Lithologic discontinuities in soils

Steven W. Ahr
University of the Incarnate Word, USA

Lee C. Nordt
Baylor University, USA

Randall J. Schaetzl
Michigan State University, USA

Accurate recording and interpretation of vertical changes within a soil profile are important for pedologists, geomorphologists, stratigraphers, hydrologists, and archaeologists. Describing soils is a fairly standardized process that follows a systematic cataloging of observable properties and their changes with depth. Many soil properties that vary with depth often do so abruptly, exhibiting stark contrasts with the upper or lower horizons. It is not always clear, however, even to those who routinely investigate soils, whether such vertical changes originated from sedimentologic/geologic layering (i.e., two or more parent materials), or from pedogenic processes. Where geologic layering has resulted in the vertical change in the soil profile, the point at which that change occurs is referred to as a lithologic discontinuity (LD); it separates the two layers (Figure 1). Each of the layers is assumed to differ substantially from the other layer in terms of particle size distribution (PSD) or mineralogy, reflecting differences in lithology. Because the sediment above an LD is always younger than the sediment below, LDs also denote age differences in the materials (Schaetzl 1998; Soil Survey Staff 2010). If no discontinuities occur within the soil material, pedogenesis is assumed to have proceeded within a single, uniform parent material.

LDs that separate different sedimentary layers, or strata, form when there is a shift from one depositional system to another (e.g., eolian to fluvial), or as changes take place in an otherwise similar sedimentary system. The former can be related to changes in parent material source, whereas the latter may reflect waning or advancing energies associated within a single depositional system. Loess overlying glacial till, alluvium overlying residuum, and colluvium overlying alluvium are examples of stratigraphic successions containing LDs that originate from different depositional agents and sediment sources. Changes in depositional energy within the same sedimentologic regime (e.g., fluvial) can also result in the formation of LDs, such as a significant shift in particle sizes due to changes in stream competence. For example, medium or fine sand overlying mostly coarse or very coarse sand can be assumed to be two different materials, due to differences in depositional energies, although they are of the same mineralogy (Soil Survey Staff 2010). Within soil-stratigraphic successions, LDs can also point to a chronological unconformity caused by a hiatus in sedimentation (beyond diastems). Such chronological unconformities within alluvial soil sequences are often marked by paleosols that form during episodes of landscape stability. The stratification of buried soils in an alluvial sequence can also be marked by LDs if the geologic materials comprising each alluvial unit are lithologically dissimilar, or if particle sizes between layers are strongly contrasting (Soil Survey Staff 2010).

The International Encyclopedia of Geography.
Edited by Douglas Richardson, Noel Castree, Michael F. Goodchild, Audrey Kobayashi, Weidong Liu, and Richard A. Marston.

DOI: 10.1002/9781118786352.wbieg0816

Figure 1 Example of LD between sandy alluvium over very gravelly glacial outwash, in a Typic Hapludalf located in southwestern Michigan, USA. Photo by R.J. Schaetzl.

Detection of lithologic discontinuities

Although easy to conceptualize, detection of LDs in the field is not always straightforward. Traditional approaches rely on methodologies designed to identify significant vertical changes in profile properties that have unquestionably resulted from geologic processes. Such approaches attempt to exclude those changes that were caused by additions, losses, transformations, and translocations that may have occurred during pedogenesis. For example, pedologists insist that LD indicators must not have resulted solely from translocation of clay during pedogenesis. The same could be said for any substance that is translocated in soils during pedogenesis. Thus, soil properties that are related to mobile soil constituents, including pH, clay content and mineralogy, organic matter and carbonates, as well as those that are affected by in situ weathering processes, should not be used for the detection of LDs. These vertical changes occur in soils due to pedogenesis, not via geologic processes. However, such properties can and often do abruptly shift at an LD. With this background in mind, we turn to the methods that have been developed to detect LDs, including morphological, textural, and mineralogical indicators.

Morphological and textural indicators

Classic morphological indicators of LDs include abrupt changes with depth that are unrelated to pedogenesis, especially those related to differences in lithology, shape, or distribution of coarse fragments. Significant horizon-by-horizon changes in the degree of weathering of soil rock fragments, rock fragment angularity, and the size and shape of resistant mineral grains observed in micromorphic thin section, can suggest different geologic origins for each layer. In areas where soils have relatively unweathered rock fragments, an LD can be indicated by an uneven distribution of rock fragments with depth. Stone lines, which commonly separate different parent materials, could suggest that a soil has developed in more than one kind of parent material, separated by an LD. Caution must be exercised, however, as stone lines are also commonly formed by pedoturbation in initially uniform materials (Johnson 2008).

In terms of textural indicators, abrupt changes in the depth distributions of sand and silt totals, or their subfractions, often point to an LD, because they may be related to changing depositional environments, such as from water to wind. Textural indictors should usually be evaluated on a clay-free basis so as to exclude pedogenic (mobile) clay. In this way, inherited lithologic differences are not obscured (or magnified) by the effects of subsequent pedogenic processes. Clay-free PSDs used to assess parent material uniformity typically include the dominant particle size fraction. For example, clay-free quartz sand can be an effective constituent due to its weathering resistance and the fact that it is not altered significantly by weathering, or mobilized during pedogenesis. Vertical consistency in PSD classes throughout the soil profile is generally taken as evidence of parent material uniformity (i.e., lack of an LD).

Ratios between particle size classes can also be plotted against depth in order to identify LDs, so long as sufficient quantities of the two fractions in question are available. Low quantities of a particular fraction, especially in the denominator, tend to magnify changes in ratios and potentially overinflate the number of observed discontinuities, or indicate LDs where there is none. Therefore, vertical profile changes in particle sizes or mineralogy ratios, while highly useful, should at times be evaluated with caution and used only in concert with other indicators. Statistical tests to identify significant differences in particle size separates can also be performed between adequately sampled horizons in order to identify LDs.

The lithology of soil rock fragments can also provide clues about the uniformity of parent materials, or the lack thereof. For example, if rock fragments within a soil exhibit a different lithology than that found in the bedrock below, it may be that the soil is not weathered from the underlying bedrock, and an LD separates them.

Mineralogical indicators

The analysis of depth trends in stable soil constituents such as Ti and Zr have long been used for detection of LDs. Both Ti and Zr are considered weathering-resistant when present in stable and insoluble mineral phases such as tourmaline and zircon, respectively. If these minerals can be isolated from the sand or silt fraction, which is normally not considered mobile in soils, the amount of Ti and Zr can be used to indicate the presence of lithologic changes. Nonuniform depth functions in Ti and Zr (and ratios between them) imply inherited layering in the soil profile and point to the presence of an LD. Alternatively, uniform values (and ratios) of these kinds of data point to parent material uniformity (Anda, Chittleborough, and Fitzpatrick 2009; Chapman and Horn 1968).

In some instances, Ti- and Zr-bearing minerals may become chemically reactive and/or mobilized, and as a result, their utility as a stable index element can become problematic. For example, Ti is normally present in ilmenite, rutile/anatase, mica, and biotite. But as these minerals weather, Ti may become incorporated into the fine clay (mobile) fraction, transported or leached, and reprecipitate lower in the soil profile (Taboada *et al.* 2006). In this case, Ti depth functions may reflect weathering and translocation processes, rather than an LD (Figure 2). Because Zr is found almost exclusively within the weathering-resistant mineral zircon, it tends to be ideal for identifying LDs, so long as it is present in the sand or silt fraction, and in detectable quantities. However, the use of Zr can also be problematic in some instances. For example, eolian additions of small amounts of zircon to the upper soil profile can significantly complicate LD detection. Zr has also been shown to be susceptible to redistribution as well as chemical weathering and leaching in extremely acidic or alkaline soils, and in volcanic soils.

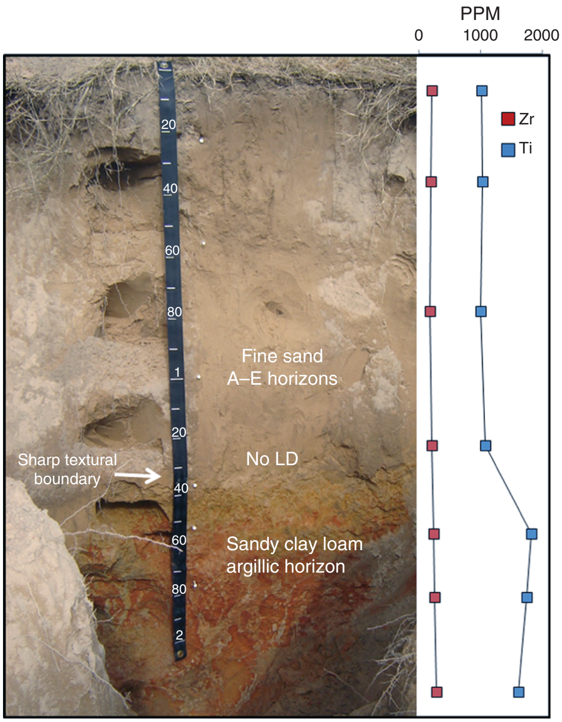

Figure 2 A texture contrast soil (Grossarenic Paleustalf) from Burleson County, Texas. Clay-free textural and mineralogical data failed to reveal any LDs within this soil, that is, the textural differences have resulted from mobilization and translocation of fine clay by pedogenesis. Note that there is virtually no change in Zr with depth. In contrast, the slight shift in Ti at the top of the argillic horizon is likely attributable to weathering of primary minerals and incorporation of Ti into the mobile clay fraction, which is 81% correlated. Photo by S.W. Ahr.

Post-depositional factors affecting lithologic discontinuities

Some LDs are so subtle as to raise the question of whether they are even worth noting. In other situations, post-depositional processes such as pedoturbation have blurred the contact between the two materials, making detection (and perhaps importance) of the LD questionable (Schaetzl and Luehmann 2013) (Figure 3).

LDs within a profile are often obscured and blurred by weathering and mixing processes that disturb the original stratification between different layers of parent materials. Such horizonation and mechanical sorting processes include various types of pedoturbation, such as shrinking-and-swelling by smectitic clays, cryoturbation, and bioturbation. These processes are most pronounced in the near-surface zone, implying that LDs are more likely to be preserved at greater depths in the soil where relict bedding can persist through multiple phases of pedogenesis and pedoturbation – even within the highly decomposed and weathered soils of humid regions.

The same processes that obscure pre-existing LDs can, in some circumstances, also transform uniform, near-surface sediments into layered sediment, especially on older upland landscapes. For example, weathering in some soils transforms coarse particles in the upper profile into silt, clay, and fine clay, and moves these particles down the profile. This process often results in the formation of a texture contrast soil, in which coarse textured layers overlie finer-textured layers enriched in clay (see Figure 2). This type of contrast is commonly observed in well-drained Alfisols, as well as Ultisols (Ahr, Nordt, and Driese 2012; Koppi and Williams 1980). The contrasting textures, often separated by abrupt boundaries, can be mistakenly interpreted as geologic layering. Such vertical changes are more appropriately interpreted as *pedologic discontinuities* that resulted from the pedogenic segregation of mobile soil constituents. Because of these complicating factors, distinguishing between pedologic and lithologic discontinuities should be determined using multiple lines of evidence.

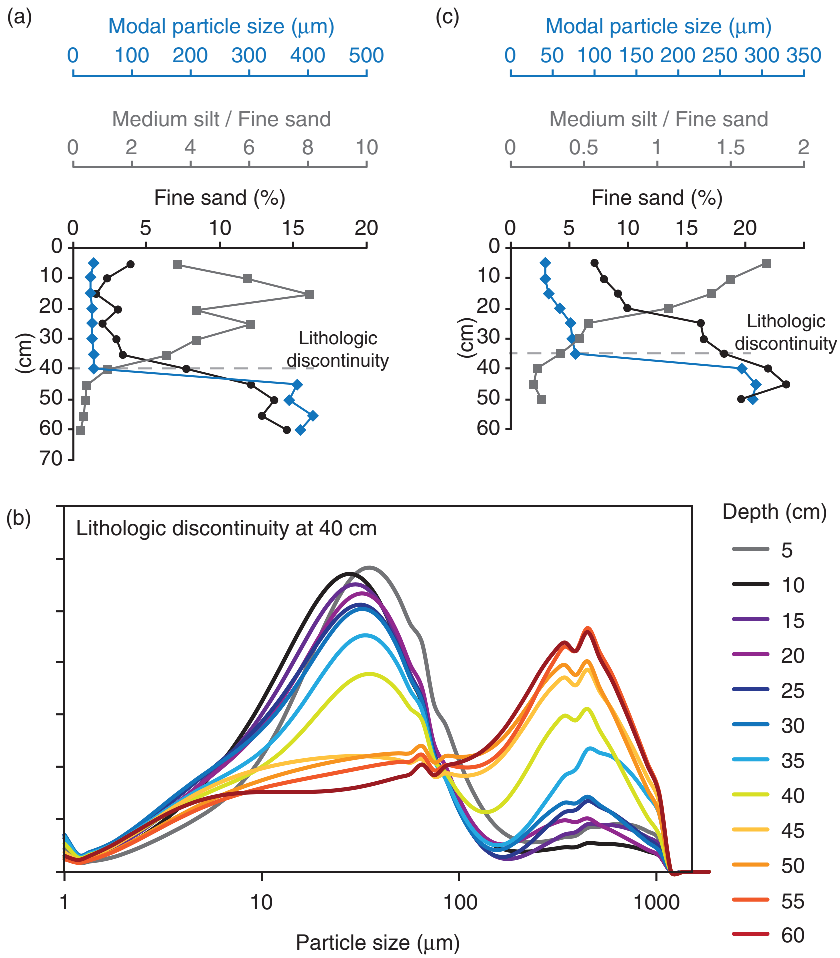

Figure 3 Examples of two different graphical methods that can be used to show LDs in soils. The data in (a) and (b) are from a profile composed of a 40-cm-thick, silt-rich, loess mantle over sandy glacial outwash. This soil has a mixed zone, rather than an abrupt and sharp LD. (a) Traditional depth plots of immobile fractions and ratios of immobile fractions, as well as modal particle size. (b) Continuous textural curves, taken by horizon. Note how these curves more readily show the presence of a distinct mixed zone in this soil, which is manifested mainly as loess mixed into the underlying sand, rather than sand mixed upward into the loess. (c) Similar data for a soil formed in 35 cm of loess over sandy glacial outwash, but with perhaps a more abrupt LD. Adapted from Schaetzl and Luehmann (2013).

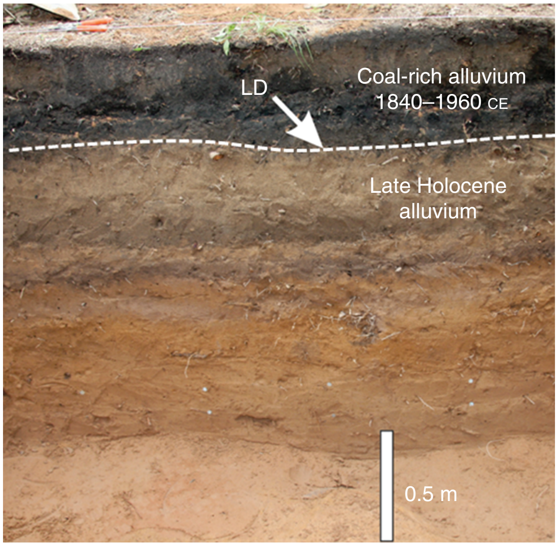

Figure 4 Historic-to-modern (1840–1960 CE) coal-rich alluvium, or "coal wash," overlying a late Holocene alluvial surface. The contact between the two materials marks an LD of both a lithologic and a temporal nature. This soil is located along Nesquehoning Creek in eastern Pennsylvania. Photo courtesy of G. Stinchcomb and M. Stewart.

Impacts of lithologic discontinuities on pedogenesis

LDs are globally widespread, and probably more common than many soils researchers recognize. LDs have been reported in loess and sand covers over glacial tills in relic periglacial environments across Europe, in volcanic soils, in sandy Atlantic and Gulf Coastal Plain soils, in the loess-mantled landscapes in North America, in soil complexes in Australia, and in highly weathered soils of the tropics. Because they are so extensive, and because changes in lithology or mineralogy that are indicated by an LD can influence the trajectory of soil formation and impact pedogenesis, the ability to detect LDs in soils and to distinguish between different parent materials is important for pedogenic studies. For example, the presence of LDs in the subsurface, particularly in fine-over-coarse layering, can influence soil hydrology, and may also inhibit the eluviation/illuviation of mobile soil constituents. Also, identification (or misidentification) of an LD can greatly affect interpretations of soil laboratory data, particularly in terms of gains and losses of soil constituents. For example, mass balance calculations, which are used to quantify soil volume changes and open-system transport of constituents into or out of the soil during pedogenesis, depend on an assumption of parent material uniformity, or absence of LDs.

New research directions on lithologic discontinuities in soils

Although traditional approaches to investigating LDs are important, Lorz and Phillips (2006) suggested that current "top-down" genetic models fail to fully account for a dynamic regolith in soil formation. They point out the need to evaluate both pedological and geological (polygenetic) processes in soil genesis studies. This approach is warranted, particularly when dealing with dynamic soil environments such as those in alluvial or other aggradational settings, areas of dust deposition, and places where historic-era anthropogenic materials have been added to the soil column. Recently, Stinchcomb *et al.* (2013) integrated the concept of *event stratigraphy* with the pedologic investigation of lithologically distinct, nineteenth- and twentieth-century alluvial coal deposits in eastern North America (Figure 4). Such deposits are becoming increasingly identified and mapped around the world, which will have important implications for biogeochemical changes to the Earth's surface, along with anthropogenic influences on deposition and erosion. This research underscores the need

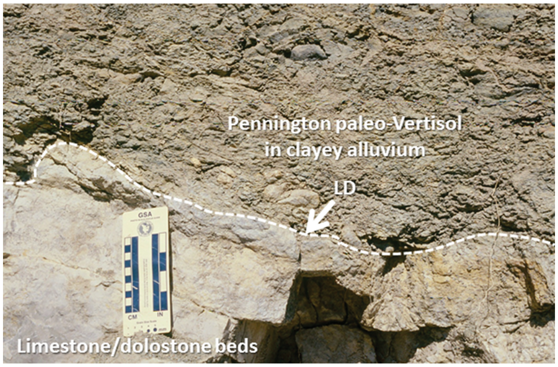

Figure 5 Photo of the Pennington paleo-Vertisol (325 Ma, Late Mississippian) overlying limestone/dolostone beds, separated by an LD. Paleosol profile located near Sparta, Tennessee. Photo courtesy of S. Driese.

to further investigate the nature of LDs as stratigraphic breaks separating Anthropocene-age sediments and older soils below.

Identifying LDs can also increase our understanding of soil genesis in lithified paleosols found in pre-Quaternary rock outcrops (Retallack 2001). In their study of Late Mississippian vertic paleosols in eastern Tennessee, Driese, Jacobs, and Nordt (2003) challenged the common assumption that nonpedogenic dolostone bedrock beneath paleosols represents the parent material for the soil. By applying a suite of pedogenic techniques, they make a strong case for a siliciclastic deposit as the soil parent material and, hence, the presence of an LD between the paleosol and dolostone (Figure 5). This type of research can increase our understanding of ancient soil genesis and depositional environments.

Conclusions

LDs are widespread, and therefore constitute an important component of most pedologic investigations. Deciphering the complexity and influence of LDs is critical in soil genesis studies because the trajectory of soil formation is greatly influenced by parent material. Traditionally, identification of LDs has yielded important information about the genesis of "modern soils." As the realm of pedology continues to expand, investigation of LDs will be instrumental in providing useful data on anthropogenic influences on local geomorphic settings, and in reconstructing ancient geologic depositional histories and soil-forming environments.

SEE ALSO: Soil mass balance; Soil taxonomy and soil classification; Soils and weathering; Soils in archaeological research; Soils in geomorphic research

References

Ahr, Steven W., Lee C. Nordt, and Steven G. Driese. 2012. "Assessing Lithologic Discontinuities and Parent Material Uniformity within the Texas Sandy Mantle and Implications for Archaeological Burial and Preservation Potential in Upland Settings." *Quaternary Research*, 78(1): 60–71.

Anda, Markus, D.J. Chittleborough, and R.W. Fitzpatrick. 2009. "Assessing Parent Material Uniformity of a Red and Black Soil Complex in the Landscapes." *Catena*, 78(2): 142–153.

Chapman, S.L., and M.E. Horn. 1968. "Parent Material Uniformity and Origin of Silty Soils in Northwest Arkansas Based on Zirconium–Titanium Contents." *Soil Science Society of America Journal*, 32(2): 265–271.

Driese, Steven G., Joseph R. Jacobs, and Lee C. Nordt. 2003. "Comparison of Modern and Ancient Vertisols Developed on Limestone in Terms of Their Geochemistry and Parent Materials." *Sedimentary Geology*, 157(1–2): 49–69.

Johnson, Donald L. 2008. "Reflections on the Nature of Soil and Its Biomantles." *Annals of the Association of American Geographers*, 95(1): 11–31.

Koppi, A.J., and D.J. Williams. 1980. "Weathering and Development of Two Contrasting Soils Formed from Grandodiorite in South-East Queensland." *Australian Journal of Soil Research*, 18(3): 257–271.

Lorz, Carsten, and Jonathan D. Phillips. 2006. "Pedo-ecological Consequences of Lithological Discontinuities in Soils: Examples from Central Europe." *Journal of Plant Nutrition and Soil Science*, 169(4): 573–581.

Retallack, Gregory J. 2001. *Soils of the Past: An Introduction to Paleopedology*, 2nd edn. Oxford: Blackwell.

Schaetzl, Randall J. 1998. "Lithologic Discontinuities in Some Soils on Drumlins: Theory, Detection, and Application." *Soil Science*, 163(7): 570–590.

Schaetzl, Randall J., and M.D. Luehmann. 2013. "Coarse-Textured Basal Zones in Thin Loess Deposits: Products of Sediment Mixing and/or Paleoenvironmental Change?" *Geoderma*, 192(1): 277–285.

Soil Survey Staff. 2010. *Keys to Soil Taxonomy*, 11th edn. Washington, DC: US Department of Agriculture, Natural Resources Conservation Service.

Stinchcomb, Gary E., R. Michael Stewart, Timothy C. Messner, *et al*. 2013. "Using Event Stratigraphy to Map the Anthropocene – An Example from the Historic Coal Mining Region in Eastern Pennsylvania, USA." *Anthropocene*, 2: 42–50.

Taboada, T., A.M. Cortizas, C. Garcia, and E.G. Rodeja. 2006. "Particle-Size Fractionation of Titanium and Zirconium during Weathering and Pedogenesis of Granitic Rocks in NW Spain." *Geoderma*, 131(1–2): 218–236.

Further reading

Evans, L.J., and W.A. Adams. 1975. "Quantitative Pedological Studies on Soils Derived from Silurian Mudstones: IV. Uniformity of the Parent Material and Evaluation of Internal Standards." *Journal of Soil Science*, 26(3): 319–326.

Karathanasis, A.D., and B.R. Macneal. 1994. "Evaluation of Parent Material Uniformity Criteria in Loess-Influenced Soils of West-Central Kentucky." *Geoderma*, 64(1–2): 73–92.

Norton, L.D., and G.F. Hall. 1985. "Differentiation of Lithologically Similar Soil Parent Materials." *Soil Science Society of America Journal*, 49: 409–414.

Phillips, Jonathan D., and Carsten Lorz. 2008. "Origins and Implications of Soil Layering." *Earth-Science Reviews*, 89(3–4): 144–155.

Sudom, M.D., and R.J. St Arnaud. 1971. "Use of Quartz, Zirconium and Titanium as Indices in Pedological Studies." *Canadian Journal of Soil Science*, 51(3): 385–396.