Chapter 15
Use of Soil Maps and Surveys to Interpret Soil-Landform Assemblages and Soil-Landscape Evolution

R.J. Schaetzl and B.A. Miller

Abstract Soils form in unconsolidated parent materials, which make them a key link to the geologic system that originally deposited the parent material. In young soils, i.e. those that post-date the last glaciation, parent materials can often be easily identified as to type and depositional system. In a GIS, soil map units can then be geospatially tied to parent materials, enabling the user to create maps of surficial geology. We suggest that maps of this kind have a wide variety of applications in the Earth Sciences, and to that end provide five examples from temperate climate soil-landscapes.

Keywords Soil surveys • Soil maps • Soil parent materials • Soil geomorphology • Soil landscapes • Lithologic discontinuities

15.1 Introduction

Soils form from (and in) unconsolidated parent materials. Parent material is one of the five main soil-forming factors (Jenny 1941), and thus pre-conditions soil development and the pedogenic system from the inception of soil formation. For example, soils forming in dune sand will never be clayey, and are likely to always be highly permeable. Similarly, soils forming in lacustrine clays will never be sandy. Glacial till parent materials are lacking in areas that have never been glaciated, and marine clays do not exist in interior, continental locations. By extension, proper interpretation of soils, as they exist today, can provide key links between them, the

R.J. Schaetzl (✉)
Department of Geography, Michigan State University, East Lansing, MI, USA
e-mail: soils@msu.edu

B.A. Miller
Department of Agronomy, Iowa State University, Ames, Iowa, USA

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soil landscape, and the geologic or geomorphic processes that emplaced the soil parent material at some time in the past (Ehrlich et al. 1955; Gile 1975; Schaetzl 1998). That is, soils can provide key information about past sedimentologic or geologic processes and systems, by virtue of their parent materials (e.g. Schaetzl et al. 2000).

Some parent materials overlie a previously formed soil, i.e. a buried paleosol (Follmer 1982; Schaetzl and Sorenson 1987). If the overlying parent material is thin, pedogenesis may "weld" the soil formed at the surface to the paleosol below (Ruhe and Olson 1980), which complicates both parent material interpretations as well as pedogenesis in the surface soil (Wilson et al. 2010). We provide this example only to note that, in this chapter, we will focus on the more common and straightforward situations, in which soils form in fresh and permeable parent material. These kinds of soils provide the best opportunity for establishing the linkages between soil type and character with the parent material type and the processes that emplaced that parent material.

Such examples abound. Many landscapes, especially those that have recently undergone recent glaciation, are rich in parent materials that are relatively unaltered and "fresh" at the time that pedogenesis began. Examples of such parent materials include dune sand, till, volcanic ash, and flood deposits. In most cases, this material is easily identified by excavating deeply, i.e. below the solum and into the C horizon. All of the materials mentioned above are unconsolidated, porous, and permeable. Hence, pedogenesis, largely driven by percolating water, can operate freely in such materials, and can begin immediately after $\text{time}_{\text{zero}}$. Thus, a clear and often indisputable link can be made between the soil and some form of past geologic/sedimentologic process.

Although much can also be gained from the proper and careful interpretation of soil parent materials on old, stable sites in continental interiors (Brown et al. 2003; Eze and Meadows 2014), most applications involving soil parent materials are found on younger landscapes. Young soils, e.g. Entisols and Inceptisols, resemble their parent materials most directly, because pedogenesis has had little time to operate and alter these materials. In these and other soils that are minimally weathered, soil parent materials can often be readily identified as to type. In older soils, however, especially highly weathered Oxisols and Ultisols, determining the type of parent material present at $\text{time}_{\text{zero}}$ can be more difficult, mainly because many of the primary minerals in such soils have been altered or destroyed by weathering. Also, erosion may have removed some of the material or brought in other materials from upslope or from upwind. Textures may have been changed by pedogenesis.

With this introduction in mind, we observe that the study of parent materials in soils has much to offer the geoscience, geomorphology, and even the landscape ecology community. Our focus will be on providing examples of studies or situations where careful examination of uniform parent material type and distribution can provide important information about the geomorphic attributes and history of the landscape.

We also provide one important caveat: many soils have formed in "stacked" parent materials, in which a thin layer of one parent material lies immediately atop a distinct but different parent material. The two parent materials are separated by a lithologic discontinuity (Schaetzl 1998). Although this situation sometimes makes parent material interpretations more difficult, it also often provides even greater opportunities for paleoenvironmental interpretation, because such soils can enlighten us about a depositional process or system (the lower material) that then changed to another type of system, i.e. twice the amount of information is potentially available. Examples follow in the text below.

15.2 Methodological Approach

The approach we present can be operationalized with a soil map and a digital elevation model (DEM). Both must be in digital form, so they can be manipulated in a GIS. Soil maps focus on surficial materials and are usually more detailed than available geologic maps due to investments in agricultural development and land valuation. Normally, we overlay the soil information on a hillshade DEM product, so that the soil information can also be matched to topography. For sites in the USA, digital soil data is provided by the Natural Resources Conservation Service (NRCS) web site via the Geospatial Data Gateway (http://datagateway.nrcs.usda.gov). Downloadable files from this site can be added to a GIS.

A key additional step is incorporating supplementary information into the GIS file. We normally code as many of the soil series as possible to parent material by using a two-step process. First, for each soil series we look up its official description on the NRCS web site (https://soilseries.sc.egov.usda.gov/osdname.asp), if we do not already know it. From the official series description, we note the parent material and code it into the GIS as one of several parent material classes, e.g. till, outwash, glacio-fluvial sediment, loess, lacustrine sediment, dune sand, residuum, and a few other, minor categories (Miller et al. 2008). For soils with loess and underlying sediment listed as the parent material, e.g. loess over till, the loess thickness and the type of underlying sediment can also be noted in separate fields.

It should be noted that the NRCS soil maps in the USA are very detailed, often produced at a scale of 1:15,840, resulting in maps that regularly subdivide parent material areas by changes in other soil forming factors. Therefore, interpreting these detailed maps for parent material generally results in an aggregation of map units. Although the relationship between soils and their parent materials is ubiquitous, the scale and purpose of the soil map could potentially deemphasize the parent material-related information available in the map.

The approach described here enables the user to display maps of parent material (and possibly loess thickness) in a GIS, and the data are matched nicely to topography. We have also added additional fields to the GIS attribute table, centering around soil texture, e.g. texture of the surface mineral (usually A) horizon, as well as its parent material (lowest horizon). We have also noted when the texture modifier on the lowest horizon contained the words “gravelly,” “cobbly,” or “stony,” allowing us to compile a data layer for soils that contain significant amounts of coarse fragments in their parent materials. The result is a digital map of surficial geology attributes with greater detail and coverage than is typically available from other sources.

15.3 Results: Analysis and Interpretation of Selected Examples

15.3.1 A Detailed Surficial Geology Map of Iowa, USA

This example illustrates how the methodological approach described above can efficiently convert soil survey information into a format customized for investigations of soil-landform assemblages and soil-landscape evolution over large areas.

In Iowa, surficial geology maps with a high level of detail are only available for a fraction of the state. In contrast, detailed soil maps are available for the entire state. Although the relationship between those producing the respective maps is strong and information is freely shared between the two groups (geologists and soil scientists), differences in disciplinary practices have left a gap in available map products. Notably, geologists here often use NRCS soil maps as base maps, but verify and enhance the information with consideration of deeper bore holes and interpretation for more specifics, e.g. age, about the respective geologic formation, stratigraphy, etc. These investigations require additional time and resources, which help explain the limited coverage of the surficial geologic maps produced in this way. Benefiting from the investment in land use and management information over the past century, detailed soil maps fully cover the state. However, they focus on the top 2 m, and only include a brief attribution of the parent material to the geology, as understood at the time of map production.

Using the methodological approach we described, Miller and Burras (2015) constructed a relational database for each of the soil series mapped in Iowa. Although the NRCS soil database does contain a parent material attribute field, it does not contain as much information as could be found in the geomorphic setting of the official soil series descriptions. However, even the official soil series descriptions often do not directly link the soil series to the recognized geologic formation and geomorphic landform; some interpretations are required. For example, the Clarion soil is described as having calcareous till as parent material, occurring on convex slopes of gently undulating to rolling Late Wisconsin till plain, and with loam to clay loam textures. These characteristics, combined with the geographic extent of the soil series, clearly match what geologists would recognize as the Dows Formation. Additional geomorphic information is gained from soils mapped in the same catena. The Webster soil is generally mapped in the swales below Clarion delineations and is described as being formed in glacial till or in local alluvium derived from till. Thus the spatial juxtaposition of these two and similar soils indicates the pattern of hillslope erosion and basin fill processes along with landform structure (Fig. 15.1b).

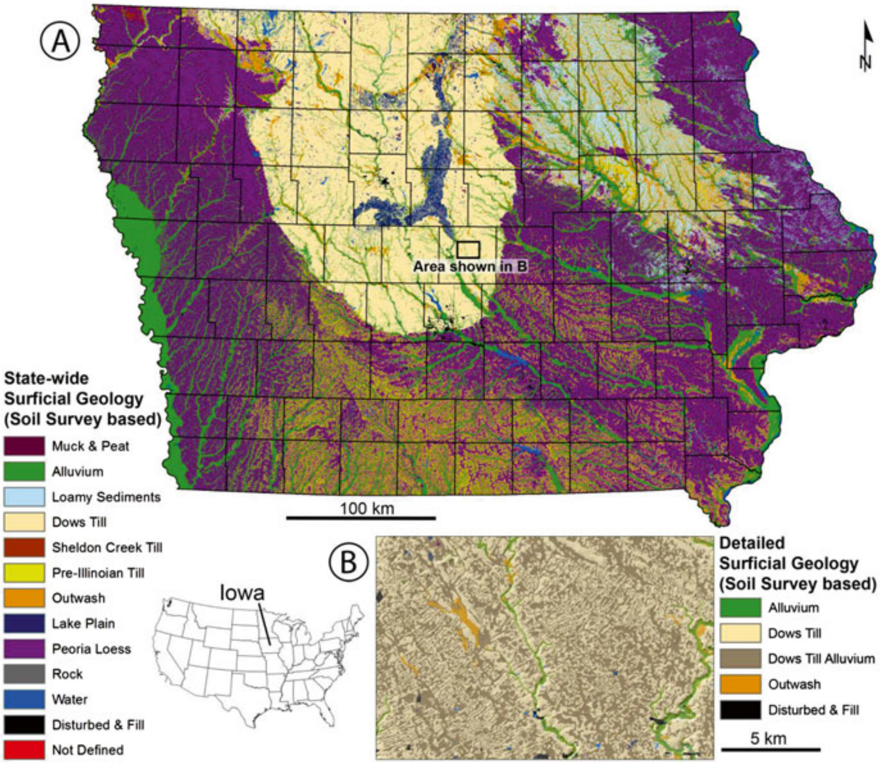

Fig. 15.1 Surficial geology maps for Iowa, USA, based on digital soil survey maps and interpretation of official soil series descriptions. After Miller and Burras (2015). (**a**) Although the same soil series in different counties are technically different soil map units, they are still constrained by definitions set in the official series description. This relationship allows for several county-scale maps to be efficiently translated to desired attribute classes. (**b**) The attribute scale can be customized by the user to include as much or as little detail as needed for the map's purpose. At this larger cartographic scale, it is useful to distinguish soils formed in till of the Dows Formation versus soils formed in the slopewash alluvium derived from that till. Patterns of parent material at this scale are complemented by the elevation hillshade that makes landscape structure more visible

Creating this translation between information recorded in the soil survey to terms useful for geomorphic purposes requires knowledge of the local geology and sometimes careful consideration of context. Nonetheless, after evaluating 863 soil series across Iowa, Miller and Burras (2015) leveraged the soil maps to efficiently and accurately create a detailed surficial geology map covering 145,700 km^2 (Fig. 15.1a). Although the resulting map does not contain as much attribute information as the maps produced by geologists, 67–99 % of the pixels in it are in agreement, and the map provides considerably more spatial information and detail than the geology maps. This level of information is often vital to environmental and geomorphic research.

15.3.2 The Loess-Covered Landscapes of Western Wisconsin, USA

This example illustrates how detailed soil surveys can help determine loess thicknesses across a landscape. Loess covers most upland sites in western Wisconsin (Hole 1976). Most of this loess originated from the Mississippi River, which was a major conduit for silt-rich glacial meltwater and which forms the western boundary of the state (Scull and Schaetzl 2011). In most cases, the loess overlies bedrock or bedrock residuum, as this part of the state has never been glaciated.

Here, soil map units in county-scale soil maps are described with a typical loess thickness and thus the maps can provide detailed information about loess thickness and distribution (Fig. 15.2). Some soil series are formed in "thick" loess, i.e. thicker than the typical 60-in. profile description, and in these cases, loess thicknesses provided by the soil maps represent only a minimum value. Most soils, however, are formed in <60 in. of loess over another parent material, e.g. residuum, bedrock, colluvium, or alluvium. For example, the official description for the Dubuque series states that it "consists of moderately deep, well drained soils formed in 46–91 cm (18–36 in.) of loess and a thin layer of residuum from limestone bedrock or reddish paleosol…" Another common soil in the area, Norden, is "formed in loess and in the underlying loamy residuum weathered from glauconitic sandstone." Note that the parent material description for Norden soils does not include loess thickness. In this case, one must examine the official profile description to determine the typical loess thickness. Norden soils have the following typical horizonation: Ap 0–8 in., Bt1 8–11 in., Bt2 11–20 in., 2Bt3 20–25 in., 2Bt4 25–33 in., 2Bt5 33–37 in., and 2Cr 37–60 in.. All horizons above the lithologic discontinuity at 20 in. are silt loam in texture, as is typical for loess. Thus, where mapped, Norden soils can be assumed to have formed in approximately 20 in. of loess.

This type of procedure can be adopted for all soils in the region, and after the loess thicknesses have been entered into the GIS, detailed maps of loess thickness can be readily created. Figure 15.2 illustrates this approach at a variety of scales. This approach has been successful in a number of loess studies performed in the upper Midwest, USA (Jacobs et al. 2011; Luehmann et al. 2013; Schaetzl and Attig 2013; Schaetzl et al. 2014). Such data are extremely valuable for determining the source areas for loess, which is usually thickest near its source. These types of maps are also useful for guiding land management decisions.

15.3.3 The Recently Deglaciated Landscape of North-Eastern Lower Michigan, USA

This example illustrates how detailed soil surveys can help interpret the geomorphic history of a recently glaciated landscape. Northeastern Lower Michigan was deglaciated roughly 12,300 cal years ago (Larson et al. 1994). At that time, ice associated

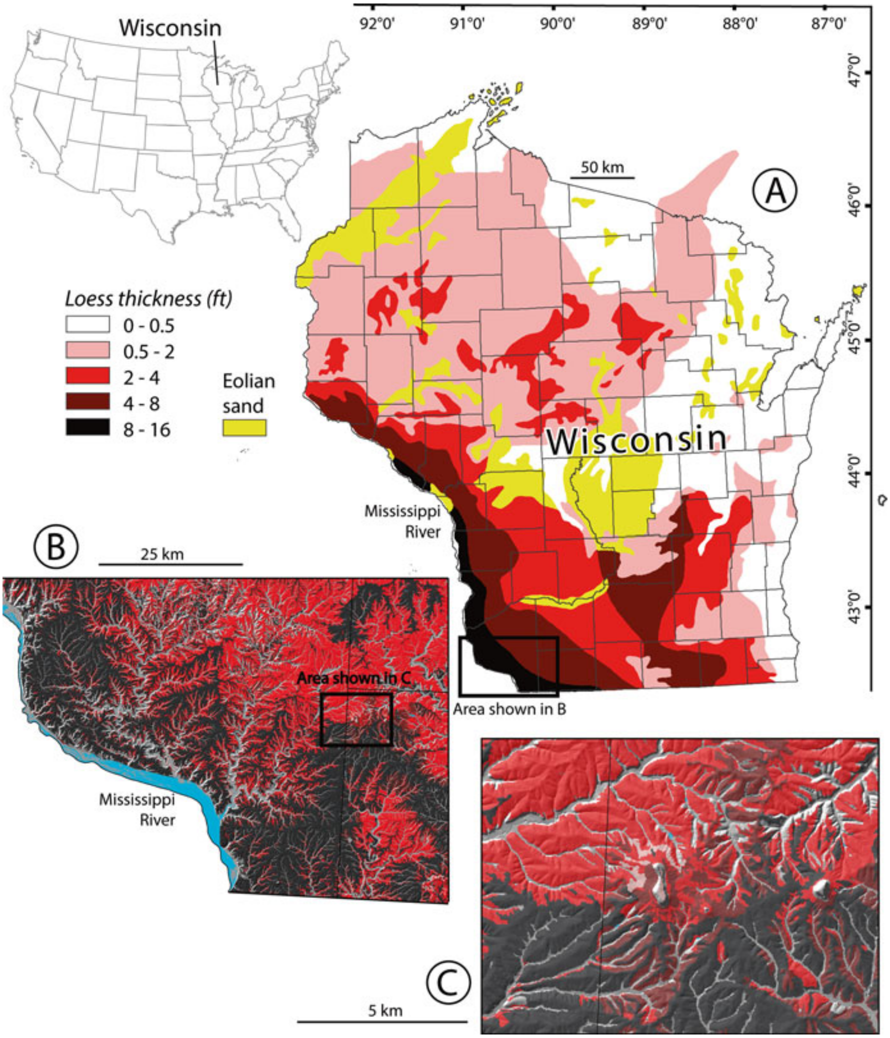

Fig. 15.2 Distribution and thickness of loess and eolian sand across Wisconsin, USA; the loess thickness color legend is similar for all three maps. (**a**) Regional loess thickness, and legend data for loess thicknesses. After Hole (1950) and Thorp and Smith (1952). (**b**) Loess thickness for south-western Wisconsin, as determined in a GIS by using soil series descriptions. (**c**) A more detailed map of loess thickness, created using similar methods but shown at a larger cartographic scale

with the Greatlakean advance of the Laurentide ice sheet had moved rapidly into the region from the northwest, out of the Lake Michigan basin. The ice then stagnated and is assumed to have melted in place (Schaetzl 2001). Associated with the Greatlakean advance and the stagnant ice margin were several shallow, short-lived, proglacial lakes, or at least this has frequently been assumed. The Greatlakean advance left no conspicuous end moraine, and thus the exact location of the outer limit of the ice advance is not known, and has been the subject of considerable debate (Melhorn 1954; Burgis 1977; Schaetzl 2001). Thus, it is conceivable that soil data (maps) may be able to help resolve the extent of this ice advance, as it has been shown to do elsewhere (Millar 2004).

Fortunately, detailed (1:15,840) soil maps and 10-m DEMs exist for this area (Knapp 1993). These maps can be used to help interpret the most recent sedimentary systems that were operational during deglaciation, because post-glacial modifications to these materials have been minimal. Topographic data are not particularly insightful for determining the limit of the Greatlakean ice in this area, because the glacier left no end moraine. However, because water presumably ponded in front of the ice, the northernmost limits of clayey glacio-lacustrine sediment can suggest a likely glacial margin (Fig. 15.3). Indeed, Schaetzl (1991) used this type of data as well as some others, gleaned from soil parent material descriptions, to infer an ice margin just to the north of large areas of glaciolacustrine sediment. Similar sediment behind (north of) this inferred margin is associated with a later, high-level paleolake and is thus clearly not associated with Greatlakean ice (Fig. 15.3).

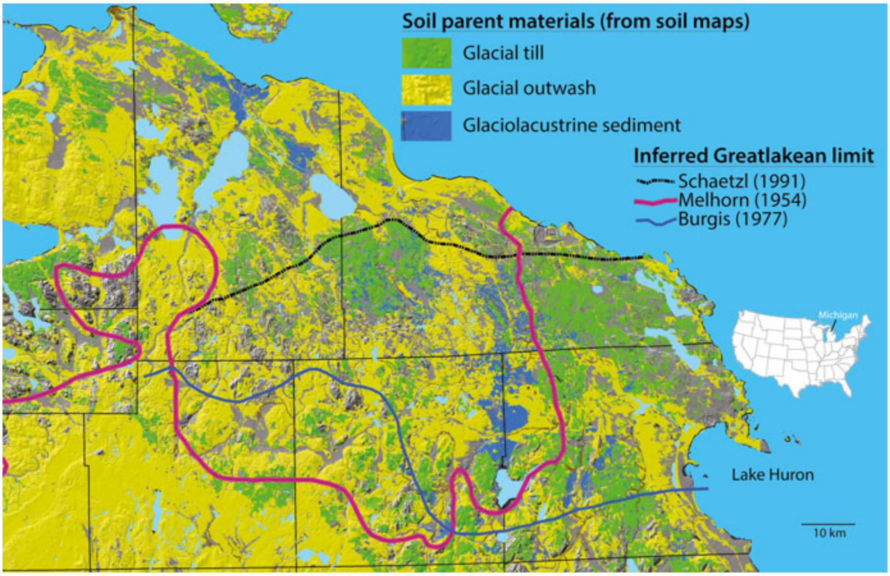

Fig. 15.3 Soil parent materials in north-eastern Lower Michigan, as determined from soil maps and the official soil series descriptions, in a GIS. Also shown are the inferred limits of the Greatlakean ice advance, ca 12,300 cal years ago

15.3.4 An Enigmatic Soil Parent Material on the Outwash Plains of Southwestern Michigan, USA

This example illustrates how field and laboratory data can help determine the parent materials for soil series that have only been described "generically", and how soils with a lithologic discontinuity can potentially provide excellent information about past changes in depositional systems.

Many soils on the low relief outwash plains of southwestern Michigan have loamy upper profiles, despite (as expected) being underlain by coarse, sandy outwash. The origin of this upper material has long been an enigma to soil scientists and geologists alike. It was too thin to be a separate layer of glacial till, and too fine-textured to be glacial outwash.

The main soils that occur on these outwash surfaces are in the Kalamazoo and Schoolcraft series. Kalamazoo soils are described as having formed in "loamy outwash overlying sand, loamy sand, or sand and gravel outwash on outwash plains", whereas Schoolcraft soils have "formed in loamy material over sand or gravelly sand on outwash plains." Typically, this generically described "loamy material" is 40–90 cm thick, and has a diffuse lower boundary. For lack of a better term, we refer to this layer as a loamy mantle.

Soil textural data, as determined by laser diffraction, from two representative pedons (Fig. 15.4) illustrate that the outwash at depth is dominated by sand, whereas the loamy mantle is either silty (Fig. 15.4a) or has a distinctly bimodal particle size distribution – with both sand and silt peaks (Fig. 15.4b). Textural data for the loamy mantle (not shown here) are almost always bimodal, and the sand peak aligns with the same peak in the outwash below. These data suggest that the loamy mantle is a mixed sediment – sand from the outwash mixed with a silty sediment above, but of unknown origin.

In a recent study, Luehmann et al. (2016) sampled and determined the textural distributions of 167 locations across the outwash plains of southwestern Michigan. The loamy mantle in almost all of these soils had a bimodal particle size distribution. Using a "filtering" method first reported in Luehmann et al. (2013), they were able to isolate the textural pattern of the original, silty sediment, and map its characteristics across the region. Spatial patterns for the loamy mantle were easily interpretable, illustrating that the silty material is silt-rich loess, and that it has been subsequently mixed with sand from below by pedoturbation. The mantle is thickest near a large meltwater valley that existed during deglaciation (Fig. 15.5), suggesting that it was the main loess source. Textural data of various sorts (not shown here) also confirmed that the loess that comprises the loamy mantle gets finer-textured and better sorted to the east, away from this channel. This type of spatial pattern is typical for loess.

This work showed that the heretofore enigmatic mantle on the outwash plains of southwestern Michigan is silt-rich loess that was derived from the Niles-Thornapple Spillway and its major tributary channels. The Spillway was active for approximately 500 years, between ca 17,300 and 16,800 cal years ago, carrying silt-rich meltwater. This study highlights the fact that not all soil parent materials are

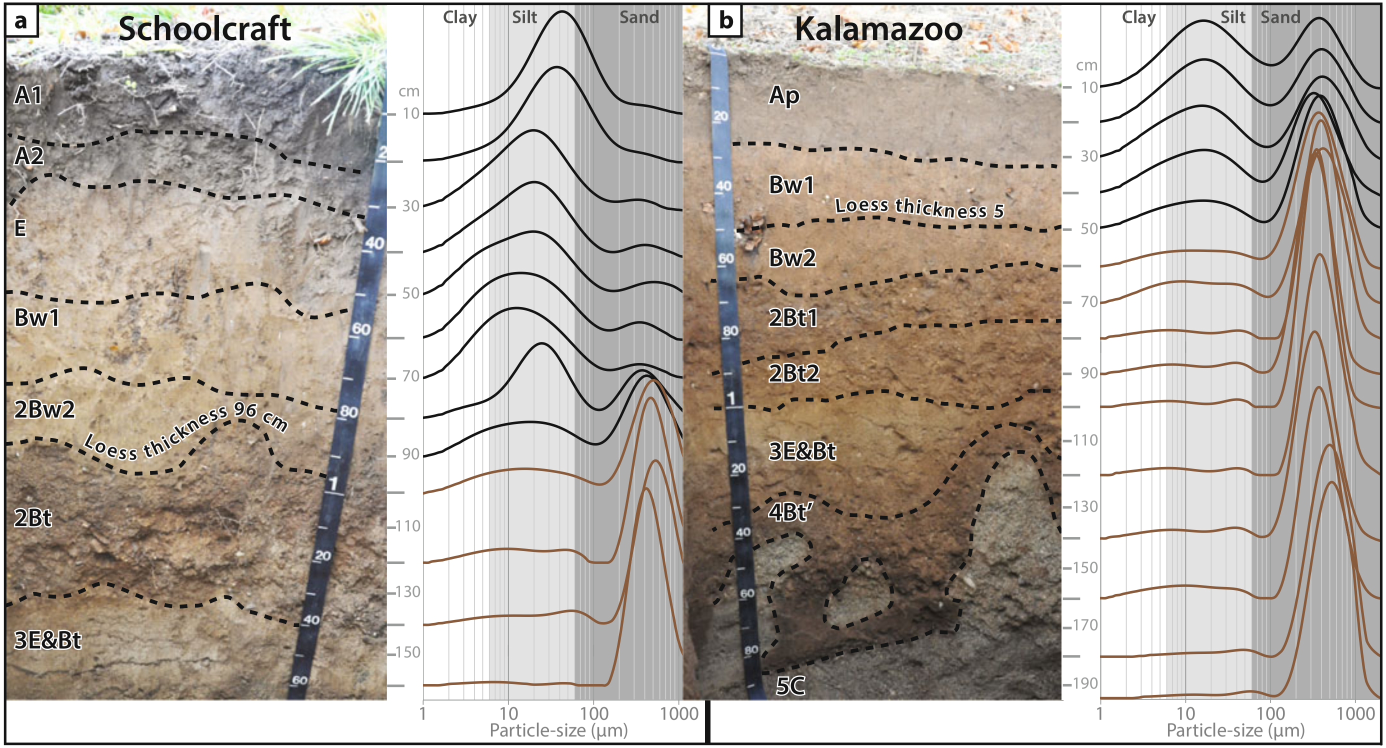

Fig. 15.4 Photos, with horizon boundaries marked, and textural curves for a (**a**) Schoolcraft and a (**b**) Kalamazoo soil profile (After Luehmann et al. 2016)

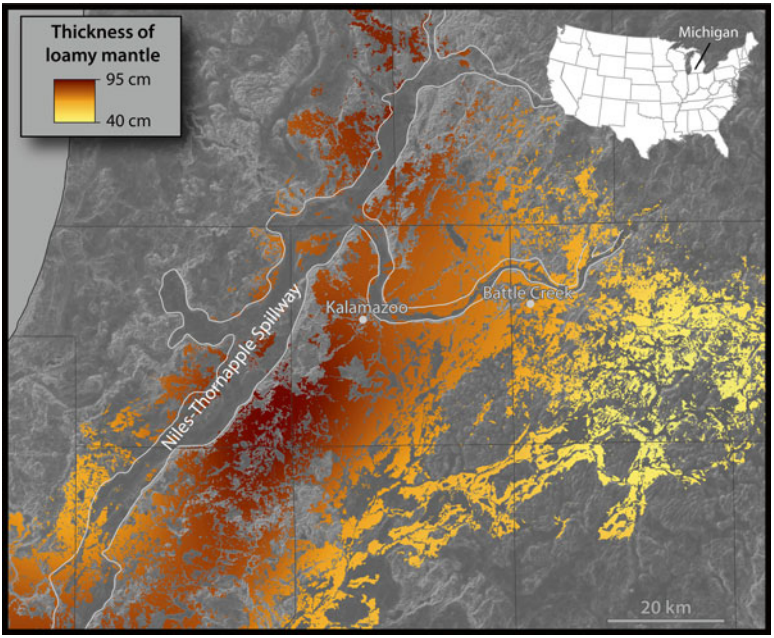

Fig. 15.5 Interpolated map, using ordinary kriging, of the thickness of the upper sediment, which is interpreted as loess, on the outwash plains of southwestern Michigan. Interpolated data are shown only in areas where outwash soils with a loamy mantle are mapped (After Luehmann et al. 2016)

"obvious" or stated in their official series descriptions, but with some work the genetic origin of the sediment can often be determined.

15.3.5 A Watershed with a Complex Geology in the Western Grand-Duchy of Luxembourg

This example illustrates how the use of detailed soil surveys for interpreting soil-landform assemblages can also be applied to non-glaciated landscapes, and thus can provide key information for other scientific inquires. In particular, relationships between bedrock parent materials, soil morphology, and indicative vegetation patterns can provide important information for hydrological modelling.

The available geologic map (1:25,000) for the Huewelerbach experimental catchment in western Luxembourg shows the locations of several geologic formations in the watershed, including units of sandstone, limestone, and claystone. Some of these formations have alternating layers of marl. The catchment also contains a colluvial-alluvial complex at the bases of many hillslopes. Complicating the spatial distribution of these formations is a fault that is believed to run mostly northwest of, and parallel to, the main trunk stream. Because of this fault, the hydrologic characteristics of the opposing hillslopes are not identical. Parent materials yielding soils with B and/or C horizons consisting of heavy clay lead to an environment dominated by overland flow. In contrast, parent materials yielding thicker soils with sandy to silty-sandy textures facilitate better infiltration and deeper percolation, and hence more lateral subsurface flow and less surface runoff.

Juilleret et al. (2012) conducted a soil survey of the catchment, classifying 6 soil map units with 70 hand auger drillings to a depth of 110 cm. They subsequently verified the relationships between the properties of the soil profile with the parent material, using a mechanized coring machine to sample a maximum depth of 400 cm at 12 locations along two transects. Using the World Reference Base (IUSS 2006) to classify the soils, they found Calcisols corresponded with geologic formations containing units of marl, Podzols with a sandstone formation that lacks marl layers, and Colluvisols with the colluvial-alluvial complex. The Podzols correspond with the occurrence of conifers, whereas the other soils occur under deciduous vegetation. Under grasslands, Pelosols and Brunisols were identified. In the Bw and C horizons of these soils, a distinctive sequence of a red clayey layer and a grey sandy layer helped reveal the presence of an additional geological formation recognized in the area, but not previously depicted on the existing geologic map. For this catchment of soils formed in a variety of sedimentary rocks, standard soil survey methods were able to improve upon the information available from the standard geologic map. This information was valuable for improving the mapping of geologic formations and for providing key information for modelling hillslope hydrology.

15.4 Summary and Conclusions

The relationship between soils and the material in which they form connects soil survey maps and geological maps. Different information collected for, and portrayed on, the respective maps – due to differences in purpose, focus, or resources – can assist investigations in other disciplines. This multiple utility is especially true for studying soil-landform assemblages and soil-landscape evolution.

Although the pedogenic pathway of a soil is constrained by the parent material, interpretation of soil properties to infer parent material origins needs to carefully consider the potential for complicating factors. For example, other factors of soil formation can alter the material, especially over long periods of time. Also, buried paleosols within the modern soil profile can result in new horizons with properties that are influenced by the interaction of modern pedogenesis with the properties of the old horizons.

Because of the interconnection between soils and geology, one should beware of the potential for circular reinforcement of information. The reason soil maps often provide more spatial information than available geologic maps is because of the greater spatial density of field sampling and greater availability of easily-observed covariates for spatial prediction. However, soil mappers also use geologic maps as one of the base maps for their soil maps (Miller and Schaetzl 2014). Therefore, the potential exists for an error on one type of map to become circularly reinforced. Only field investigation is capable of catching these problems and better informing all maps.

In many cases, soil maps and surveys –together or singly –provide information that is not available from any other source, particularly with regard to spatial detail and characteristics of the top meter of unconsolidated material. Therefore, these maps often represent an untapped potential for improving our geomorphic understanding of landscapes (Brevik and Miller 2015).

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