Soil Stratigraphy of the C-740-U Landfill Site

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Foreword. At the request of the ITR team, selected cores from the C-740-U Landfill Site stored at the Kentucky Geological Survey Core Facility in Lexington, Kentucky, were examined on 10/3/2005 for a soil stratigraphic analysis. Comments in this report are based on interpretations from nine 30 foot cores examined for several hours, thus interpretations are preliminary. One core was inspected in detail and compared to the others. All cores had the same major units and were quite similar in most respects. Depths to corresponding units among the cores appeared to be within a few feet of average.

In cores of this type the geologic units are obscured by strong pedogenic modification. Boundaries of major units can be easily missed because of an apparent continuity across them. Explanation of the factors causing uncertainty is added to the discussion below. To confirm interpretations a more rigorous examination is needed that involves continuous examination of split faces of all cores, thin section study and selected laboratory testing.

The following comments and interpretations are largely derived from the first core with comparisons and comments on adjacent cores. For a rigorous appraisal of soil stratigraphic features, soil and geologic attributes need to be integrated and considered together. In order to avoid confusion between soil and geological features, background information is added throughout the discussion to clarify concepts and interpretations, which can be deleted as necessary.

Observations and interpretations

Preface note: Traditional soil and geologic descriptions and interpretations overlap to some degree, but are different in ways that cause conflicting interpretations. The significance of this is described by Follmer (1984). A common ground between traditional Quaternary geology and pedology lies in the fact that both use soils as key elements in their studies. However, their focus and concerns are different. Soil genesis and classification is the focus of the pedologist. In contrast, geologists use the major paleosols (buried soils) to subdivide the major time stratigraphic units of the Pleistocene. Commonly geologists interpret paleosols but do not describe them in pedologic terms. Unfortunately, some terms in common use in soil and geology studies have different or opposite meanings, such as "massive", which mean uniform without soil structure to a pedologist but means uniform or homogeneous to geologists. Thus a "layer" may be homogeneous as well as having soil structure. In soil stratigraphic work this is a critical distinction.

In several hours of inspection of nine cores, I was able to distinguish 7 soil stratigraphic units. Much of the character, "soil fabric", needed to assess the soil units in all cores has been modified or destroyed, which makes it difficult to identify soil horizons and locate geologic boundaries (see addendum and recommendations). After allowing for this limitation, sufficient features and relationships were recognized that enables us to determine the following soil stratigraphic sequence:

1. Peoria loess with a complete solum; 0 to 7 feet*
2. Roxana loess with upper solum characteristics; 7 to 10 feet
3. Loveland with a complete solum; 10 to 13 feet
4. Metropolis Formation with 4 members; 13 to 30 feet
    - 4.1 Silty with solum characteristics; 13 to 18 feet
    - 4.2 Silty to loamy [minor sand content] with C horizon characteristics; 18 to 22 feet
    - 4.3 Silty to loamy with solum characteristics; 22 to 25 feet
    - 4.4 Loamy [about equal amounts of sand-silt-clay] re-oxidized, weak Gley horizon, Bg or Cg; 25 to 30 feet

* Depths are average estimates. Units vary up to 2 feet in thickness between cores.

<u>Surficial deposits and impact of soil formation</u>

For a full understanding of a soil stratigraphic sequence, soil and geologic properties need to be distinguished. In generic terms a soil is a modified or altered geologic deposit. A soil is considered complete where all the genetic horizons are present. In simple terms this includes the A, B and C horizons. An E horizon is a significant accessory horizon. A solum is the part of a soil profile where the original geologic fabric has been modified to a pedologic fabric, which in broad terms is equivalent to soil structure in pedology. By definition the solum includes the A, E and B horizons.

The upper 3 geologic units at the C-740-U Landfill Site are loesses that are well known in the Midwest (Follmer, 1996 and Grimley et al., 2003). All units, major and minor, contain paleosols (fossil soils) that are used to define tops of loess units, or subdivisions with major loess units. The upper three loess units, Peoria, Roxana and Loveland, are usually present on the uplands along all big valleys beyond the limit of the last glaciation (Late Wisconsinan = Marine Oxygen Isotope Stage 2 or MIS 2) in the central US (see maps in Follmer, 1996). The age of the Peoria loess deposition is in close agreement with other known contemporaneous glacial events of the last glaciation, which occurred between 13 to 24 ka (C-14). In pedologic terms the modern soil on stable land throughout the Midwest started forming before the Holocene about 13 ka, when loess sources started to disappear.

The geologic boundaries throughout the cores are blurred due to the overlapping influence of soil formation. In general the depth to which pedogenic alteration goes for each soil is deeper than the thickness of the upper unit of its parent material. A mixing or turbation process occurs within all soils. When younger sediment is deposited over a soil profile, the materials become blended by a process known as "welding" in pedology. The thickness of the mixing zone is up to a meter thick. Thus components of one unit are translocated into the other, which decrease with distance from the original contact. This is called stratigraphic leakage by paleontologists. In conformable sequences with repeating soil and sediment units, this causes geologic boundaries to be gradational, but often produces distinctive soil morphological features.

<u>Wisconsinan loesses</u>

In the Midwest the major loess units are distinctive where each is more than 3 feet thick. Where units are thinner the succession appears to be continuous. In upland positions the Peoria is commonly yellowish in color and commonly contrasts with the Roxana, which is commonly browner or reddish in color. Where Roxana is thin, it is hard to distinguish because it takes on properties more like the Peoria, or the top of the Sangamon Geosol. Because of this some researchers have combined the Roxana and Peoria into one stratigraphic unit and call it Wisconsin(an) loess. Both formed during the Wisconsinan Stage and overlie the Sangamon Geosol [a formally defined, buried, fossil soil in stratigraphic terms].

For the best interpretation of a buried soil in the sense of geologic age, the buried soil catena needs to be determined. The catena, a lateral sequence of soil types that repeat across a landscape, is a critical part of the geosol concept that was introduced in the stratigraphic code in 1983. The other critical part is the stratigraphic position of the parent material in the catena. One of the reasons the concept of a geosol was established for geological work is to avoid the confusion with soil type in the pedological sense. This applies to the Farmdale "Soil", a name given to a weakly developed soil in the top meter of the Roxana loess. It was originally intended to be understood as a catena, in that the lateral pedologic facies were considered to be a part of the "soil". However, soil used in this sense was commonly confused with a soil type, a concept that excludes a facies change. So it is recommended that a buried soil in the stratigraphic sense be referred to as a geosol in an informal local sense, or a Geosol for established units such as the Farmdale. Then, the term soil can be used in all the common uses of the term except for the stratigraphic sense.

Applying this to the Farmdale Geosol developed in the Roxana, a field investigation that interprets Roxana loess to be present would require that it is buried by the Peoria and that a soil is or should be in the top of the Roxana. The top layer should be an A horizon based on pedological principles. If not, then evidence for truncation should be present. In most cases when no erosional evidence is apparent, it is more reliable to conclude that the A horizon is present and has lost the A horizon expression through diagenesis, rather than assuming the soil has been truncated. This is analogous to the loss of "soft parts" of fossils. Some of the persistent features of buried A horizons in oxidized environments (well drained to the soil scientist) include compressed granularity preserving some coprolitic material, fire-borne charcoal (black angular grains) and fine-grained black nodules (Fe-Mn oxyhydroxides).

The Farmdale Geosol is an important stratigraphic marker. In poorly drained settings the top layer is commonly black and rich in degraded organic debris and is designated as an Ao horizon. In the past it was common for this horizon to be called the "Farmdale soil". This horizon has been C-14 dated across the Midwest to be in the range of 24,000 to 27,000 years old. Under the Ao is usually a black mineral A horizon and a gray [gleyed] Bg horizons in most settings. Where more oxidized such in the cores, a Bg horizon is replaced with a Bw. This is very hard to distinguish because the Roxana is thin and the weak Farmdale features are superposed on stronger Sangamon Geosol characteristics.

Fossils found in the Farmdale throughout the Midwest indicate that it formed during a cool climate interval that existed before the last glaciation, which started about 24 ka. At the C-740-U Landfill site the upper horizon of the Farmdale in the Roxana is grayish brown in color, which indicates that the site was an upland during this time interval. The Roxana is thinner here than at other places, suggesting that it may have been partially eroded during its episodic deposition during the interval from about 27 ka to about 50 ka, before the Farmdale soil forming episode started (Follmer, 1996).

Loveland loess

The Loveland loess is commonly found below the Peoria and Roxana along the major rivers of the Midwest (Follmer, 1996, and Grimley, et al., 2003). It was deposited during the Illinoian glaciation, which correlates with MIS 6 and has an age of about 125 to 180 ka. In most places the Loveland is modified by formation of the Sangamon Geosol during the following interval from about 75 to 125 ka, MIS 5, called the Sangamonian Age/Stage in the Midwest. Where the Loveland has a lower zone of less weathered C horizon material, it is very similar in color and lithology to the C horizon in Peoria. Simple clay mineralogy tests can usually differentiate the three units when the Roxana is present (unpublished work by H. Glass, ISGS). Therefore, when taken out of stratigraphic context, the Loveland and Peoria can be easily confused.

The typical soil features in the Loveland are quite notable, usually in the range of a strongly developed Alfisol – weak A, strong E and Bt, and usually so thick that the lower soil horizons are superposed on the underlying unit where the Loveland is less that 5 feet thick. In the Midwest the Sangamon Geosol was not buried by loess until after about 55 Ka (Curry and Follmer, 1992). Although the climate changed from warm to cool conditions, loess was not generated. Thus, Sangamon soil formation continued into Wisconsinan time, and the soil stratigraphic interval evolved into a polygenetic soil catena. Some of its properties changed; chiefly it developed more mollic (grassland) characteristics. Also, significantly more conifer and other cool climate fossils are associated with this change.

The Loveland has the same silty properties as the Peoria, whereas the Roxana has a greater proportion of course silt than the others. Soil development on the Peoria and Loveland developed mature Bt horizons, the development on the Roxana did not, which provides a useful soil stratigraphic pattern for recognizing the loess units. Weathering (pedogenesis) in the Peoria and Loveland modified the B horizon interval, about 2-5 feet below original ground surface, from a silt with less than 10 % clay [2um] to 30 to 40% clay in the Bt horizons. Weathering in the Roxana enriched the clay content from about 10 to 20%. When older weathered loesses are found they may have 50% or more clay and be confused with residuum on bedrock. Thus pedogenic processes modify the geologic properties to the point where they are difficult to distinguish.

The clay and morphological trends within a parent material provide a basis for judging position of the pedogenic profile within it. This is similar to geopetal indicators in sedimentology, which are features that indicate top and bottom. In soil profiles, morphological features of soil horizons have this value. The most distinctive features are usually found in B horizons, which is a welded "soil structure" in buried soils that reliably relates to the top, an interval of maximum expression and a fade away at the bottom of the horizon. Thus in cores or even when limited to hand specimens, the soil morphology can be used to estimate where it came from and how deep it may have been below the original ground surface, i. e., during formation before burial. In terms of clay content the trend is from low clay in the upper solum (A and E horizons) to a maximum in a Bt horizon that decreases to low values in the C horizon.

The Loveland at the C-740-U Landfill site appears to be in the range of normal Loveland loess. It appears to have an upper solum [A+E horizons] that has been modified by younger pedogenesis and has been badly crushed by the sampling [the pedo-fabric has been destroyed by the sampling procedure]. The upper solum overlies the upper Bt that is well expressed in one of the cores examined. It shows a coarse, healed ["welded"] soil structure, ped faces that face each other in symmetrical fashion that have a bleached white zone on both sides that are bordered by orange iron stains. A thin gray argillan [clay skin] marks the line of symmetry, essentially where the ped faces meet. The void space has been closed, presumably by the argillan that filled the space. These are normal features of a Bt horizon. They indicate iron mineral weathering, bleaching due to the organic acids in the leachate and clay translocation due to seasonal changes in water content. These are indicators for an Alfisol. The argillan is gray which means that it formed under reducing conditions and has not oxidized since formation. I suspect that it is a modern argillan from the modern soil.

The ped structures are the primary features for interpreting a Bt horizon. The structure gets coarser downwards, mottling when present gets larger and iron manganese stains and nodules get bigger in most soils, which are intermediately oxidized or reduced. In more oxidized or reduced environments, these features are absent or poorly expressed. This is another application of a "fining-upward" concept. Soil features in a simple profile always fine upward. In some of the cores the Sangamon Bt horizon has a few large features that appear to be *Krotovina*, infillings with multiple components including argillans, peds immersed in white silt, and layered intervals. It resembles a breccia. It represents a disturbance that caused a large void to form that was later filled with debris that came from above. This could be the result of burrowing animals, decayed tree roots, mass wasting or extreme desiccation. The cause of these features was not evident.

For making parent material determinations, the grain size distribution patterns are more reliable than color patterns that can be misleading. In the cores we noticed a slight increase in sand and a few pebbles in the Sangamon Bt horizon. The Bt characteristics of unit 3 get stronger downward, then fade out with depth. It grades into a similar silty material that has upper solum features, which are millimeter scale features with rounded forms and other fine features. The features are interpreted as compressed granular aggregates, a ubiquitous characteristic of buried surficial soil horizons. This indicates a soil surface horizon in general and is a reliable basis for drawing a geologic boundary here.

<u>Metropolis Formation</u>

The next unit down, unit 4, is present in all cores, from about 13 feet to the bottom of the cores. It correlates nicely to the Metropolis Formation across the river in Illinois. It is a complex fluvial sequence containing several unnamed paleosols. It always contains a complete or partially truncated paleosol in the upper part on relatively flat stable surfaces. It is expected to contain primary bedding structures in the lower parts of thick sequences but has rarely been observed in outcrop beyond its type section.

The cores examined from the landfill site show a consistent stratigraphy of 4 members. The upper member, 4.1, from about 13 to 18 feet, strongly resembles unit 3 above. It contains a well developed Alfisol that has a gradual increasing sand content downward in a silty parent material. Solum features dominate this interval. Evidence for stratification at the bottom was selected for defining the base of this unit, 4.1. The unit may have been originally stratified, but the soil formation blended the material. The upper part is rather uniform and is a gray brown silty clay loam with fine features in the millimeter range, and lacks B horizon structure. The lower part is brown to gray silty clay loam with more sand than above. It has Bt features and some breccia-like infillings similar to the Sangamon in unit 3 above.

The top of unit 4.2 in placed where the stratification becomes evident. A fine-grained sand-rich sand-poor stratification is present from about 18 to 22 feet. In the pedogenic sense this is the C soil horizon of the soil in unit 4.1. This soil has qualities of a Yarmouth Geosol but I hesitate to make this claim. In the broad sense the Yarmouth represents a long span of time correlated to MIS 7-11 (Grimley et al., 2003). This means that in nondepositional environments that several soils may have formed one on another [an evolution of soils] i. e., if parent material was not added during glacial stages within this interval. Here it appears that sediment accumulated during MIS 7-11 interval, producing the units in the cores.

It is likely that the upper part of the Metropolis Formation contains the stratigraphic record of the long interval classically called the Yarmouthian Stage. In this setting the fluvial units in the Metropolis represent the glaciation or aggradation phases of a glacial- interglacial cycle and the soils represent the interglacial phases. Therefore, it is plausible that the soil stratigraphic units within the Metropolis are an indirect record of the glacial history and that the sediments record in the Metropolis spans the interval between the Sangamonian Stage and the beginning of the Pleistocene. The lower parts of the Metropolis are sandy, and may be preglacial in the sense that loess of glacial origin did not impact the region until glaciers passed the drainage divide to rivers flowing south in the central US.

The source of the sediment for the Metropolis Formation was from the Tennessee and Cumberland Rivers, and was not affected by the glacial meltwater rivers except for back water affects and the eolian factor, which may have been significant. The cumulative effects of the regional loess deposition may explain why the Metropolis becomes more silty upwards. Indirectly the beginning of the silt increase may reflect the beginning of glacial effects in the region. The youngest member of the Metropolis is as silty as the Loveland loess. The local circumstances suggest that the Metropolis was a source for the Loveland, which would explain the similarity. This part of the story deserves further study.

The third unit in the Metropolis, unit 4.3, is a zone from about 22 to 25 feet deep that is a gleyed Btg horizon. The grain size appears to be a uniform silt loam with a high sand content. In soil terms it is a wetland soil that likely formed on a flood plain. The apparent lack of O or A horizon characteristics indicates that it is a youthful soil that was subject to slow sediment accumulation. The Bt characteristics are weak, but suggest that the soil experienced seasonal drying and was located on a surface above a 10 year flood plain, or one that had low sedimentation rates. More study is needed to determine the actual rate of formation. In geologic terms the soil-sediment sequence does not represent much time, perhaps it is in the range of a 1000 years. Diagenesis after burial can explain the disappearance of a weakly developed A horizon. If larger amounts of organic matter were ever present, I would expect a portion of it to be preserved.

The fourth unit, 4.4, from about 25 to 30 feet deep, is a gley zone with much reddish orange iron stains. The bright stains have thoroughly permeated some of the more sandy parts that reflect primary stratification. Grain size is probably in the range of a clay-rich loam and is slightly brittle, probably because of iron cementation. Scattered small pebbles indicate a higher energy fluvial origin compared to unit 4.3. All these features suggest that this unit is a continuation of unit 4.3 that is coarsening downward. In the soil sense it is a Cg or weak Bg that has been modified by iron oxyhydroxides.

The bright colors of the iron stains in unit 4.4 suggest that it is the result of iron-oxidizing bacteria. This can occur when the water table is lowered, which promotes oxidation of iron by bacteria. Or it could be related to ground water discharge, but I don't see how this can be related to the site. In normal poorly drained soils it is typical to find an iron oxide accumulation below a gley horizon, but the color of the iron is usually a dull combination of yellow, orange, brown and black. This unit appears to have been gleyed (chemically reduced) first and later on it was modified by an invasion of reddish orange iron compounds. If bacteria are involved their colonies commonly form microbotryoidal clusters that can be identified with a 10x power hand lens. Other forms of precipitated iron are amorphous.

<u>Summary of the Metropolis Formation:</u> It is a fining-upward fluvial sequence that has been modified by soil formation. The upper part is silty and has properties similar to the Loveland loess, which suggests that Loveland and Metropolis have a close geologic relationship. The soils in them are also similar. The Metropolis becomes more sandy downward, a feature that may indicate a decreasing influence from loess of glacial origin. In the core interval observed, 13 to 30 feet, the Metropolis contains the horizons of two mature soil profiles. In Illinois, about 10 miles to the north, three mature profiles have been observed in the Metropolis.

At present we do not have age control on units within the Metropolis Formation. The top and bottom are reasonably constrained. The top is Sangamonian in age and the base in practical terms is the base of the Pleistocene. Finite ages have not been determined on these materials, but the age estimates used in this discussion are based on correlations that have been verified and dated.

<u>Addendum:</u> For future studies, better sampling techniques should be considered for preserving morphology of the soils. The character of the natural morphology is the essence of soil structure, which is necessary for a full diagnosis of soil horizons. It is needed for distinguishing the sequence of formation of the features, which is analogous to paragenesis in petrography. Core samples that are compressed loose much of the natural fabric and the compression generates an artificial fabric. Collecting cores in soft sediments for a soil stratigraphic analysis using a standard Geoprobe tool (which has a blunt, thick bit) is comparable to a paleontologist collecting samples with a backhoe.

<u>Recommendations:</u> Adapt Giddings soil sampling core barrels that have sharp bits and thin-walls to the Geoprobe, or take the blunt Geoprobe bit and sharpen it to reduce the differential between the OD and ID. In other words, a thin-walled barrel with a sharp bit works best. The core can be extruded in good condition most of the time, but a split barrel modification is better for extracting undisturbed samples. At a depth where the bulk density exceeds about 1.7 g/cm^3, it is best to switch to a stronger barrel, because thin-walled barrels will collapse or the bits will break under the higher pressure needed to drive the sampler.

Also, head space should be allocated in the core barrel to accommodate extension of the core in plastic materials. The core will lengthen in proportion the OD:ID ratio. If it is 1.1, then full recovery in a 5-foot core barrel pushed 5 foot will yield 5.5 foot of recovery. If you don't accommodate this factor, then all “full recovery” cores in plastic materials will be truncated – top and bottom. It makes it difficult to determine real discontinuities when every “full” core is truncated, let alone the problem of core loss.

An alternative procedure would be to limit core runs to 4 feet within a 5-foot barrel when sampling soft materials. Geoprobe originally provided 4-foot barrels and 4-foot drill rods; later they upgraded to 5-foot barrels and rods. Using 4-foot rods with the 5-foot barrel would enable the driller to keep track of depth while not over-filling the tube.

References

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