# Cambic Horizons in Pennsylvania Soils

by

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## Contents

## INTRODUCTION

Cambic horizons are subsurface soil layers of pedogenic change without appreciable accumulation of illuvial material (clay, Fe + Al + humus, carbonate or gypsum), and are part of the USDA Natural Resources Conservation Service's (formerly the USDA Soil Conservation Service) Soil Classification System "Soil Taxonomy" (Soil Survey Staff, 1975, 1996). The occurrence of soils with cambic horizons is fairly extensive in Pennsylvania, covering approximately 40 percent of the land area of the state (Tables 1 and 2). The presence of the cambic horizon in a soil indicates a distinctive pathway of soil development (Smith, 1983; Brasfield, 1983). Although this is the case, very little has been published on the genesis and distribution of cambic horizons in Pennsylvania soils. Thus, the intent of this publication is to focus on the distribution, properties, and genesis of cambic horizons as they are found in Pennsylvania. This is the third publication on the subject of subsoil horizons in Pennsylvania soils. The other publications focused on fragipans (Ciolkosz et al., 1995) and on argillic horizons (Ciolkosz et al., 1996).

## DISTRIBUTION

Cambic horizons are found in Inceptisol, Mollisol, Aridisol, Andisol, and Vertisol soils (Soil Survey Staff, 1996). Of these kinds of soils, only Inceptisols and Mollisols occur in Pennsylvania, and Mollisols have a very inextensive distribution (Table 1). Although some Mollisols can have argillic horizons, those in Pennsylvania do not because they are found on floodplains, and Pennsylvania floodplain soils are too young to have had a significant amount of illuvial clay accumulated in the subsoil (Bilzi and Ciolkosz, 1977).

In Pennsylvania, soils with cambic horizons are found extensively in all parts of the state except on the Southwest Plateau (Table 2 and Fig. 1). In this region, most of the soils have weak to moderately well developed argillic horizons (Ciolkosz et al., 1997).

Table 1. Order, suborder, and great group acreage data for Pennsylvania soils (from Ciolkosz and Dobos, 1989). In Pennsylvania only Inceptisol and Mollisol soils have cambic horizons.

| ORDER | Acres | % | SUBORDER | Acres | % | GREAT GROUP | Acres | % |
|---|---|---|---|---|---|---|---|---|
| Alfisols | 5,652,900 | 19.68 | Aqualfs | 1,524,800 | 5.31 | Fragiaqualfs | 1,444,200 | 5.03 |
| | | | | | | Ochraqualfs | 80,600 | 0.28 |
| | | | Udalfs | 4,128,100 | 14.37 | Fragiudalfs | 790,300 | 2.75 |
| | | | | | | Hapludalfs | 3,337,800 | 11.62 |
| Entisols | 1,218,300 | 4.24 | Aquents | 714,700 | 2.49 | Fluvaquents | 714,700 | 2.49 |
| | | | Arents | 2,800 | 0.01 | Arents | 2,800 | 0.01 |
| | | | Fluvents | 69,100 | 0.24 | Udifluvents | 69,100 | 0.24 |
| | | | Orthents | 410,200 | 1.43 | Udorthents | 410,200 | 1.43 |
| | | | Psamments | 21,500 | 0.07 | Quartzipsamments | 12,100 | 0.04 |
| | | | | | | Udipsamments | 9,400 | 0.03 |
| Histosols | 18,400 | 0.06 | Saprists | 18,400 | 0.06 | Medisaprists | 18,400 | 0.06 |
| Inceptisols | 12,106,200 | 42.15 | Aquepts | 1,557,300 | 5.42 | Fragiaquepts | 1,390,300 | 4.84 |
| | | | | | | Haplaquepts | 140,700 | 0.49 |
| | | | | | | Humaquepts | 26,300 | 0.09 |
| | | | Ochrepts | 10,548,900 | 36.73 | Dystrochrepts | 8,443,600 | 29.37 |
| | | | | | | Eutrochrepts | 146,900 | 0.51 |
| | | | | | | Fragiochrepts | 1,968,400 | 6.85 |
| Mollisols | 40,800 | 0.14 | Aquolls | 16,700 | 0.06 | Haplaquolls | 16,700 | 0.06 |
| | | | Udolls | 24,100 | 0.08 | Hapludolls | 24,100 | 0.08 |
| Spodosols | 109,200 | 0.38 | Orthods | 109,200 | 0.38 | Fragiorthods | 9,800 | 0.03 |
| | | | | | | Haplorthods | 99,400 | 0.35 |
| Ultisols | 9,581,900 | 33.35 | Aquults | 934,400 | 3.25 | Fragiaquults | 408,100 | 1.42 |
| | | | | | | Ochraquults | 526,300 | 1.83 |
| | | | Udults | 8,647,500 | 30.10 | Fragiudults | 3,392,700 | 11.81 |
| | | | | | | Hapludults | 5,254,800 | 18.29 |
| | | | | | | TOTAL | 28,727,700 | 100.00 |

## PROPERTIES

Soil Taxonomy (Soil Survey Staff, 1975, 1996) defines a cambic horizon as a nonsandy zone of weak pedogenic development. Cambic development is manifested primarily as soil structure, color change, or the loss of carbonates. The definition also excludes cemented horizons and horizons with argillic, kandic, oxic, or spodic properties from cambic horizons. As indicated by Guy D. Smith (the author of Soil Taxonomy) the cambic horizon definition was an attempt to define a subsurface horizon that was found in a large number of soils that were excluded from other soil orders such as Alfisols, Oxisols, etc. (Brasfield, 1983; Smith, 1983; Smith, 1986). Generally cambic horizon soils show weak B horizon development. Because of the wide array of genetic pathways encompassed in soils with cambic horizon, the cambic definition tends to be cumbersome and less quantitative than the definition of other Soil Taxonomy subsurface horizons (e.g., argillic and spodic horizons).

## HORIZON NOMENCLATURE

Some confusion exists between soil horizon nomenclature (A, B, C, etc.) and Soil Taxonomy subsurface horizons such as the cambic horizon. Soil horizon nomenclature is a qualitative field assessment of the type of pedogenesis that has taken place in a particular layer of the soil. Thus, the horizon symbol Bw indicates that in the judgment of the field soil scientist this subsurface horizon shows an observable amount of structure and/or color change between the C and Bw horizons. Soil Taxonomy (Soil Survey Staff, 1996) also requires a nonsandy texture and some additional criteria in poorly drained soils, particularly on floodplains for a subsoil layer to qualify as a cambic horizon. Thus, in sandy or poorly drained floodplain soils the Bw horizon may not be a cambic horizon. In summary, it can be said that soil horizon nomenclature is a qualitative assessment while the cambic horizon of Soil Taxonomy is a quantitative or more restrictive assessment of the pedogenesis that has taken place in a soil layer during soil formation.

Table 2. Percentage of each geographic region of Pennsylvania with various soil or land characteristics. Data from the USDA Natural Resource Conservation Service (NRCS) Map Unit Use File (MUUF). The MUUF was obtained from the NRCS office in Harrisburg, PA, in 1991 and is complete for all counties of Pennsylvania. The slight differences in the data between Table 1 and Table 2 are due to different sources of the data. See Fig. 1 for the location of the geographic regions.

| Soil or Land Character | Glaciated Northeast Plateau | Glaciated Northwest Plateau | Southwest Plateau | Central Plateau | Northern Plateau | Ridge and Valley | Triassic-Piedmont | Pennsylvania |
|---|---|---|---|---|---|---|---|---|
| Inceptisols | 89 | 31 | 4 | 19 | 49 | 41 | 17 | 40 |
| With Fragipans | 53 | 15 | 0 | < 0.5 | 12 | 1 | < 0.5 | 12 |
| Without Fragipans | 36 | 16 | 4 | 19 | 37 | 40 | 17 | 28 |
| Cambic horizons | 89 | 31 | 4 | 19 | 49 | 41 | 17 | 40 |
| Fragipans | 54 | 62 | < 0.5 | 21 | 39 | 22 | 15 | 31 |
| Argillic horizons | 2 | 59‡85 | 71 | 47 | 51 | 71 | 50 | |
| Aquic moisture regime† | 27 | 54 | 6 | 11 | 7 | 7 | 12 | 16 |
| Slope Classes | | | | | | | | |
| 0-3% | 13 | 29 | 8 | 9 | 7 | 12 | 22 | 13 |
| 3-8% | 33 | 40 | 11 | 28 | 29 | 30 | 46 | 32 |
| 8-15% | 18 | 16 | 17 | 22 | 12 | 19 | 18 | 18 |
| 15-25% | 24 | 9 | 30 | 21 | 19 | 20 | 10 | 19 |
| 25+% | 12 | 6 | 34 | 20 | 33 | 19 | 4 | 18 |

†Somewhat poorly and poorly drained. The remainder are well or moderately well drained.
‡Very weakly developed.

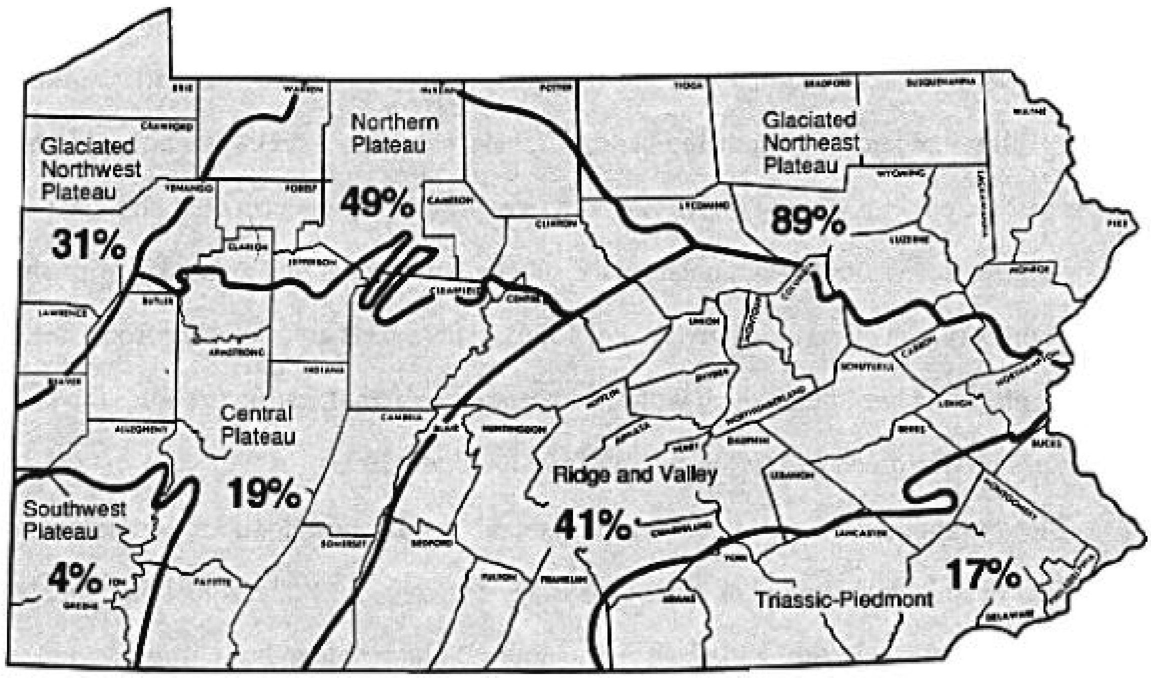


Fig. 1. Generalized physiographic-parent material regions of Pennsylvania. These regions are those given in Table 2 (from Ciolkosz and Cunningham, 1987). The numbers in each region give the percentage of that region's soil area that has a cambic horizon. Pennsylvania covers an area that is about 300 miles east-west and 170 miles north-south.

## GENESIS

### PROCESS

The cambic horizon is a weakly developed horizon in the pedogenic sense (Aurousseau et al., 1985). In an idealized chronosequence, the cambic horizon would be the first B horizon developed (Fig. 2). In its basic form it is a color and/or structural B horizon and generally indicated as a Bw in pedon descriptions. Thus, the two main processes in its formation are pedogenic structure and color development.

| | | | | | |
|---|---|---|---|---|---|
| Entisol -----> | Inceptisol -----> | Alfisol -----> | Ultisol -----> | Ultisol -----> | Oxisol |
| A-C | A-Bw-C | A-Bt-C | A-Bt-C | A-Bt-C | |
| A-Bo-C | | | | | |
| No B | Cambic B | Argillic B | Argillic B | Kandic B | Oxic B |

Fig. 2. Idealized chronosequence of soil development. All of these type of soils except Oxisols and Ultisols with kandic B horizons are found in Pennsylvania (modified from Ciolkosz et al., 1989).

Structure Development

If the soil's parent material has stratification (rock structure) inherited from sediments (loess, till, alluvium, etc.) or weathered bedrock (shale, sandstone, gneiss, granite, etc.), volume changes associated with wetting and drying and freezing and thawing (in cold climates) rearrange the soil particles into granular, platy, blocky (subangular and angular), or prismatic structural units (peds) of various size (White, 1966). These peds are separated from each other by natural planes of weakness which with the exception of granular structure form the faces of adjacent peds (Nikiforoff, 1941; Soil Survey Division Staff, 1993).

Blocky (angular and subangular) and prismatic are the most common B horizon structural types found in soils with cambic or other subsurface horizons. In B horizons it is frequently observed that blocky structure will occur in the upper B and with depth it will grade into prismatic with blocky or massive interiors. The factors favoring blocky over prismatic B horizon structure formation are unclear. Although this is the case, Harper (1937) indicates that prairie areas have a greater tendency to have prismatic than blocky subsurface structure. This relationship is also noted in the study of Pennsylvania prairie soils (Waltman and Ciolkosz, 1995). This relationship may be associated with the root distribution and moisture withdrawal patterns of tree vs. prairie grass vegetation. This trend may also be related to the rate and frequency of wetting and drying. Some granular structure has been described in spodic horizons (Bhs) of Spodosols but not in Pennsylvania cambic horizons (Bw). Spodic horizon granular structure as is the case with A horizons seems to be associated with the accumulation of organic matter. Platy structure is frequently observed in B horizons as a secondary structure (prismatic parting to platy), but in most of these cases the bulk of the platyness is inherited from the layering of the parent material (alluvium, loess, etc.). Although inherited, with time, the parent material platyness maybe enhanced by pedogenesis.

Although freeze-thaw may be significant in epipedon formation (A and E horizons) (Pawluk, 1988), it probably is only of slight importance in the formation of cambic horizons in

Pennsylvania soils. Most Pennsylvania soils with cambic horizons have developed in glacial or periglacial deposits or frost-churned material (Goodman, 1953; Ciolkosz et al., 1997) and are Woodfordian age (18,000 years). Thus, they have developed during the last 18,000 years with the bulk of their development occuring during the Holocene (last 10,000 years). Deep sea oxygen isotope (Mix, 1987) and Paleovegetation data (Watts, 1979; Delcourt and Delcourt, 1983) indicate with the exception of the Hypsithermal (Mid-Holocene) the climate of the Holocene was somewhat similar to today's climate. The data of Post and Dreibelbis (1942) and Carter and Ciolkosz (1980) indicate that presently under natural vegetation (forest) Pennsylvania soils do not freeze below 10 in. (25 cm) (approximate minimum depth to the top of the cambic horizon). Thus, it would appear that except in cleared, bare areas, without snow cover freeze-thaw cycles do not influence soil structural development in the cambic horizon today. These data would also indicate that freeze-thaw has not influenced cambic structural development in the last 10,000 years. Although this is the case, older soils may have subsoil platy structure due to freeze-thaw. These soils were exposed to deep freeze-thaw cycles during the Woodfordian (last glacial advance into Pennsylvania--18,000 years ago), and many had permafrost (Ciolkosz et al., 1986; Ciolkosz et al., 1989). Support for the freeze-thaw platyness process comes from the study of Fedorova and Yarilova (1972) who report that soils in Siberia that are frozen to 60 in. (1.5 m) for 8 months have platy structure throughout the depth of freezing, and the work of Van Vleit-Lanoe et al. (1984). The soil mineralogy may also affect structure formation during the freezing process. Czurda et al. (1995) report that when fine-textured soil material that is dominated by kaolin freezes, ice lens form; but if montmorillonite is the dominant mineral, both horizontal and vertical ice zones form. This would likely give a blocky and not a platy type of structure.

Generally, the size of blocky and prismatic peds increases with depth in the B horizon. The reasons for this trend is that with depth the wetting and drying cycles are less frequent and less rapid, which allows for a slower volume change with less stress and less fracturing of the soil material (White, 1966; Van de Graaff, 1978). In addition the weight of the overlying soil material is believed to retard the expansion and contraction which also leads to larger structural units in the lower part of the B horizon (White, 1966). Frequently in Pennsylvania it is also noted that in the B horizon with depth the grade (degree of development; weak, moderate, strong) of structure decreases. This trend may also be related to less frequent and less rapid volume changes with depth. The decrease in grade of structure with depth noted in Pennsylvania is opposite to that reported for North Carolina coastal plain soils by Southard and Buol (1988).

The texture of the parent material also greatly influences the development of structure. Clay (< 2 µm size material) is the only material in the soil that expands and contracts significantly upon wetting and drying. Harper (1937) and White (1966, 1967) indicate that higher clay contents in the soil material produce smaller size B horizon peds (both blocky and prismatic). This trend has also been observed in Pennsylvania soils. Harper (1937) and White (1967) also indicate that high clay contents favor stronger grades of structure and blocky over prismatic structural types. Southard and Buol (1988) also cite some examples that support these conclusions. In addition the type of clay also affects structure formation. The amount of soil volume change varies with vermiculite and montmorillonite giving much greater change than kaolinite or illite (Ciolkosz et al., 1979). Therefore, it is logical to assume that expansive clays will give smaller sizes and stronger grades of structure than non or slightly expansive clays. Peterson (1944) from a laboratory study reports that montmorillonite produces blocky structure and kaolinite produces platy structure. Southard and Buol (1988) also indicate that soils dominated by smectitic clay often give rise to strong grades of structure. Thus, the amount and type of B horizon structural development are a function of the number of wet-dry cycles, the severity of the wet-dry cycle, the amount of clay and the type of clay. These conclusions are based on a minimal amount of information and more study is needed to sharpen our understanding of the factors that affect the development of B horizon structure.

The amount of aluminum on the soil exchange complex may also influence the degree of structural development. Waltman (1985) from a study in northcentral Pennsylvania indicates that there appears to be a relationship of an increasing grade of structure with an increasing percent Al saturation of the cation exchange complex. Waltman (1985) indicates this relationship is a result of a greater flocculating capacity of Al than other less highly charged cations. This relationship may be important in the development of Pennsylvania's cambic horizons because most of Pennsylvania's cambic horizons have low to very low pH's. This relationship needs further study to ascertain the magnitude and possible interactions associated with this trend.

An additional factor often cited in structure development and ped durability is coatings (White, 1967). Clay, oxide (Fe and Mn) and carbonate (in arid areas) apparently stabilize peds and promote the opening and closing of interped areas at the interface of two adjacent peds. Plant roots also may aid in ped face stabilization. Roots grow in the interped area and exude material into the rhizosphere (area adjacent to the root). This material includes a very large number of compounds (Rovira, 1962; Rovira and McDougall, 1967). Many of these compounds undoubtedly have stabilizing properties. Because many of these compounds are organic and because the roots themselves are organic, the ped face area is also a zone of major bacteria and fungi activity (Amelung and Zech, 1996). These organisms also produce both metabolic and degradational products which may also help stabilize the ped faces (Kay, 1990). Roots also extract water from the soil and their location in the interped area would trigger contraction in the ped face soil material first in a drying cycle and tend to perpetuate the opening and closing of interped areas at the same place in the soil. This process would also help stabilize the peds and make them more durable.

Mixing

In addition to wetting and drying, and faunal activity (earthworms, groundhogs, etc.; Lee and Foster, 1991), root movement and treethrow also assist in displacing and mixing parent material and obscuring bedrock structure. In place mixing through root pulling due to tree trunk wind movement would be minor compared to wetting and drying and faunal activity as a mixing process. Treethrow locally is a much more important mixing process than root pulling. When trees are blown over, their root systems are ripped from the soil and protrude above the ground surface. With time the soil that adhered to the roots falls back to the soil surface and frequently forms pit and mound microtopography. Denny and Goodlett (Denny, 1956) indicate that in

Potter County, Pennsylvania (northcentral area adjacent to New York) most soils have been disturbed by treethrow in the last 300 to 500 years. The treethrows in this area have also undergone recent study (Small et al., 1990; Small, 1997). Denny and Goodlett (Denny, 1956) and Goodman (1953) ascribe the youthfulness of the Potter County soils (cambic horizons) to the treethrow process. There certainly are treethrows with pit and mount microtopography in the area of Potter County and in other areas of Pennsylvania (northern and central plateau and parts of the glaciated area), but there are also many areas in the state that do not show this type of surface microtopography. In the author's experience, treethrow is associated with a shallow rooting depth which is caused by a high water table, a fragipan, bedrock, or major lithologic or pedologic (buried B horizon) discontinuities. A branching tree root system (as opposed to a tap root system) also contributes to treethrow. In addition wind patterns and landscape position may also influence treethrow (Cremeans and Kalisz, 1988). An awareness of the soil factors that are conducive to treethrow is not new. Most of the factors were noted 50 years ago (Day, 1950; Lutz, 1940), but there still is a broad brush application of this process by many, well beyond its range of application. All of the mixing processes noted help to obscure bedrock structure and thus are cambic horizon soil forming processes.

Aggregation

A large body of literature has developed on the subject of soil aggregation (Baver, 1963; Harris et al., 1966; Lynch and Bragg, 1985; Kay, 1990; Symposium, 1991; Symposium, 1993; Hartge and Stewart, 1995; Quirk, 1994). This research has been done primarily by soil physics and crop management workers. The thrust of this work has been to keep the surface Ap horizon aggregated during farming operations to reduce surface crusting and maintain permeability (Sumner and Stewart, 1992). Crusting decreases seedling emergence and increases water runoff and soil erosion. The major method used to determine the degree of aggregate stability is a vigorous shaking in water and a sieving of the soil material. The aggregates retained on the sieves are dried and a weight percentage is calculated based on the total amount of soil shaken. The aggregates reported are usually sand and silt size. These data largely report fragments of the pedogenic structure that soil morphologists observe and describe in the field. In addition, the vast majority of aggregate research has been limited to Ap horizons and only a small number of studies have included subsurface horizons (Stout and Ciolkosz, 1974). Thus, the bulk of the soil aggregate studies are not directly applicable to the study of the genesis of B horizon soil structure.

Although the bulk of soil aggregate studies ignore morphologic structure, Oades (1993) recognizes an aggregate hierarchy in which there is a series of small aggregates which make up a larger aggregate which in turn makes up an even larger aggregate (Fig. 3). The hierarchical orders sizes are: (1) micrometers, (2) microaggregates (one-tenth of a millimeter), (3) macroaggregates (several millimeters), and (4) clods (tens of centimeters). This hierarchical order according to Oades (1993) also shows an increasing stability with decreasing aggregate size. Although this system and the general approach of workers in soil aggregation tend to ignore the soil morphologist's approach to soil structure (Soil Survey Division Staff, 1993), some accommodation is apparently being made (see the review of Kay, 1990). It appears that there is overlap in the soil morphology and soil aggregate approaches. Figure 4 indicates that soil structural units are separated by distinct planes of weakness while aggregates are particles

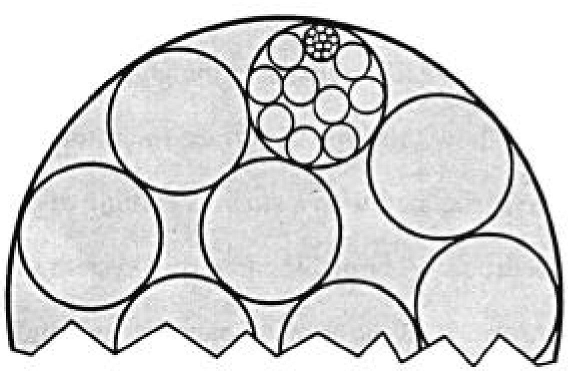

Fig. 3. The concept of aggregate hierarchy (Reprinted from Oates, 1993 with permission of the publisher, Elsevier Science).

bonded to each other. Aggregate size increase is accomplished by bonding some parts of smaller aggregates to adjacent aggregates. This process continues until overlap occurs with ped formation. In some aggregate literature (Kay, 1990), the morphologist's planes of weaknesses are called failure zones, in other literature they are called planar voids, cracks, or joints. The aggregate system approach may well be appropriate for Ap horizons, but it ignores or subjugates B horizon morphological structure to a very minor role in soil importance. The aggregate approach neglects the very important impact that the interped zone has on root growth and water and air movement in soils (Bouma, 1991; Coen and Wang, 1989; O'Neal, 1949). In this regard, recent soil permeability work has centered on macropore flow in soils. This work, like soil aggregate work, has been done largely by nonpedological soil scientists, and worm and plant root holes are usually given as the pathways of macropore flow. With few exceptions, such as the work of Bouma (1991), the interped zones are given little credit for macropore flow. This shortcoming in macropore work hopefully will be corrected in future work.

In the aggregate literature there are occasional references to a crack or cracks, but little is made of their importance or that they are the interped zones of the natural (morphological) soil structure. If the soil aggregate researches would recognize the morphologist's structure as a macrostructure and their fragments as various types of microstructure or substructure, it would

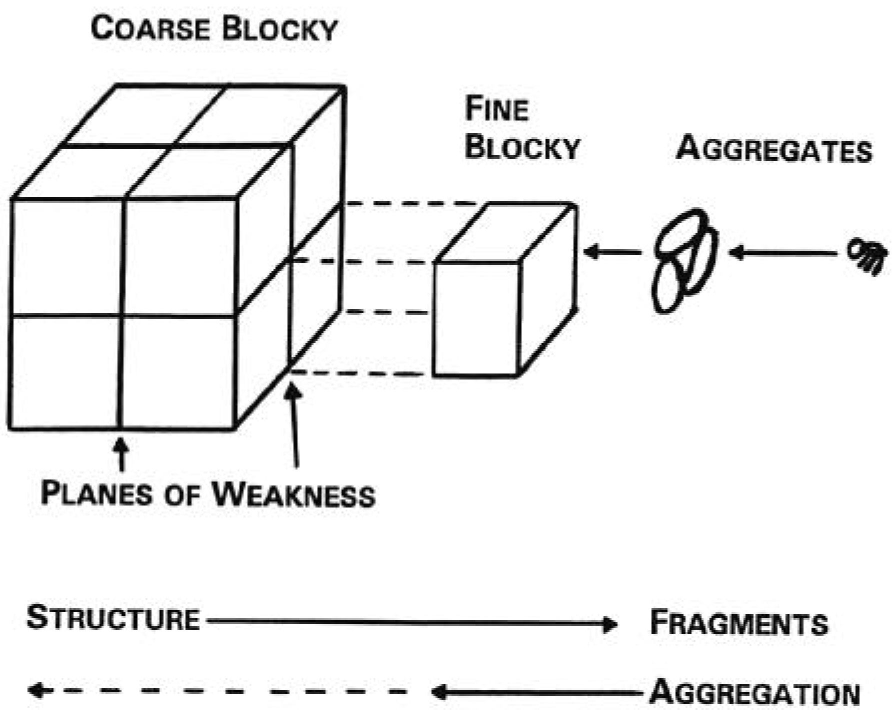


Fig. 4. Soil structure-aggregate model.

be a more realistic (real world) model and be more acceptable to soil morphologists. In addition in the aggregate literature some works use the terms aggregate and structure interchangeably. A slightly more realistic approach is that of the micromorphologist, although they also tend to ignore the large features and concentrate on the intraped microscopic fabric (Brewer, 1964; Douglas, 1990).

Color Development

Color or more correctly the change in color in cambic horizon development stems from two sources. The first source is the oxidation of primary minerals in well drained soils and the accumulation of iron from the primary minerals as the free iron oxide minerals goethite and hematite. These iron oxides give the cambic horizon its yellowish-brown (goethite) or red (hematite) color (Ciolkosz and Dobos, 1990a). The weathering and release of the iron oxides in the cambic usually gives this horizon a higher chroma and sometimes a redder hue when compared to the C horizon. Although the accumulation of illuvial material is not extensive, some illuvial clay has accumulated in some Pennsylvania cambic horizons. In well drained soils the clay itself provides some additional color, but more importantly, free iron oxides also accumulate with the clay; and they provide a great deal of color enhancement. In many sandy soils at higher elevations some humus + Fe + Al complexes have accumulated but not enough to form a spodic horizon. These soils generally are structureless (single grained), but they have enough B horizon color if not too sandy to have a cambic horizon.

The second source or condition of color change is soil wetness. In soils with fluctuating water tables (usually seasonal) reducing condition (aquic conditions: episaturation-perched water table; endosaturation-regional water table; Soil Survey Staff, 1996) produce gleyed or redoximorphic (mottled) color patterns. A totally gleyed horizon (chroma of 2 or lower) would be completely gray with the gray color being the color of the surfaces of the soil material (Ciolkosz and Dobos, 1990a). A mottled horizon may have a matrix color (the most abundant color) and redoximorphic depletions (low chroma mottles, gray color) and redoximorphic accumulations (high chroma mottles, reddish brown color). In wet conditions Soil Taxonomy

(Soil Survey Staff, 1975, 1996) also requires cambic horizons to have a regular decrease in organic carbon content with depth (this requirement is presently under study, and it may be dropped in the near future).

## PARENT MATERIAL AND TIME

### Northeast and Northwest Plateaus

The cambic horizons in the soils of the glaciated northeast and northwest plateaus (Fig. 1; Table 2) are developed in glacial till of variable thickness (Ciolkosz et al., 1997). The northeast area has greater relief and the till deposits are the thinnest on the narrow uplands, shoulder slopes and steep upper back slopes. In these areas moderate deep (20-40 in.; 50-100 cm to bedrock) soils are common with horizon sequences of A-Bw-C-R. In other landscape positions the till is thicker (> 40 in.; 100 cm) and soils with A-Bw-Bx-C horizon sequences are found. In the glaciated northwest area there is much less relief, more gentle slopes (Table 2) and thicker till deposits, some of which are slightly calcareous. Deep soils (> 40 in.; 100 cm to bedrock) with horizon sequence A-Bw-Bx-C and A-Bw-Bxt-C are found in this area. Soils with Bxt horizons have the most carbonate influence and some clay films in the upper part of the fragipan. These soils have been classified as Alfisols. Although classified as Alfisols (argillic B horizon) there is minimal clay accumulation and these soils are at best marginal Alfisols. In both the northeast and northwest areas the cambic horizons have silt loam to loam textures, 10-35 percent rock fragments (Ciolkosz et al., 1997), and show weak color and weak to moderate structural development. The glacial material in both the northeast and northwest areas was deposited about 18,000 years ago. Some loess is found in these areas, usually associated with the major rivers (Ciolkosz et al., 1986).

### Southwest, Central, and Northern Plateaus

The southwest plateau has the lowest percentage of soils with cambic horizons (4 percent) of any area in Pennsylvania (Table 2). Most soils in this area have argillic horizons (Ciolkosz et al., 1996). The main reason for the lack of cambic horizons is that for the most part the parent material of this area has moderate to high carbonate content and a medium to fine texture. The combination of these two factors tends to produce argillic horizons in Pennsylvania soils. In this area, the cambic horizons are found mainly in floodplain soils which are usually a few hundred to a few thousand years old (Bilzi and Ciolkosz, 1977) or in soils formed from acid, sandstone bedrock material. Acid sandstone is also the parent material for many of the soils with cambic horizon on the central plateau. In the central plateau cambic horizons are also found in shallow soils (< 20 in.; 50 cm to bedrock) developed in acid, gray shale. The moderately deep (20-40 in.; 50-100 cm to bedrock) soils developed in these shale parent materials tend to have argillic horizons, although many of these argillic horizons are weakly developed. The texture of the cambic horizons in the floodplain soils of all plateau areas is usually silt loam with few rock fragments, and its structure shows moderate development. This contrasts with upland sandstone cambic horizons which usually are sandy loam, have a high rock fragment content and weak structural development. The shale derived soils with cambic horizons also have high rock fragment content, weak structure, but silt loam textures. The soils of the northern plateau are similar to the central plateau except there are more sandstone soils and the landscape tends to be more steeply sloping. The age of the soils of the unglaciated plateau is believed to be dominantly late Pleistocene (Woodfordian). This is based on the weakly developed soil profiles, and the abundance of Woodfordian, periglacial footslope colluvium in the area. The colluvium indicates significant truncation of the upland and backslope areas and the movement of this material to footslope areas approximately 18,000 years ago (Aguilar and Arnold, 1985; Waltman et al., 1990; Mader and Ciolkosz, 1997).

Ridge and Valley

The cambic horizons in the ridge and valley area are found in soils on the ridge tops developed from sandstone and in soils on the valley floors developed from acid, gray shale. The sandstone soils are deep (> 40 in.; 100 cm) to bedrock while the gray shale soils are moderately deep (20-40 in.; 50-100 cm) (Ciolkosz and Dobos, 1990b). Soils developed in red shales adjacent to the gray shale soils are usually deep (> 40 in.; 100 cm) and have weak argillic horizons

(Ciolkosz et al., 1990; Ciolkosz et al., 1996). Thus, the red shale parent materials tend to weather more rapidly than gray shale material. In the red shale areas on narrow uplands, shoulder slopes and upper backslopes of steep areas moderately deep (20-40 in.; 50-100 cm), red shale soils are found. The cambic horizon in these soils retain their bedrock color, usually 2.5YR 4/4 (dusky red), while the gray shale analogs usually show some yellowing (10YR color) in the cambic horizon. This parent material influence carries through all redbed parent materials in Pennsylvania regardless of geologic age (Paleozoic to Triassic). This effect is so strong that even most of the deep soils with argillic horizons developed in redbed materials retain the bedrock color. An exception to these statements occurs when the redbed soils become saturated (poorly drained). When this happens the hematite (the red coloring material) is reduced, and the soil becomes mottled and gleyed (Ciolkosz and Dobos, 1990a). Although this is the case, the redbed material seems to be more resistant to the reduction and gleying process than gray or brown soil parent materials (Elless et al., 1996; Macfie, 1991). The color of the redbed soils is due to the iron oxide mineral hematite (Elless and Rabenhorst, 1994), and its resistance to gleying is probably related to the hematite grains being large and very well crystallized. These ridge and valley soils have been truncated and/or turbated by periglacial processes during the Woodfordian, and pedogenic processes in the last 18,000 years have not impacted these resistant parent materials significantly. Thus, only cambic horizons have developed in the soils found on the sandstone and gray shale parent material. The texture and structural development of the cambic horizons in these soils is similar to that found on comparable parent materials on the unglaciated plateau.

Triassic-Piedmont

This area, like the ridge and valley, has a very complex bedrock geology (Ciolkosz et al., 1984). It encompassed red Triassic sediments, limestones, and crystalline (igneous and metamorphic) rock parent materials (Ciolkosz et al., 1997). In this diverse area the cambic horizons are found dominantly in the crystalline rock area (mainly schists), and in this area they make up about one-fourth of landscape area. These soils are deep to bedrock and tend to be found on the more erodable parts of the landscape; the narrow uplands, shoulder slopes, and upper backslopes (Pollack, 1992). These areas, like the rest of Pennsylvania, have been affected by periglacial erosion. This erosion has probably been the main factor in the evolution of these cambic horizon (Inceptisol) soils. Although this may be the case, some argue that the 200 to 300 years of agricultural tillage of the area has added greatly to the truncation of these landscapes through accelerated erosion. This point is well taken because these soils have silt loam surface and subsurface textures and are found on sloping landscapes. Both of these conditions lead to rapid erosion when the soil is tilled, and the surface is not protected with wise soil conservation practices.

Sandy Texture

Soil Taxonomy (Soil Survey Staff, 1996) excludes color Bw horizons in well drained soils with very sandy textures from cambic horizons. In order for a soil horizon to qualify as a cambic horizon, its texture must be very fine sand, loamy very fine sand, or finer. Guy D. Smith's rational for this requirement was that he wanted to group all the sandy soils together in Entisols (Psamments) for interpretation reasons and that color B's in sandy soils may develop very rapidly, and only indicate very weak pedogenesis (Brasfield, 1983). The second reason is illogical because the concept of the cambic horizon is a very weakly developed B. The lack of logic in the textural exclusion is also pointed out by the fact that acid, sandy, Woodfordian age outwash or dune soils are classified as Entisols while minesoils 40 years old are classified as Inceptisols (Ciolkosz et al., 1985). Pedologically it is also somewhat illogical that if sandy soils have less than 35 percent rock fragments, they are classified as Entisols; but if they have greater than 35 percent rock fragments, they are classified as Inceptisols. It is most logical that A-C soils should be classified as Entisols (no cambic) while all A-Bw-C soils should be classified as Inceptisols (cambic). Therefore, the texture requirement in most cases is not a useful criteria in the definition of the cambic horizon, and Soil Taxonomy should be amended to exclude this requirement in the definition of the cambic horizon.

Floodplains

Soils on floodplains in Pennsylvania form another interesting genesis-classification anomaly (Fig. 5). The well drained soils have cambic horizons while the wet members of the catena by definition do not have cambic horizons. Guy D. Smith indicates the reason for this separation was that recently deposited floodplain materials, which had not been oxidized enough to destroy deposited carbon, should be included with Entisols (Brasfield, 1983). Like the reasoning for sandy textured Bw horizon exclusion from cambic horizons the wet floodplain reasoning is not convincing and cambic horizons should be allowed in poorly drained floodplain

| Well drained - - - -> | Moderately well- - - -> drained | Somewhat poorly - - - -> drained | Poorly drained |
|---|---|---|---|
| Inceptisol | Inceptisol | Entisol | Entisol |
| Cambic | Cambic | Non-Cambic | Non-Cambic |
| Bw | Bw | Bw | Bw |

Fig. 5. Generalized floodplain catenal sequence in Pennsylvania.

soils. As a matter of fact, Guy Smith even admits that having Entisols as the poorly drained soils and Inceptisols as the better drained soils on the same age alluvial surface is illogical (Brasfield, 1983). This classification anomaly is presently under study and may be resolved with the next major revision of Soil Taxonomy.

## CLIMATE AND VEGETATION

Although parent material and time are the two most important factors in cambic horizon formation in Pennsylvania soils, the interaction of precipitation, temperature, and vegetation also impact its development. This occurs in the cooler (Carter and Ciolkosz, 1980), moister (Waltman et al., 1997) areas of the state where spodic horizons are found. In these regions, in sandy and some loamy soils, a color Bw can form that has some character of a spodic horizon (Bhs). These B horizons are more illuvial than residual but do not qualify as a spodic B, and are classified as cambic B's. In the sandy soils these cambic horizons are mainly color B's that are structureless or have weak blocky structure while in the loamy soils they show slight color changes associated with the weak to moderate (mainly blocky) structure. There has been some indication that tree vegetation favors blocky while prairie grasses favor prismatic B horizon structure. This idea needs to be tested under rigorous scientific conditions. In addition in the cooler, moister areas of the state, the soil moisture regime is perudic or near perudic (Waltman et al., 1997). This condition also may favor the development of cambic horizons over argillic horizons because of the apparent need for a non-leaching season (summer) for the formation and stabilization of argillic horizons (Smith, 1986; Ciolkosz et al., 1996).

## CONCLUSIONS

Cambic horizons are color and/or structural subsurface (Bw) horizons. Bw horizons in very sandy or poorly drained floodplain soils are not considered cambic horizons. These exclusions are a part of the criteria of Soil Taxonomy and in the author's opinion these exclusionary criteria should be dropped, and these kinds of soils should be recognized as having cambic horizons.

The factors affecting structural development in cambic horizons are not totally clear. Although not clear wetting and drying, clay content, type of clay, freezing and thawing, and possibility vegetative type (tree vs. prairie grass) may influence the size, grade, and type of structure found in cambic horizons. Color development in well drained Pennsylvania cambic horizons is due to inplace weathering of primary minerals and the formation of secondary iron oxide minerals as well as some deposition of humus + Al + Fe as complexes from overlying horizons. In addition, cambic horizons are also found in many poorly drained non-floodplain soils. In these soils structure as well as redoximorphic features are the defining criteria.

Cambic horizons are found throughout Pennsylvania. Although, they are most abundant in the glaciated northeast plateau. In this area, as well as the glaciated northwest plateau, they are relatively young in age (18,000 years), loam to silt loam texture, and developed from acid till. Where the till is slightly calcareous (in parts of the northwest area), weak argillic horizons tend to form. On the unglaciated plateau cambic horizons are found in soils developed from acid sandstones and shales. The sandstone and shale soils are found on unstable landscape areas and have been truncated by periglacial processes. In the ridge and valley the cambic horizons are also found in sandstone (ridge tops) and acid shale (valley floors) soils. In the Triassic-Piedmont, the cambic horizon soils are found again on the less stable landscape areas, but in this case the bedrock is mainly crystalline (schist).

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