russian Soils (2004) suggests identifying a central image of soil and its genetic features that reflect the influence of different soil-forming factors and predetermines the main soil-forming processes, i.e., their intensity, combinations and interactions, which ultimately determine modifications in structure and properties of diagnostic horizons. Soil diagnostic features reflect the modern soil functioning regimes, the past evolutionary stages of pedogenesis (particularly, man-induced transformation) and genetic links between soil types. The Russian system is very appropriate for Vertisols in view of a vast volume of data accumulated over the past 50 years and a remarkable improvement of our understanding of Vertisols distribution, properties and processes, their associations with other soil types, age and evolution. In particular, it has been established that Vertisols and vertic (compact) soils have a very wide distribution range and occur not only in tropical and subtropical climates, as was thought before, but also in continental and even ultra-continental climates. Their morphology and microstructure are also very diverse. These findings have influenced our perception of the central image of Vertisols and replenished our knowledge of their genesis and evolution.

The present paper is aimed at analysing the progress of our understanding of the central image of Vertisols, discussing and interpreting their genetic features at different levels of structural organization – from the soil cover to the soil microstructure and other micro-features.

RESULTS AND DISCUSSION

Profile approach: initial concepts of Vertisols. Diagnostics of Vertisols is based mostly on morphological features. A clayey soil with slickensides, wedge-shaped aggregates and more than 30% clay content is diagnosed as Vertisol. Before the term “Vertisol” has become generally accepted, there were over 20 local names including dark clay soils, black clay soils, black cotton soils, black earth, etc. (Dudal, 1965; Dudal and Eswaran, 1988). In addition to the dark colour, the central image of this soil group was characterized by a highly homogenous profile distribution of most properties and a lack of horizonation resulted in “simple” A–AC–C horizon sequence. A deep humification and homogeneous appearance of dark compact soils were explained by a consistent development of wide and deep cracks followed by falling of surface mulch into those cracks. Subsequent soil moistening and swelling caused the soil material mixing and upward raising, overturning and “self-swalling”. Such features were reflected in the Soil Taxonomy (1985), where a presence of cracks at least 50 cm deep and 1 cm wide was an obligatory diagnostic feature of non-irrigated and noncultivated Vertisols. An excessive material accumulated within the cracks accounted for pressure rise causing local-scale shifts of soil material with formation of slickensides and gilgai microrelief. The processes of cracking and swelling, self-mulching, pedoturbations, formation of slickensides, wedge-shaped aggregates, smectite and concretions, dark colouring and clay accumulation were considered as general characteristics of Vertisols (Mermut et al., 1996).

At the same time the existence of not dark, but brown and red Vertisols was recognized (large group of Chromuderts in the Soil Taxonomy) and possibilities for forming calcareous and gypsum concretions and gleyic horizons were mentioned. Many Vertisols did not fit into existing concept of continuous mixing of soil material, because they had regular distribution of organic matter, calcium carbonate and soluble salts, radiocarbon age increasing with depth, eluvial and illuvial horizons, etc. (Wilding and Tessier, 1988; Mermut et al., 1996). Moreover, there was new information about a wide occurrence of Vertisols beyond tropical regions.

Spatial approach: change in the central image of Vertisols. In the 1980s there was a new approach to studying Vertisols by trench method (Williams and Touchet, 1988; Wilding et al., 1990; Kovda et al., 1992; Khitrov et al., 1994). The data base on geography and properties of Vertisols were growing. Concepts of the central image and genesis of Vertisols were changing accordingly. An alternation of “bowl” and diapiric structures, with microrelief being either present or not, was established as a new characteristic feature of these soils. A new central image of a mature Vertisol included a combination of two structural types, one being homogenous and monotonous, generally corresponding to the original central image, and the other – heterogeneous profile with humus horizon of variable thickness, often with fragmented structure and an area of subsurface soil being pushed upwards. A concept of “gilgai complexes” was developed (Fridland, 1984; Thompson and Beckmann, 1982). Similar approach was later applied to studying all Vertisols, with or without surface microrelief (Kovda and Wilding, 2004).

A new central image of Vertisols implied a need to reconsider the contributions and roles of processes forming these soils. The leading role was transferred from the processes of cracking, surface mulch falling into cracks and pedoturbations to the processes of bowl and slickensides formation as well as lateral shearing. Bowl structures outlined by master slickenside are accumulators of moisture that induces swelling within the lower part of such structures. Subsequently that causes soil material to move in lateral directions or at an angle, which leads to formation of wedge-shaped and parallelepiped aggregates, subhorizontal movement of solid-phase components and development of diapiric structures (Lynn and Williams, 1992). A new approach to studying 3-D soil polygons and morphons instead of traditional soil horizons was introduced. A leading process forming the central image of Vertisols was defined as lateral shearing i.e. plastic deformations or plastic movements and gradual upward pushing of moist material (analogy of defluction process).

The new trench-based approach to studying the morphology of Vertisols resulted in modification of their genetic concept. Taking into account a wide geographic distribution of Vertisols and their age differences, we believe that both central images of Vertisols have a right to co-exist. A prevalence of arid conditions leads to soil cracking with surface soil falling into cracks, which results in colour homogenization within the soil. A lesser degree of dryness and a presence of additional moisture in the subsoil lead to soil swelling, shearing and deformations, which result in micro-variability as soil ages and ultimately a cyclic profile in mature Vertisols. In practice, particularly, in the USA, a lack of appreciation of micro-variability was often leading to inadequate diagnostics, characteristics and mapping of Vertisols, with prevalence given to soils of micro-lows by error of visual judgement. The role of pedoturbation processes seems to be insignificant in forming both central images.

Microscopic methods in diagnostics of the central image and genetic features of Vertisols. As was mentioned above, main soil processes contributing to the central image of Vertisols include shrinking, cracking, swelling, formation of specific structure with wedge-shaped and parallelepiped aggregates, self-mulching of the surface layer, vertical mixing and lateral movements. Less important processes result in minor genetic features (depending on the age of soil, type of parent rock and degrees of climate humidity/aridity and continentality) and include humus accumulation, salinization/desalinization, leaching, formation of calcareous, gypsum, iron and manganese pedofeatures, illuviation, ferritization, alkalization/dealkalization, clay mineral transformation, smectite synthesis and weathering including cryogenic weathering (Kovda et al. 1992, 2003; Mermut et al., 1996; Kovda and Lebedeva, 2013).

The most of micromorphological features of Vertisols can individually be encountered in other soils and, therefore, the micromorphological method alone is considered as insufficient for diagnostics of Vertisols and distinguishing them from vertic (compact) and other soils (Mermut et al., 1996; Blokhuis et al., 1991).

Micromorphological features typical of Vertisols, i.e., associated with shrink-swell phenomena, cracking, mixing and lateral shearing that are reflected in the central image of Vertisols are shown in the Table and Figure below, with provisional subdivision of Vertisol profile into above-vertic (AV) and vertic (V) horizons and the parent rock (P).

Additional characteristics can be obtained using a scanning electron microscopy (SEM) or transmission electron microscopy (TEM). For example, slickenside surface features identified by SEM were used in assessment of activities of swelling, lateral movements and smectite synthesis (Morgun et al. 2003).

CONCLUSION

Micromorphology supports the interpretation of the new central image of Vertisols based on the morphological data obtained in trench studies on these soils. Application of micromorphological method is especially promising in identifying features that reflect recent processes in Vertisols (development of structure, surface mulch falling into cracks with formation of micro-zonality, redistribution and segregation of ferruginous compounds, cryogenic weathering and structuring in ultra-continental climates, calcium carbonate accumulation that prevents swelling in arid climates, gleyization, salinization, etc.) as well as relic processes (e.g., illuviation under wetter climatic conditions in the past and residual evidence of former shrink-swell phenomena in modern arid climates).

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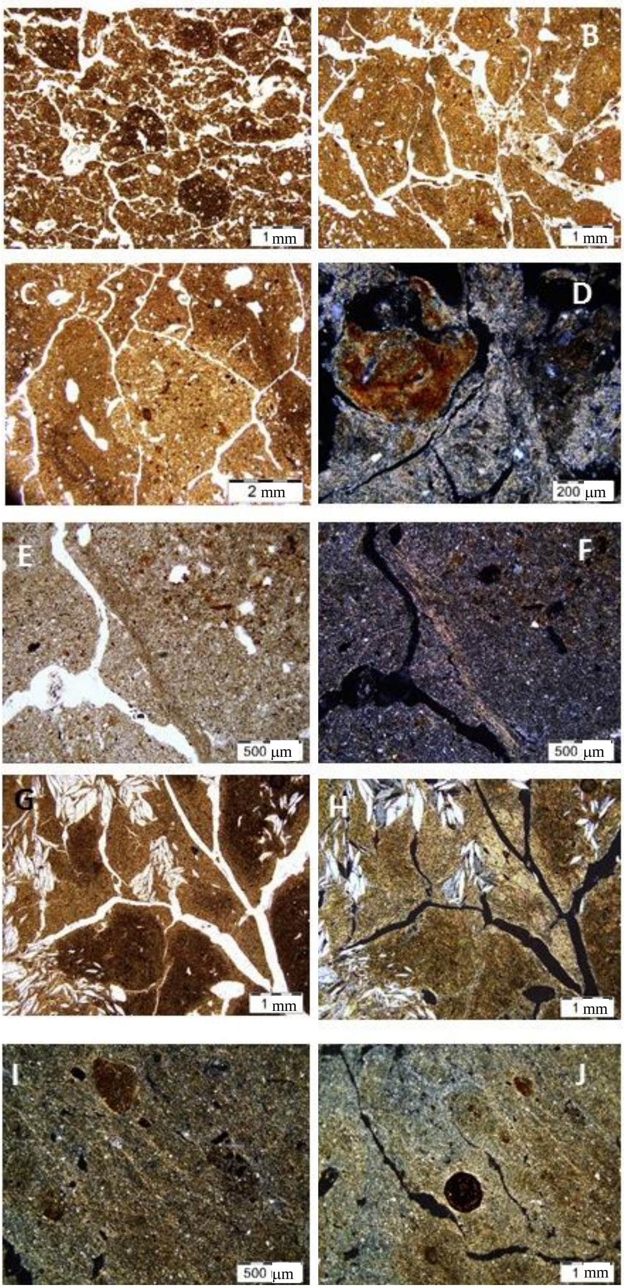
Micromorphological representation of typical and diagnostic processes in Vertisols

Process	Horizons	Microfeatures	Figure
Shrinking and cracking	AV, V	Massive microstructure, planar voids; disintegration of components; high degree of accommodation	B, C
Self-mulching	AV	Granular and crumb aggregates; granular and crumb microstructure; high degree of aggregation; low degree of accommodation	A
Compaction	AV	Massive microstructure; simple aggregates; low intrapedal porosity	B, C
Structuring (wedge-shaped and parallelepiped aggregates)	V	Angular micro-aggregates; angular blocky microstructure; high degree of accommodation	B, G, H
Pedoturbations (vertical mixing)	AV, V	Homogenous and dark to a great depth; cluster distribution; micro-zonality; intrusive pedofeatures; phytoliths at a great depth	G, H
Swelling	AV, V, P	Striated (poro-, grano-, cross-, parallel-, mono-striated) and strial b-fabrics, deformed pedofeatures	H–J
Lateral shearing	V, P	Mono- and parallel striated, strial and kinking b-fabrics; linear distribution; perpendicular orientation; inclined planar voids; disintegration of components; intrusive pedofeatures ; sharp boundaries of pedofeatures; micro-zonality	G–J
Montmorillonite clay formation	V, P	Porphyric c/f related distribution	E–J
Segregation resulted of alternate moisture regime	AV, V, P	Concentric concretions; complex pedofeatures; micro-zonality and redistribution of Fe-Mn compounds	D, J


A
1 mm
B
1 mm
C
2 mm
D
200 µm
E
500 µm
F
500 µm
G
1 mm
H
1 mm
I
500 µm
J
1 mm

Micromorphological illustration of typical and diagnostic processes in Vertisols (Cyrillic letter markings decoded in the Table).

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