VERTISOLS (VR)

Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. The name Vertisols (from L. vertere, to turn) refers to the constant internal turnover of soil material. Common local names are 'black cotton soils' (USA), 'regur' (India), 'vlei soils' (South Africa), 'margalites (Indonesia), and 'gilgai' (Australia).

Definition of Vertisols

Soils

1 having a vertic horizon within 100 cm from the soil surface, **and**

2 having, after the upper 20 cm have been mixed, 30 percent or more clay in all horizons to a depth of 100 cm or more, or to a contrasting layer (lithic or paralithic contact, petrocalcic, petroduric or petrogypsic horizons, sedimentary discontinuity, etc.) between 50 and 100 cm; **and**

3 having cracks, which open and close periodically.

Note: A crack is an open space between gross polyhedrons. Cracks may be filled mainly by granular materials from the soil surface but remain open in the sense that the polyhedrons are separated.

Common soil units:
Thionic, Salic, Natric, Gypsic, Duric, Calcic, Alic, Gypsiric, Grumic, Mazic, Mesotrophic, Hyposodic, Eutric, Pellic, Chromic, Haplic.

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Summary description of Vertisols

Connotation: churning heavy clay soils; from L. vertere, to turn.

Parent material: sediments that contain a high proportion of smectite clay, or products of rock weathering that have the characteristics of smectite clay.

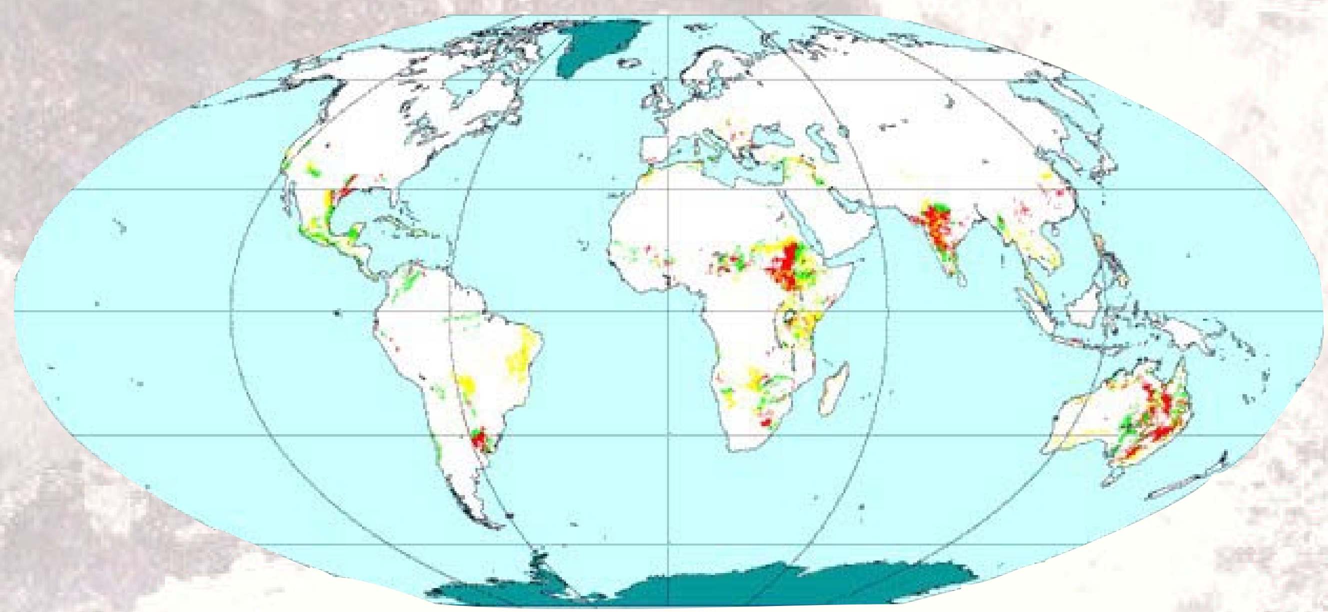
Environment: depressions and level to undulating areas, mainly in tropical, semi-arid to (sub)humid and Mediterranean climates with an alternation of distinct wet and dry seasons. The climax vegetation is savanna, natural grassland and/or woodland.

Profile development: A(B)C-profiles. Alternate swelling and shrinking of expanding clay results in deep cracks during the dry season, and formation of '*slickensides*' and wedge-shaped structural elements in the subsurface soil.

Use: Vertisols become very hard in the dry season and are sticky in the wet season. Tillage is difficult, except for a short period at the transition between the wet and dry seasons. Vertisols are productive soils if properly managed.

Regional distribution of Vertisols

Vertisols cover 335 million hectares worldwide. An estimated 150 million hectares is potential crop-land. Vertisols in the tropics cover some 200 million hectares; a quarter of this is considered to be useful land. Most Vertisols occur in the semi-arid tropics, with an average annual rainfall sum between 500 and 1000 mm, but Vertisols are also found in the wet tropics, e.g. in Trinidad where the annual rainfall sum amounts to 3000 mm. The largest Vertisol areas are on sediments that have a high content of smectite clays or produce such clays upon post-depositional weathering (e.g. in the Sudan), and on extensive basalt plateaus (e.g. in India and Ethiopia). Vertisols are also prominent in Australia, southwestern USA (Texas), Uruguay, Paraguay and Argentina. Vertisols are typically found in lower landscape positions such as dry lake bottoms, river basins, lower river terraces and other lowlands that are periodically wet in their natural state. Depending on parent rock and environmental conditions, Vertisols occur only in bottomlands or also on contiguous lower foot slopes or, as residual soils, even on (gently) sloping hill-sides.



Dominant Associated Inclusions Miscellaneous lands

Figure 1. Vertisols worldwide.

Associations with other Reference Soil Groups

Vertisols stand apart from other soils by having a vertic horizon, with high clay content, typical wedge-shaped or parallelepiped structural aggregates, and intersecting '*slickensides*'. They form deep, wide cracks upon drying. Other soils may show one or more of these properties, but not to the extent characteristic of Vertisols. Such soils form intergrades and extragrades to Vertisols and normally occur together with Vertisols. They may have cracks that are not sufficiently wide, or slickensides or wedge-shaped aggregates only, or a vertic horizon underlying a coarser textured surface layer, or they may be clayey with a beginning vertic horizon that has not yet become sufficiently deep. Most associated vertic intergrades (e.g. Vertic Calcisols, Luvisols, Cambisols) occur in higher landscape positions than Vertisols, e.g. on gently sloping or moderately steep plateaus, on mesas and on pediment surfaces. Figure 2 shows a Vertisol landscape with associated soils.

(click to enlarge)

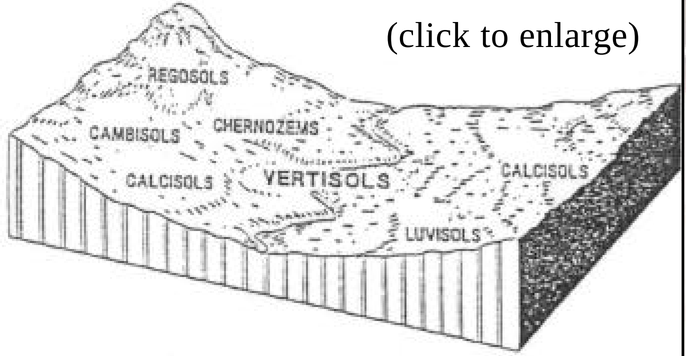


Figure 2. Vertisol landscape with associated soils. Source: Spaargaren, 1994

In the same topographic position, Vertisols on the arid side of the climatic spectrum grade into soils with accumulated soluble compounds (Calcisols, Gypsisols, Solonchaks), a consequence of the high evaporation surplus. On the humid side, intergrades to Vertisols have stronger accumulation of organic matter because of a more lustrous vegetation (e.g. Phaeozems and Chernozems). Toposequences with Nitisols and/or Luvisols (on slopes) and Vertisols/Planosols (in low-lying positions) are common in tropical and subtropical regions with basic rocks. Areas with sodium-rich parent materials may develop combinations of Vertisols and Solonetz, with the latter in a transitional position between upland soils (often Luvisols) and Vertisols. In river areas, depositional patterns play a role in the lateral linkages with other soils. Vertisols in backswamps are often associated with Solonetz and/or Planosols in more elevated positions, and with Fluvisols, Gleysols (and even Histosols) in central backswamp areas. Vertisols in marine deposition areas may occur alongside Solonchaks.

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Genesis of Vertisols

Formation of smectite-rich parent material

The environmental conditions that lead to the formation of a vertic soil structure are also conducive to the formation of suitable parent materials.

1. Rainfall is sufficient to enable weathering but not so high that leaching of bases occurs.
2. Dry periods allow crystallization of clay minerals that form upon rock or sediment weathering.
3. Impeded drainage hinders leaching and curbs loss of weathering products.
4. High temperatures, finally, promote weathering processes. Under such conditions smectite clays can be formed in the presence of silica and basic cations - especially Ca^{2+} and Mg^{2+} - if the soil-pH is above neutral.

The formation of Vertisol parent materials and Vertisol profiles becomes evident if one examines 'red-black' soil catenas[1], as abundant in Africa, on the Indian subcontinent and in Australia (Blokhuis, 1982). The typical configuration features red soils (Luvisols) on crest and upper slope, shallow or moderately deep red soils (Leptosols and Cambisols) on steeper sections of the slope, and black Vertisols in lower positions.

Smectite is the first secondary mineral to form upon rock weathering in the semi-arid to sub-humid tropics. Smectite clay retains most of the ions, notably Ca^{2+} and Mg^{2+}, liberated from weathering primary silicates. Iron, present as Fe^{2+} in primary minerals, is preserved in the smectite crystal lattice as Fe^{3+}. The smectites become unstable as weathering proceeds and basic cations and silica are removed by leaching. Fe^{3+}-compounds however remain in the soil, lending it a reddish colour; aluminium is retained in kaolinite and Al-oxides. Leached soil components accumulate at poorly drained, lower terrain positions where they precipitate and form new smectites that remain stable as long as the pH is above neutral.

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1. A catena is a succession of soils developed from the same parent material and extending from a high position in the landscape to a low position.

There are more reasons why there is a relative dominance of smectite in the lower members of the catena:

1 fine clay in which the proportion of smectites is greater than in coarse clay, is transported laterally, through surface and subsurface layers, **and**

2 drainage and leaching of soluble compounds decrease from high to low terrain positions. Internal drainage is impeded by the formation of smectites. (It is increased when kaolinite forms: ferric iron, released from the smectite lattice, cements soil particles to stable structural peds and maintains a permanent system of pores in the soil.)

These combined processes of rock weathering, breakdown of primary and formation of secondary minerals, and transport of soil components produce the typical catenary differentiation with reddish, well-drained soils on higher positions, and black, poorly drained soils in depressions (see Table 1).

Colour differences among Vertisols are often indicative of differences in drainage status. The more reddish hue or stronger chroma of relatively better-drained Vertisols reflects higher contents of free iron-oxides. Poorly drained Vertisols are low in kaolinite and have less free ferric iron; their hues are less red and their chromas are weaker.

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Table 1: Some analytical data of the highest (Luvisol) and the lowest member (Vertisol) of a 'red-black' soil catena in the Sudan.

Profile	ABC	Depth	Clay	pH	CEC	CEC-clay	BS	SiO_2/Al_2O_3	Org. C	Lime
		(cm)	(%)		(cmol(+)/kg)		(%)	clay fr.	(%)	(%)
Luvisol	A	0-10	4	6.6	nd	nd	nd	3.8	0.5	0
	AB	10-30	15	6.1	9.0	60	71	3.3	0.6	0
	Bt1	30-60	23	4.7	15.5	68	49	3.5	0.3	0
	Bt2	60-85	33	4.5	21.4	66	45	3.3	0.3	0
	Bt3	85-105	43	4.5	22.6	50	51	3.1	0.2	0
	BC	105-135	39	4.4	27.4	69	47	3.0	0.1	0
	C	135-160	39	4.7	27.4	71	57	3.2	tr	0
Vertisol	A	0-30	78	6.6	66.6	86	100	4.3	0.9	0.7
	Bw1	30-90	78	7.2	78.4	100	100	4.6	0.9	1.2
	Bw2	90-150	81	7.3	78.2	96	100	4.6	0.7	1.2
	BCwk	150-180	79	7.3	80.2	103	100	4.5	0.4	1.5

Formation of a vertic horizon

The formation of characteristic structural aggregates ('vertic structure') is the principal genetic process in Vertisols. This typical structure may occur in most of the solum but has its strongest expression in the vertic horizon; the grade of development and the sizes of peds change only gradually with depth. In the following, the processes at work will be explained assuming a level plain with (smectitic) clayey sediments and a semi-arid tropical climate with a distinct rainy season:

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The clay plain is flooded at the end of the rainy season, but most of the standing water will eventually evaporate. When the saturated surface soil starts to dry out, shrinkage of the clayey surface soil is initially one-dimensional and the soil surface subsides without cracking. Upon further drying, the soil loses its plasticity and tension builds up until the tensile strength of the soil material is locally exceeded and the soil cracks. Cracks are formed in a pattern that becomes finer as desiccation proceeds. In most Vertisols, the surface soil turns into a '*surface mulch*' with a granular or crumb structure. Vertisols, which develop surface mulch, are called '*self-mulching*'. See Figure 3.
Granules or crumbs of the mulch fall into the cracks. Upon re-wetting, part of the space that the soil requires for its increased volume is occupied by mulch material. Continued water uptake generates pressures that result in shearing: the sliding of soil masses against each other.

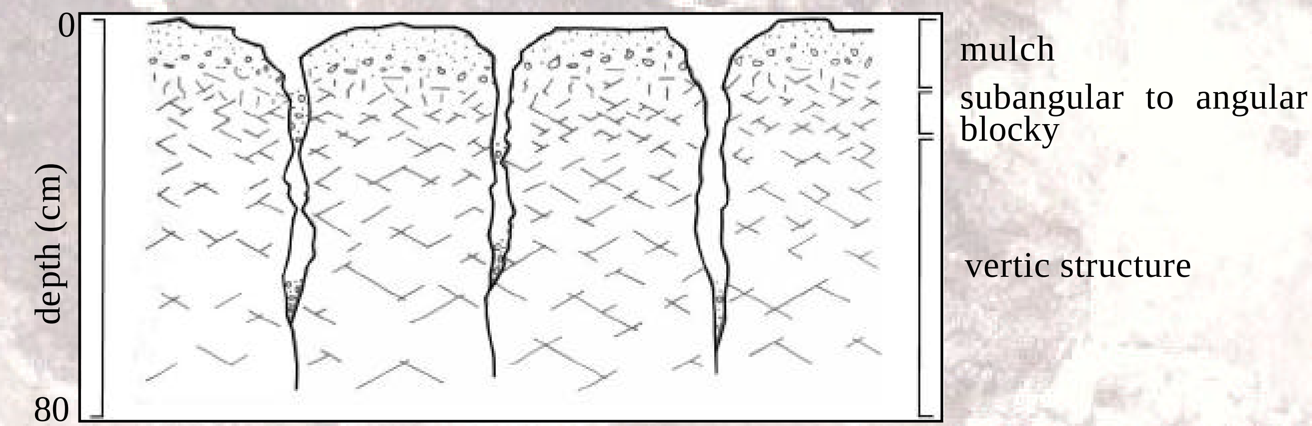

Figure 3. Cracks, surface mulch and soil structure in a Vertisol during the dry season

Shearing occurs as soon as the '*shear stress*' that acts upon a given volume of soil exceeds its '*shear strength*'. The swelling pressure acts in all directions. Mass movement along oblique planes at an angle of 20 to 30 degrees with the horizontal plane resolves this pressure.

The shear planes are known as '*slickensides*', polished surfaces that are grooved in the direction of shear. Such ped surfaces are known as 'pressure faces'. Intersecting shear planes define wedge-shaped angular blocky peds. Although the structure conforms to the definition of an angular blocky structure, the specific shape of the peds has prompted authors to coin special names such as 'lentils', 'wedge-shaped peds', 'tilted wedges', 'parallelepipeds' and 'bicuneate peds'. The type of structure is also called 'lenticular' or 'bicuneate' but shall be referred to as ‘vertic’ in this text. See also Figure 4.

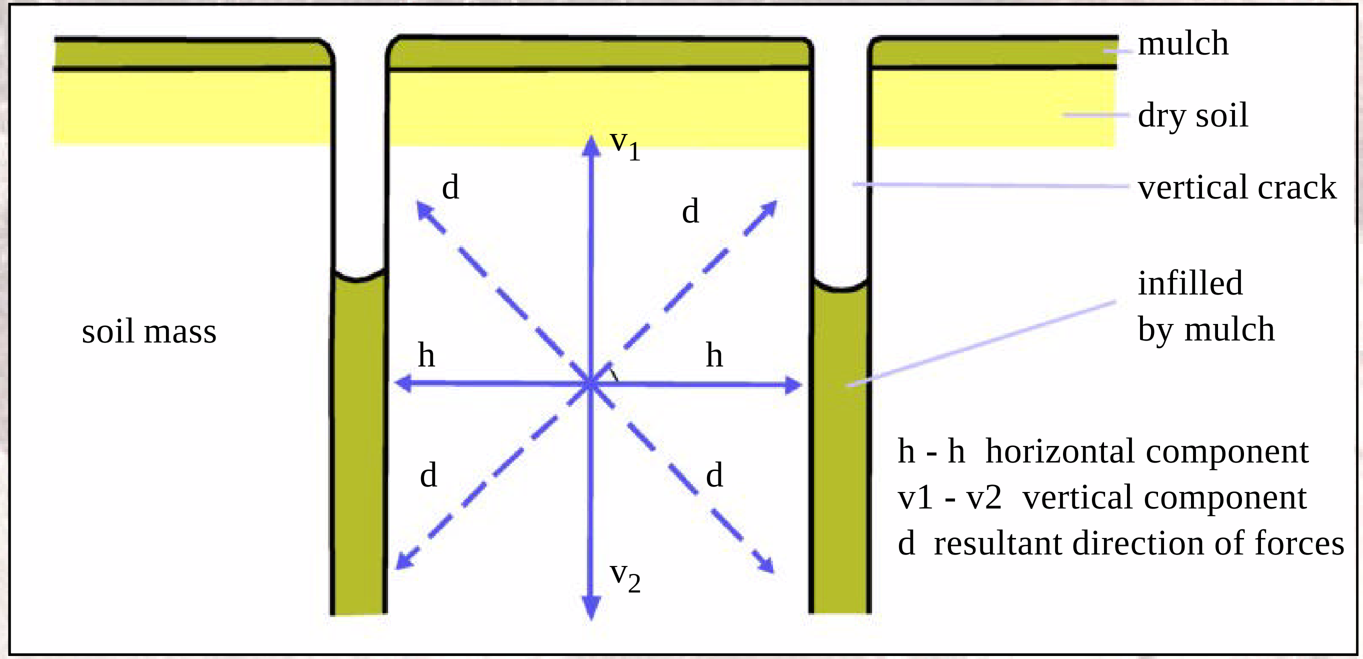

Figure 4. Schematic stress diagram Soil at three-dimensional expansion stage (source: De Vos & Virgo, 1969).

The size of the peds increases with depth. In uniform soil material this is attributable to:

1. the *moisture gradient* during drying and wetting. This gradient is steepest near the surface where small aggregates are formed in loose packing ('*mulch*'). The moisture gradient decreases with depth except around cracks where wetting and drying are much more rapid than in the interior of crack-bounded soil prisms.
2. the *increasing overburden*, i.e. the increasing load of the overlying soil. At greater depths, higher swelling pressures are needed to exceed the soil's shear strength. Such pressures can only be generated in a large volume of swelling soil material and, consequently, structural aggregates are larger.

The characteristic vertic horizon extends from some 15 or 20 cm below the surface mulch down to the transition from solum to substratum, i.e. just below the depth of cracking. Where there are no seasonal moisture changes in the substratum, the vertic structure is *fossil*. Vertisols with very deep, fossil, vertic horizons are common where sedimentation has alternated with periods of geogenetic standstill.

The sliding of crumb surface soil into cracks and the resultant shearing have important consequences:

1. Subsurface soil is pushed upwards as surface soil falls into the cracks. In this way surface soil and subsurface soil are mixed, a process known as 'churning' or (mechanical) 'pedoturbation'. Churning has long been considered an essential item in Vertisol formation. However, recent morphological studies and radiocarbon dating have shown that many Vertisols do not exhibit strong homogenization. In such Vertisols, shearing is not necessarily absent but it may be limited to up-and-down sliding of soil bodies along shear planes.
2. In churning Vertisols, coarse fragments such as quartz gravel and hard, rounded, carbonatic nodules are concentrated at the surface, leaving the solum virtually gravel-free. The coarse fragments are pushed upwards with the swelling soil, but most of the desiccation fissures that develop in the dry season are too narrow to let them fall back.
3. Aggregates of soft powdery lime indicate absence of churning, unless such aggregates are very small and form rapidly. Soft powdery lime is a substratum feature in Vertisols.

Note that not all Vertisols develop a surface mulch; some develop a hard surface crust. Cracks in such soils are sharp-edged, remain open throughout the dry season, and little surface soil falls into them. Swelling pressures will still build up because of differential wetting between adjoining parts of soil. Therefore these soils do have a vertic structure but the grade of the structure is weaker than in self-mulching Vertisols.

Crusty Vertisols are but one example of the variation in structure formation among Vertisols. Fine peds or, alternately, cracks at close intervals, are generally formed in soil materials that have low tensile and shear strengths, whereas large peds (cracks at wider intervals) are formed in soil materials with high tensile and shear strengths. Vertisols that are rich in sodium have greater tensile and shear strengths than soils with lower sodium saturation; many of such soils have a surface crust rather than a mulch. If the exchangeable sodium percentage (ESP) is low and there is much finely divided lime, surface mulching is maximal and peds are fine. The processes that lead to a vertic structure become stronger with increasing clay content and with a higher proportion of swelling clay minerals. Sandy Vertisols have limited swell and shrink; they develop narrow cracks and a surface crust.

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Formation of a 'gilgai' surface topography

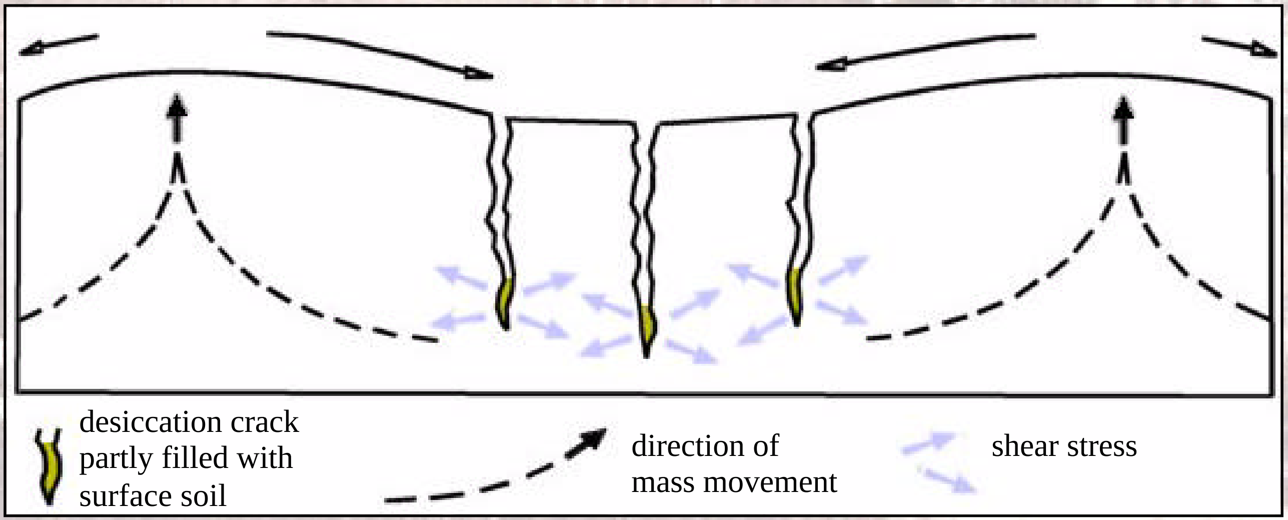


Figure 5. Sketch showing the kinematics of mass movement in Vertisols that result in gilgai microrelief (after Beinroth, 1965).

A typical self-mulching Vertisol has an uneven surface topography: the edges of crack-bounded soil prisms crumble, whereas the centres are pushed upward. The scale of this surface irregularity is that of the cracking pattern, usually a few decimeters. 'Gilgai' however denotes micro-relief at a larger scale, superimposed on this unevenness. Gilgai on level terrain consists of small mounds in a continuous pattern of small depressions, or depressions surrounded by a continuous network of narrow ridges.
Several hypotheses have been put forward to explain the gilgai micro-relief. These have in common that they relate gilgai to mass movement in swell/shrink soils. Gilgai is sometimes seen as the result of sloughing of surface mulch into cracks and upward thrust of soil between cracks upon subsurface soil swelling. However, gilgai is clearly superimposed over the cracking pattern; it originates in the subsurface soil and substratum. For gilgai to form, the soil must have sufficient cohesion to transfer pressures all the way to the soil surface.

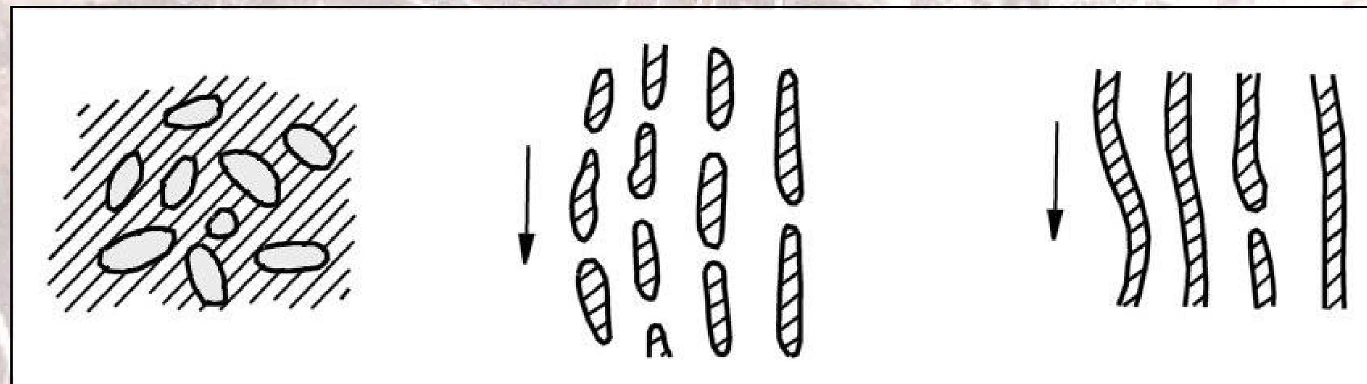
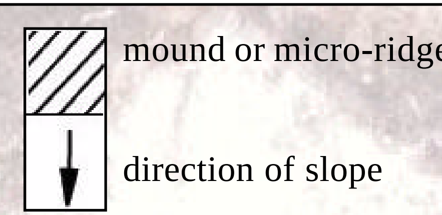


Figure 6. Common forms of gilgai



There are two observations to support a subsurface origin of gilgai micro-relief:

1 A trench profile through a complete 'wave' of mound and depression shows that slickensides in the lower solum and upper substratum are continuous from below the centre of the depression towards the (higher) centre of the mound. The oblique shear planes show a preferential direction. Substratum material is pushed upwards alongside such sets of parallel slickensides. See Figure 5.

2 A gilgaied land surface that is levelled will have gilgai reappearing in a few years.

The commonest form of gilgai is the 'normal' or 'round' gilgai. On slightly sloping terrain (0.5 to 2 per-cent slope) 'wavy' or 'linear' gilgai occurs; 'lattice' gilgai is a transitional form on very slight slopes. Wavy gilgai consists of parallel micro-ridges and micro-valleys that run with the slope, i.e. at right angles to the contours. The wavelength (from centre of mound to centre of depression) is between 2 and 8 m in most gilgais; the vertical interval or 'amplitudo' is normally between 15 and 50 cm. Figure 6 presents some common forms of gilgai.

Most gilgaied areas have Vertisols, but not all Vertisols develop a gilgai micro-relief. In the Sudan, Vertisols occur in a more or less continuous clay plain over a distance of some 700 km from north to south. The annual rainfall sum increases in that direction from 150 to 1000 mm. Gilgai micro-relief occurs only in the 500-1000 mm rainfall zone. Gilgaied Vertisols in the south have thinner and less clearly expressed surface mulch and are less calcareous than non-gilgaied Vertisols in the north.

The morphology of gilgaied Vertisols differs between mound and depression areas. The A-horizon is thin on the mounds whereas profiles in depression areas have a deeper (thickened) and usually darker A-horizon. Coarse components of substratum material that reach the soil surface at the mound site, e.g. quartz gravel and carbonate concretions, remain at the surface whereas finer soil material is washed down to the depressions.

Note that '*high gilgais*', with wavelengths up to 120 m and amplitudes of up to 240 cm, occur in Australia. These high gilgais may well have formed in an entirely different way.

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Characteristics of Vertisols

Morphological characteristics

Vertisols have A(B)C-profiles; the A-horizon comprises both the surface mulch (or crust) and the underlying structured horizon that changes only gradually with depth. The subsurface soil with its distinct vertic structure conforms to the definition of a vertic horizon, but it is not always clear where the A-horizon ends and the B-horizon begins. Important morphological characteristics such as soil colour, texture, element composition, etc are all uniform throughout the solum. There is hardly any movement of soluble or colloidal soil components. (If such transport occurs, pedoturbation counteracts it.) A calcic horizon or a concentration of soft powdery lime may be present in or below the vertic horizon. Gypsum can occur as well, either uniformly distributed over the matrix or in nests of gypsum crystals.

Physical characteristics

Vertisols with strong pedoturbation have a uniform particle size distribution throughout the solum but texture may change sharply where the substratum is reached. Dry Vertisols have a very hard consistence; wet Vertisols are (very) plastic and sticky. It is generally true that Vertisols are friable only over a narrow moisture range but their physical properties are greatly influenced by soluble salts and/or adsorbed sodium.

Infiltration of water in dry (cracked) Vertisols with surface mulch or a fine tilth is initially rapid. However, once the surface soil is thoroughly wetted and cracks have closed, the rate of water infiltration becomes almost nil. (The very process of swell/shrink implies that pores are discontinuous and non-permanent.) If, at this stage, the rains continue (or irrigation is prolonged), Vertisols flood readily. The highest infiltration rates are measured on Vertisols that have a considerable shrink/swell capacity, but maintain a relatively fine class of structure. Not only the cracks transmit water from the (first) rains but also the open spaces between slickensided ped surfaces that developed as the peds shrunk.

Data on the water holding capacity of Vertisols differ widely, which may be attributed to the complex pore space dynamics. Water is adsobed at the clay surfaces and retained between crystal lattice layers. By and large, Vertisols are soils with good water holding properties. However, a large proportion of all water in Vertisols, and notably the water held between the basic crystal units, is not available to plants. Investigations in the Sudan Gezira have shown that the soil moisture content midway between large cracks changes very little, if at all, when the clay plain is flooded for several days or even several weeks. The soil's moisture content decreases gradually from more than 50 percent in the upper 20 cm layer to 30 percent at 50 cm depth. Deeper than 100 cm, the soil moisture content remains almost invariant (at about 20 percent, corresponding with a matric suction of some 1500 kPa) throughout the year.

Chemical characteristics

Most Vertisols have a high cation exchange capacity (CEC) and a high base saturation percentage (BS). The soil reaction varies from weakly acid to weakly alkaline; pH-values are in the range 6.0 to 8.0. Higher pH values (8.0-9.5) were measured on Vertisols with much exchangeable sodium. The CEC of the soil material is commonly between 30 and 80 cmol(+)/kg of dry soil; the CEC of the clay is of the order of 50 to 100 cmol(+)/kg clay. The base saturation percentage is greater than 50 and often close to 100 percent with Ca^{2+} and Mg^{2+} occupying more than 90 percent of the exchange sites; the Ca/Mg-ratio is normally between 3 and 1.

Salic and Natric Vertisols are common in the more arid parts of the Vertisol coverage. In places, sodicity occurs also in higher-rainfall areas, e.g. in depressions without outlet. The effect of sodicity on the physical properties of Vertisols is still a subject of debate. As stated earlier, Na-clays have greater tensile and shear strengths than Ca-clays, and a high exchangeable sodium percentage (ESP) is associated with soil structure of a relatively coarse class.

The effect that a high ESP has on the diffuse double layer (wide double layer, hence low structure stability) is offset by the high ionic strength of the soil solution in Vertisols that are both saline and sodic. Clay dispersion accompanied by clay movement, the normal consequence of high sodium saturation in clay soils, cannot take place on account of the low hydraulic conductivity and low volume of soil that ever becomes saturated with water. Salinity in Vertisols may be inherited from the parent material or may be caused by irrigation. Leaching of excess salt is hardly possible. It is, however, possible to flush salts that have precipitated on the walls of cracks. Surface leaching of salts from rice paddies in India was achieved by evacuating the standing water at regular intervals. There are strong indications that the fallow year observed in rotations in the Gezira/Managil irrigation scheme in Sudan, is indispensable for maintaining a low salinity level in the surface soil.

Management and use of Vertisols

Large areas of Vertisols in the semi-arid tropics are still unused or are used only for extensive grazing, wood chopping, charcoal burning and the like. These soils form a considerable agricultural potential but adapted management is a precondition for sustained production. The comparatively good chemical fertility and their occurrence in extensive level plains where reclamation and mechanical cultivation can be envisaged are assets of Vertisols. Their physical soil characteristics and notably their difficult water management cause problems.

Farming systems on Vertisols

The agricultural use of Vertisols ranges from very extensive (grazing, collection of fire wood, charcoal burning) through smallholder post-rainy season crop production (millet, sorghum, cotton, chick peas) to small-scale (rice) and large-scale irrigated agriculture (cotton, wheat, barley, sorghum, chickpeas, flax, noug (*Guzotia Abessynica*) and sugar cane). Cotton is known to perform well on Vertisols allegedly because cotton has a vertical root system that is not severely damaged by cracking of the soil. Tree crops are generally less successful because tree roots find it difficult to establish themselves in the subsoil and are damaged as the soil shrinks and swells. Management practices for crop production ought to be primarily directed at water control in combination with conservation or improvement of the soil's fertility level.

Physical land management on Vertisols

The physical properties and the soil moisture regime of Vertisols represent serious management constraints. The heavy soil texture and domination of expanding clay minerals result in a narrow soil moisture range between moisture stress and water excess. Tillage is hindered by stickiness when the soil is wet and hardness when it is dry. The susceptibility of Vertisols to waterlogging is the single most important factor that reduces the actual growing period (below estimates based on climatic data). Excess water during the rainy season must be stored for post-rainy season use ('water harvesting') on Vertisols with very slow infiltration rates.

Several management practises have been devised to improve the water regime:

1 *Evacuation of excess surface water.* Surface drainage by using alternating broad beds and furrows, protects crops from water logging of the root zone. The drained water may be stored in small ponds and used for watering cattle, growing vegetables, etc. This practice proved very successful in the Ethiopian Highlands where the yields of local wheat varieties increased by 150 % and horse bean yields went up by 300 %. The only disadvantage of broad bed and furrow systems recognised so far is that they promote soil erosion by concentrating water flow in the furrows. The broad bed and furrow technology solves problems on individual farmers' fields but solutions have still to be found to bring the runoff water safely down to the lowest part of the landscape (e.g. along grassed waterways) without enhancing erosion of neighbouring farmland. A participatory approach involving all stakeholders is needed to solve this problem at watershed scale.

2 *Gully control.* Containing gully erosion on Vertisols may require special dam constructions in the lower parts of the landscape, designed keep the groundwater table at a level that keeps the subsoil moist. In this way, swell-shrink is inactivated and many processes related to gully formation (slumping, pipe erosion, subsoil cracking) are curbed.

3 *Storage of excess water within the watershed*. If excess water is harvested behind micro-dams, strategic irrigation of Vertisols downstream of the dam site becomes an option. Seepage losses from the dams benefit the ecosystem as a whole, since the water will surface as recharge in lower landscape positions. Livestock benefit from these micro-dams in many ways, e.g. by increased fodder availability from crop residues, presence of drinking water and increased fodder production in recharge zones. Even though micro-dam projects are generally appreciated as successful, salinisation and sodification of the irrigation perimeters and high percolation losses are serious hazards. At some of the dam sites, up to 50 % of the harvested water is lost each year. This is a direct consequence of the swell-shrink behaviour of smectite clay. The use of a membrane or of other construction materials, e.g. more weathered clay which may occur in the same landscape, has been suggested as a remedy. The build-up of soil salinity is a serious problem. In a mere decade, salinity may build up to the extent that the whole dam has to be demolished and the surrounding land left to regenerate for several years before it can be taken into cultivation again.

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4 *Water harvesting in areas with Vertisols*. The deep and wide cracking of Vertisols retards wetting of the surface soil after a dry spell. Management should therefore be directed at storing water in the subsurface soil; the greater soil moisture reserves extend the possible length of a crop's growing period. Time-tested water harvesting techniques on Vertisols are:

- *Construction of small ponds* for harvesting (drainage) water and keeping it in the higher parts of a watershed. This water can be used later, e.g. for strategic irrigation of vegetable gardens and/or for watering livestock.
- *Contour ploughing and bunding* to enhance infiltration of water in the soil. A beneficial side effect of contour bunding is that it diminishes soil erosion, which is a severe problem of many Vertisols on slopes. In the highlands of Northern Ethiopia, continued contour ploughing resulted in stepped landscapes ('dagets') with step heights from 0.3 m to 3 metres. Grasses are planted on the riser and a more or less large strip of grass is maintained on the shoulder.
- *Vertical mulching* to enhance infiltration of water in the subsoil. Stubble of crops is placed vertically in contour trenches with the stubble protruding 10 cm above the soil surface. Trenches are 4 to 5 metres apart.
- *Construction of tied ridges*, as practised by farmers in Zimbabwe, to enhance infiltration of water in the subsoil. Note that this system can only be successful on strongly self-mulching Grumic Vertisols.

5 *Improvement of rooting conditions*. Several techniques to restore soil structure after many years of cultivation have been tried:

- *Soil heating/burning* is practised in the Ethiopian highlands (the technique is locally known as 'guie'). Burning causes the clay fraction to fuse to sand-sized particles.
- *Flood fallowing'* (flooding the land for 6 to 9 months) has been tried on low-lying Vertisols. Gases produced by fermentation and redistribution of oxides improve rooting conditions in heavy clay surface soils.
- *Deep ploughing* of Vertisols with indurated horizons (e.g. some Calic and Gypsic Vertisols and Duric Vertisols) breaks the hardened subsoil.

SET 3
VERTISOLS
DEFINITION
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SLIDESHOW

Maintaining the nutrient status of Vertisols

Vertisols are considered to be among the most fertile soils of the seasonally dry tropics. The soils are rich in bases, with calcium and magnesium prevailing on the exchange complex. Many traditional farming systems observed a fallow period of 1 – 4 years in which Vertisols could restore the organic matter content of the surface soil after a period of intensive use. Increased population pressure has now reduced the proportion of fallow land (read: the fallow period) and many areas are left in fallow only when completely degraded. Trials have shown that continuous cropping can be sustainable provided that soil and water conservation and fertiliser management are adequate.

Many Vertisols are deficient in nitrogen, in line with their low organic matter content. Nitrogen fertilisers have to be applied in such a way that excessive volatilisation of ammoniacal nitrogen or leaching of nitrate ions are avoided. Placement of nitrate fertiliser in the root zone is best in dry regions whereas split banded application is preferred in wet conditions (Van Wambeke, 1991). If nitrogen is supplied in the ammonium form, is may be retained by the exchange complex of Vertisols, which curbs (leaching) losses. Many Vertisols have a low content of *available* phosphorus. In the East-African highlands, Vertisols on weathered basalt showed little response to application of phosphate under low-intensity farming but phosphorus became strongly limiting if farming was intensified (and yields went up). Aridic, Alic and Chromic Vertisols contain much exchangeable aluminium and are notorious for inactivating fertiliser phosphate. In places Vertisols are low on sulphur and/or zinc.

It is generally believed that application of animal manure would improve soil organic matter and soil physical properties, but trials remained largely inconclusive. Crop residues should be returned to the land but are rather used as animal feed, fuel and building materials. Trials with green manure (legumes) showed a remarkable increase of the yields of cereals and increased efficiency of mineral fertiliser uptake. Combining broad beds and furrows with application of phosphorus fertiliser and inter-cropping of cereals and legumes takes full benefit of crop-livestock interactions. The legumes overgrow the cereal stover after harvest (Jutzi et al., 1987; Gryseels, 1988).