

# Morphologic evidence of lamellae forming directly from thin, clayey bedding planes in a dune

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## Abstract

An excavation in a sand dune in southern Michigan revealed numerous, thin (< 3 mm) clay-enriched strata between otherwise weakly stratified, clean, fine sand deposits. The parallelism of both the sandy and clayey strata suggest that they have direct geologic origins, having been deposited during formation of the dune. Although the clay-enriched strata and the intervening sandy layers are both within the sand textural class, the former contained between 3.0% and 5.4% clay, and the latter < 1.8% clay. In areas of preferred leaching, such as below vertical root traces, the clayey strata thin out and become absent, or “bend downward”, become wavy and contorted, and take on the appearance of typical pedogenic lamellae. These observations support a theory of lamellae genesis that is both pedogenic and geogenic. Thin sedimentary strata may be pedogenically “transformed” into features that would normally be described as (entirely pedogenic) lamellae. Thus, many thin lamellae in Pleistocene-aged soils may simply be deformed and pedogenically altered sedimentary strata. This conclusion has implications for the nature and cyclicity of clay deposition in environments where thin lamellae are common in sandy soils. © 2001 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

A lamella is an illuvial soil horizon less than 7.5 cm thick that contains an accumulation of oriented silicate clay on or bridging sand and silt grains (Soil

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Survey Staff, 1999). Also referred to as laminae, pseudofibres, clay bands and covarvany, their presence is commonplace in coarse-textured soils worldwide (Host et al., 1988; Host and Pregitzer, 1992; Prusinkiewicz et al., 1998). Commonly, sandy pedons contain several lamellae (Bt horizons) separated by horizons containing less or no clay (Robinson and Rich, 1960). Lamellae are typically recognized by having higher chromas, redder hues, and/or lower color values, than the adjacent eluvial horizons (Van Reeuwijk and de Villiers, 1985). They usually appear as thin “clay bands”, which often have wavy upper and lower boundaries, and are not always laterally continuous. Lamellae commonly occur in eolian sand or sandy alluvium (Kemp and McIntosh, 1989).

In this paper, I present and describe morphologic features from within a sand dune that resemble traditional lamellae, but which overlie and, in some situations merge into, thin, parallel, clay-enriched, geological strata. The latter are original bedding/stratigraphic structures and not pedogenic in origin. Therefore, the purpose of this paper is to examine morphologic evidence that sedimentary strata may, in some instances, be *genetic precursors to lamellae*. I will show that thin lamellae can, in fact, be polygenetic features, with initial *geogenic* origins followed by *pedogenic* alteration and overprinting. In so doing, I present a hypothesis on lamellae genesis.

## 2. Genesis of lamellae

The genesis of lamellae is poorly understood and controversial (Wurman et al., 1959; Dijkerman et al., 1967; Gray et al., 1976). Gile (1979), Bond (1986), and Kemp and McIntosh (1989) pointed out that thin lamellae could be formed wholly by infiltrating water via pedogenesis. This “pedogenic theory” of formation implies that the clay in the bands is illuvial, either from the entire solum above or from the eluvial zone immediately overlying the lamella (Wurman et al., 1959). Clay in lamellae is presumed to have been deposited at subtle textural discontinuities (Bouabid et al., 1992), at the lower limit of wetting fronts, or in calcareous zones (Van Reeuwijk and de Villiers, 1985; Schaetzl, 1992). Incipient lamellae formed in this manner then may act as filters and gain additional clay when clay–water suspensions pass through them during future infiltration events (Gile, 1979; Soil Survey Staff, 1999). Eventually, clay may be stripped from lamellae by infiltrating water and translocated to lamellae below (Van Reeuwijk and de Villiers, 1985). Evidence in support of the pedogenic theory of lamellae development includes the following: (1) lamellae that cross bedding planes, (2) absence of lamellae deep within and below the profile (C horizon) and in the uppermost eluvial zone (E horizon), (3) increasing lamellae development (thickness, color and number) in soils of increasing age (Gile, 1979; Berg, 1980; Prusinkiewicz et al., 1998), and (4) the clear, sharp

upper boundaries and lower, ragged (presumably degrading) boundaries of lamellae (Van Reeuwijk and de Villiers, 1985). Most proponents of the purely pedogenic origin of lamellae studied soils in which the lamellae are thin (typically < 1 to < 2 cm in thickness).

In other situations, usually involving thicker lamellae, a geologic origin is inferred or presumed. Evidence in support of a geologic origin includes situations where the lamellae or clay bands (1) conform to bedding planes, (2) are too thick to have been formed by pedogenesis (i.e., in young soils), (3) do not conform to the land surface (i.e., are closer to the surface in some places than others), (4) underlie a zone so devoid of clay as to preclude it as a clay source, and/or (5) occur at great depth (Robinson and Rich, 1960; Hannah and Zahner, 1970; Gray et al., 1976).

Lamellae occurring at abrupt or even subtle lithologic contacts are more difficult to interpret. These features could be geologic, having been deposited at the contact as the environment of deposition or the energy of the depositional system changed subtly. Alternatively, there is ample evidence in support of the notion that downwardly moving clay, in suspension, will be preferentially deposited at lithologic contacts (bedding planes, of sorts), where wetting fronts “hang” momentarily (Van Reeuwijk and de Villiers, 1985; Bouabid et al., 1992).

Adding to the confusion is the pedogenic “timing” of lamellae formation. Clay illuviation may form incipient textural bands while sandy parent materials are accumulating. These lamellae may then be buried by additional sediment (Kemp and McIntosh, 1989). Under this model, such deep lamellae are assumed to be relict and “isolated” from surficial processes (Schaetzl and Sorenson, 1987). Gray et al. (1976) suggested just such an origin for deep textural bands (3 to 50 mm in thickness) in eolian sand in Oklahoma. The presence of these bands was explained not by contemporary pedogenesis but by (paleo)infiltration events translocating some clay downward during deposition of the parent material.

The above review suggests that lamellae may form in different ways, i.e., they may be an example of equifinality, and that lamellae may be polygenetic (e.g., Johnson and Watson-Stegner, 1987; Eghbal and Southard, 1993). The thoughts of the Soil Survey Staff (1999, p. 82) on lamellae genesis are paraphrased below.

Evidence indicates that lamellae form initially in (stratigraphic) bedding planes. As used here, bedding planes are very thin layers with finer soil particles and smaller pore spaces than the materials above and below, deposited during a time of lower depositional energy. Wetting fronts can only penetrate these bedding planes at or near saturation. Any clay suspended in the soil solution during such an event is then deposited, reducing the pore size within the finer stratigraphic layer. Each succeeding wetting front reduces the pore size even further and “lamellae form” (emphasis is mine).

The text above suggests that lamellae form at bedding planes, rather than from deformation of *existing structures* at bedding planes. The Soil Survey Staff also appears to suggest that clay bands should only be referred to as “lamellae” after they have been affected by pedogenesis, in this case, by wetting fronts carrying suspended particles. Thus, lamellae formed under the above genetic scenario would be pedogenic.

Often soil profiles with lamellae can be subdivided into three zones, in which the lamellae are presumably in different stages of development. The text below refers to this issue and is, again, paraphrased from the Soil Survey Staff (1999, pp. 82–83).

Lamellae nearer the soil surface (upper zone) generally have the least concentration of clay and have the faintest color contrast from the overlying eluvial horizon. These lamellae are generally more wavy and discontinuous than those below. Lamellae in the middle zone appear to have the highest concentration of clay near the top of each lamella. In the lower part of these lamellae, some sand grains are devoid of clay and some have only thin clay coatings, similar to lamellae in the upper zone. The deepest lamellae are commonly very thin and not very wavy. Parallel to each other, they may be, in fact, sedimentary strata or bedding planes (emphasis is mine).

Clay is moved from upper to lower lamellae. Clay is stripped from the lower part of one lamella and redeposited in the top of the next lower lamella; lamellae thicken as clay is added to their tops.

Based on the above observations, lamellae may change from continuous, linear, parallel features at depth, to wavy, discontinuous features nearer the soil surface. Eluviation of clay from the uppermost lamellae seems to be the most likely reason for the loss of clay and discontinuous nature of the uppermost lamellae.

Loss of clay from its base, coupled with additions of clay to the top of a lamella, causes it to move away from the bedding plane from which it originated. The stripping of clay from the lower part of a lamella and redeposition in the top of the next lower lamella is a continuation of this movement upward and away from the bedding plane. Because the movement of each lamella upward is not uniform throughout its extent, lamellae are wavy rather than smooth like the bedding planes from which they originated. Branching in lamellae occurs where a part of a lamella has moved up more rapidly than the overlying part of the next higher lamella and they become joined in this part. This is further evidence that lamellae form upward and that the movement is not uniform (Soil Survey Staff 1999) (emphasis is mine).

The notion that lamellae form from/within original bedding planes and then migrate upward as clay is translocated downward (see above) is a theory that

was first advanced by Van Reeuwijk and de Villiers (1985) and has since been adopted by the Soil Survey Staff (1999). This study is the first to examine and test that theory.

### 3. Study area

The study site is located on a sand dune in Mason County, Michigan (Fig. 1). In Michigan, small fields of inland sand dunes (“sand ridges” of Taylor, 1990) are not uncommon on flat landscapes, even if those landscapes are wet (Arbogast et al., 1997). This particular dune is part of a ridge overlying a till plain of low relief. The ridge itself, located in Section 25 of T20N, R17W, attains heights of 6–8 m (Fig. 1).

When first encountered, the dune had been “scalped”, i.e., the topmost few m had been removed. At present, the remaining sand is being removed for construction-grade materials, exposing a 2 m vertical face (Fig. 2). This face is a profile from deep (> 2 m below the original surface) within the C horizon of a soil originally mapped as Grattan sand (sandy, mixed, mesic Entic Haplorthods) (Johnson, 1995). In Mason County, Grattan soils are mapped in sandy, well-drained landscape positions, where lamellae are *not* present. If lamellae had been present within 150 cm of the surface, the site would probably have been mapped within the Coloma series (mixed, mesic Argic Udipsamments) (John-

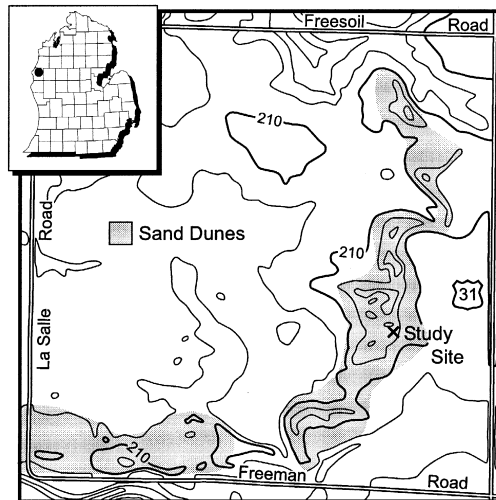


Fig. 1. Part of the Kings Corners (1:25,000) topographic map, near the study site in Mason County, Michigan. Contour interval is 3 m. Distance between Freesoil Road and Freeman Road is one mile.

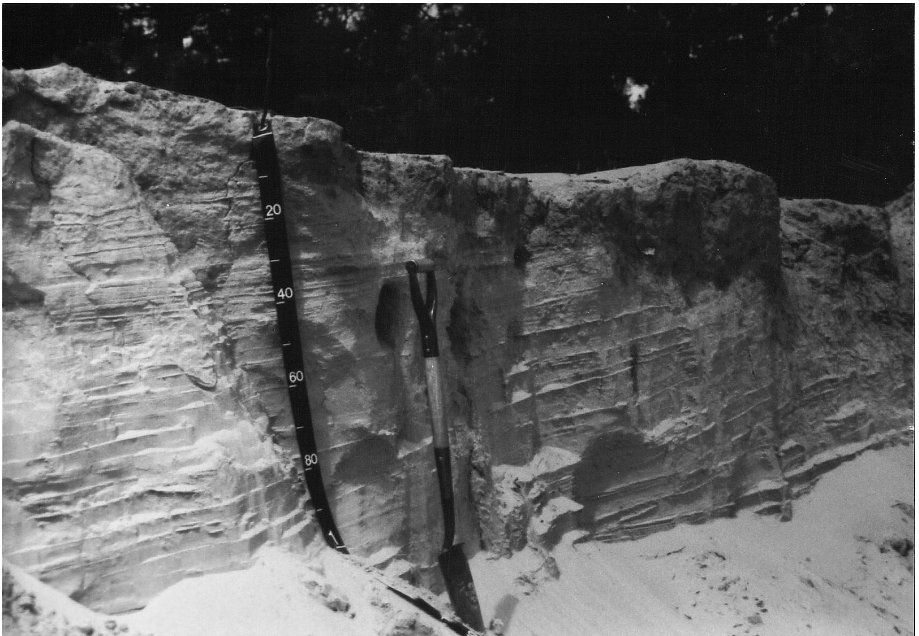


Fig. 2. Photograph of a small section of the profile face at the study site, showing the “scalped” dune and the recent cut into the C horizon of the dune. Marks on the tape are in cm and represent depths from the top of the “scalped” dune surface, not the original top of the dune.

son, pers. comm., 1998). Thus, any lamellae currently present on the face probably occurred at least 2 m below the *original* soil surface.

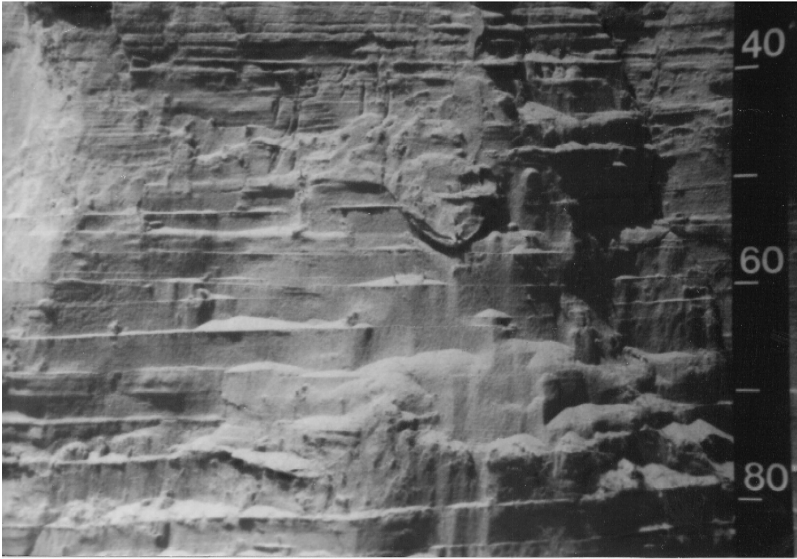
#### 4. Methods

At the dune, various profiles were inspected, examined, and numerous photographs taken of the original stratification (sandy and clayey strata). Samples (five replicates) were then taken of thin, clay-enriched strata exposed at various locations along the dune face, where they were sufficiently thick to

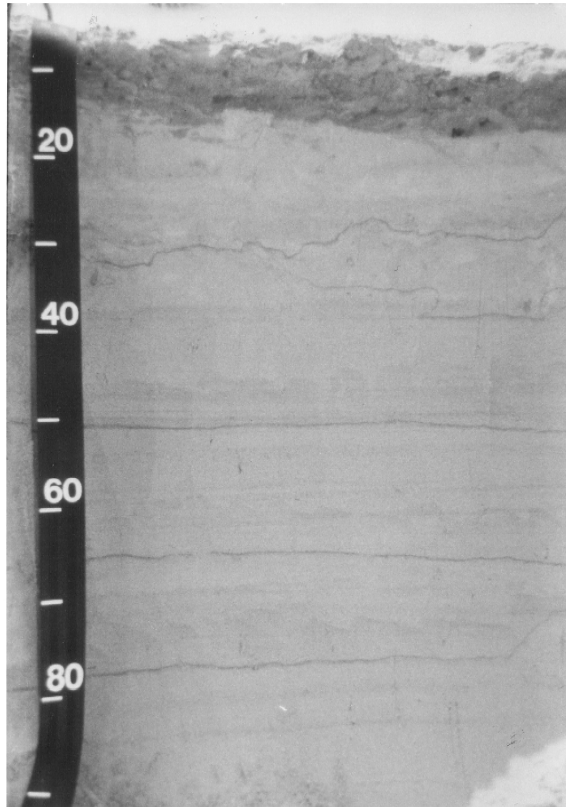
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Fig. 3. (A) Photograph of the C horizon, > 3 m below the surface of the dune. Scale shown on the photograph is from the top of the “scalped” dune surface, not the original top of the dune. Linear, clay-enriched strata are evident in the photo and act as slightly more resistant “shelves”. Loose sand has accumulated on top of the clayey strata where they form such shelves. (B) Stratification deep within the sand dune. The face has been scraped clean to better reveal the characteristics of the bedding. Near the top of the profile the strata take on a wavy appearance, more typical of lamellae. As above, the scale shown on the photograph is from the top of the “scalped” dune surface, not the original top of the dune.

A



B



permit sampling. Standard particle size analysis (pipet) was run on these samples (Soil Survey Laboratory Staff, 1996). Bulk samples were also taken in triplicate from the sandy zones between the clayey strata. The samples were air-dried and the sand fraction isolated by dispersion (as above), followed by washing through a 53- $\mu\text{m}$  sieve. Sand splits were determined on the dry sands, using sieves of 2.0, 1.4, 1.0, 0.71, 0.5, 0.355, 0.25, 0.18, 0.106, and 0.053 mm.

## 5. Results and discussion

The lower part of the dune, within the C horizon, consists of perfectly laminar, bedded sand with thin, interbedded, clay-enriched strata of obvious geologic origin (Fig. 3A and B). These strata are usually less than 3 mm in thickness, and contain 3.0–5.4% clay. The cleaner sand layers between are 5–30 cm thick and contain 0.0–1.8% clay. No sample, either from the sandy layers or the clay-enriched strata, contained more than 0.3% silt. All samples classify as “sand” in texture. Grouped together, all samples were dominated by medium and fine sands, containing 46.4–61.1% medium sand, and 28.7–41.8% fine sand. Very coarse sand was not present in any sample. The clayey strata had slightly higher mean values for coarse (27.5 vs. 16.2%) and medium sand (56.7 vs. 53.5%) contents, and slightly less mean fine (32.4 vs. 36.8%) and very fine sand (50.1 vs. 72.6%), than did the clay-poor, sand layers.

At most places deep within the dune, the clay-enriched strata retain their original sedimentological characteristics; the reddish, clay-rich beds are restricted to obvious bedding planes (Fig. 3A). Near the surface, however, similar strata become convoluted and wavy; they cross-cut bedding planes and their parallelism is lost (Fig. 3B). This tendency generally agrees with the theory proposed by the Soil Survey Staff (1999), outlined above. Waviness of lamellae is best expressed near sites of preferential flow, or preferred leaching, such as below old root traces (Fig. 4). These morphologic data demonstrate that clay, originally deposited in bedding planes, is capable of being translocated and redeposited as thin, wavy lamella, rather than being widely dispersed among the matrix.

The Soil Survey Staff (1999) suggested that most of the clay translocated out of a bedding plane is deposited in the upper parts of the lamella immediately below, causing lamellae to gradually grow upward by deposition on their upper surfaces and loss of clay from their lower surfaces. Evidence in support of this process was not encountered at the Mason County dune. Rather, I observed strong evidence that (1) geologic strata were being pedogenically “pushed” downward, especially beneath sites of preferential flow, and (2) the clay translocated out of original geologic strata may illuviate to form new lamellae, rather than simply being deposited on preexisting, lower lamellae. Morphologic data from this site suggested that most of the clay translocated out of a bedding



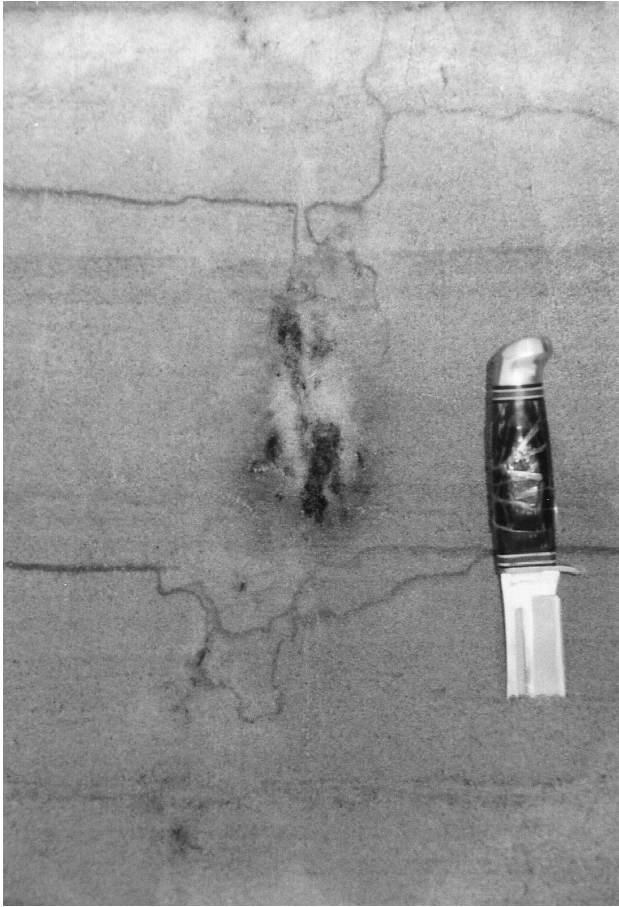


Fig. 4. Linear, clay-enriched strata which become wavy and bend downwards near a site of preferred leaching: an old root trace. Knife is present for scale; handle of knife is nearer the soil surface than is the blade.

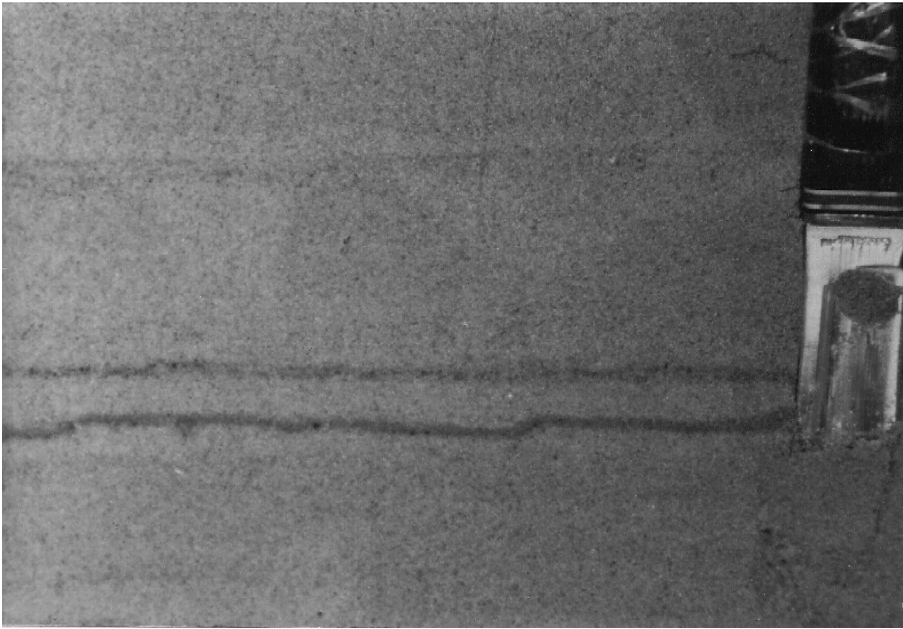
plane is deposited in a lamella somewhere above the next lower clayey strata/bedding plane — not at a bedding plane or on top of another lamella per se. In many instances, I observed clayey “couplets” composed of an upper clay-enriched stratum that was clearly degrading, as evidenced by its lighter color and less-red hue, and an incipient lamella below. The stratum above did not cross bedding planes whereas the lamellae forming below usually did (Fig. 5A and B). The clay in the lamella may be illuviating into/at a subtle pore size discontinuity (Bouabid et al., 1992) or at a location associated with a previous wetting front. Couplets like those in Fig. 5 were commonplace at the site, and illustrate that lamellae forming from geologic strata do not, in fact grow upwards, as suggested by Van Reeuwijk and de Villiers (1985) and the Soil Survey Staff (1999).

Further evidence for the theory being proposed here comes from the lee side of the dune, where steeply dipping, laminar beds of clean sand and clay exist.

A



B



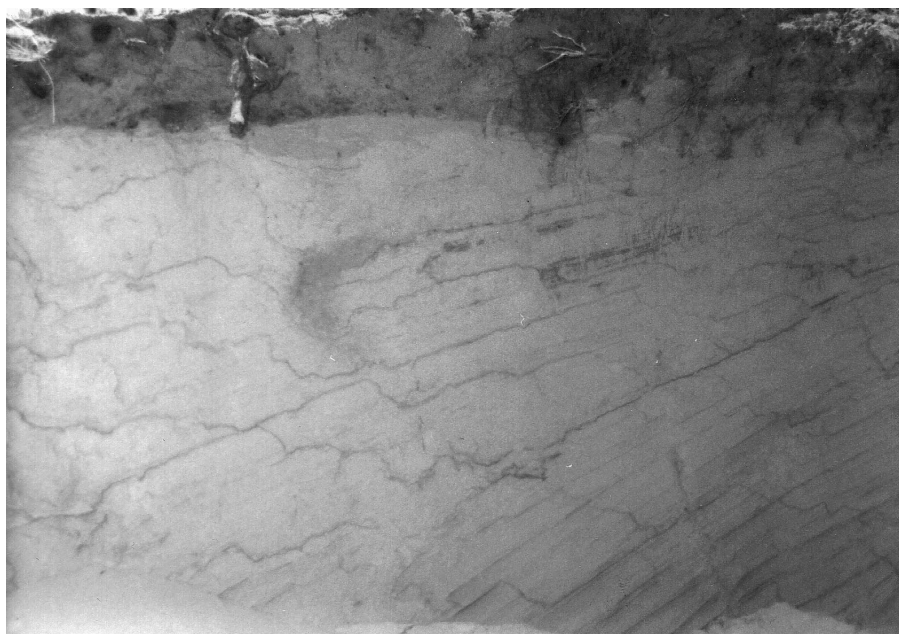


Fig. 6. Deep (> 3 m) cut into the lee side of the dune, showing steeply-dipping beds of sand with clay-enriched strata between. Lamellae are beginning to form in this environment, as bridges between existing bedding planes. Dark layer near the top of the photo is the Ap horizon.

Here, lamellae are forming that obviously cross-cut the inclined bedding planes (Fig. 6). As at the other parts of the dune where strata are more or less horizontal, the translocated clay that formed these lamellae did not stop preferentially at existing clayey strata or bedding planes.

The notion that clay within thin strata can be pedogenically translocated and deposited at depth is not entirely new. Robinson and Rich (1960) suggested that, in the upper part of some profiles small, elongate, clay-rich nodules provide evidence for the destruction of preexisting, geological clay bands by pedogenesis. They also noted that clay strata, which were horizontal and straight at depth, became more wavy nearer the surface. Van Reeuwijk and de Villiers (1985) and the Soil Survey Staff (1999) suggested that most lamellae originate at geologic bedding planes. However, they stressed that waviness comes about as clay is stripped off the bottom of geologic strata and deposited on the tops of strata

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Fig. 5. (A) “Couplets”: thin, geologically deposited, clay-enriched strata (above) and lamellae (below). Tape at right shows increments of 10 cm. Note the gray linear areas that represent sands of differing color, and demonstrate that the original parent material was deposited in linear beds. Small fault near the left side of the photo crosscuts these strata. Darker colored, clayey strata follow the original bedding planes; lamellae are immediately below. The lamellae cross-cut bedding planes. (B) Close-up of one area shown in (A).

below, rather than a complete transfer of clay from such strata into a totally new depositional feature: a lamella.

The present study provides strong evidence that lamellae can form as clay is translocated downward from geologic strata, and that the eventual, illuvial “stopping point” of translocating clay need not be associated with a bedding plane or another lamella. Morphologic evidence in support of the notion that clay from degrading geologic strata is being translocated downward to form lamellae is shown in Fig. 5, where a lamella is clearly forming below an existing and degrading geologic stratum. The high degree of waviness of many lamellae, which is so commonly observed, is also more easily explained by the theory advanced here than by that of Van Reeuwijk and de Villiers (1985) and the Soil Survey Staff (1999).

The results of this study have wide-reaching importance, for if thin lamellae like these, common in many soil series in glaciated regions and on dunes worldwide (Ahlbrandt and Fryberger, 1980; Miles and Franzmeier, 1981), can form in (or are typical of) sandy deposits containing thin clay-enriched strata, it has direct implications for the sedimentary environments under which the sand was laid down. Operating within a purely pedogenic framework, one might have thought that thin lamellae like the ones described here could only have formed in weakly-bedded or homogeneous deposits of sand containing small amounts of clay intimately dispersed through the matrix (Schaetzl, 1992). This study suggests that soils with thin lamellae could have formed in deposits typified by alternating layers of clean sand and clay-enriched sand. Thus, parent materials of soils with thin lamellae, such as Argic Ustipsamments and Udipsamments, and perhaps even Lamellic or Psammentic Hapludalfs and Haplustalfs, may have experienced periods of episodic deposition. Lastly, the results of this study support the notion, advanced by others (e.g., Berg, 1984; Prusinkiewicz et al., 1998), that lamellae can form very rapidly.

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