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PERIGLACIAL FEATURES AND LANDFORMS OF THE DELMARVA PENINSULA

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ABSTRACT

This study documents a paleosol impacted by periglacial features at a site on the Delmarva Peninsula of Southern Delaware. This paleosol is characterized by increased stiffness/density, change in matrix color, evidence of induration and cementation, relict fluvial versus aeolian sedimentary structures, secondary structures associated with permafrost or deep seasonal frost, and fossil roots and animal burrows. Partially-lignitized roots, root channels, animal burrows and secondary sedimentary structures associated with subaerial exposure and soil-forming processes truncate abruptly at the contact with the overlying massive, loose, aeolian sand. We hypothesize that this paleosol developed within fluvial beds of the Beaverdam Formation during a lengthy period of subaerial exposure. Several layers of parent material of different origins were noted: a) structureless clays, b) structureless aeolian sands, c) fluvial, normal-graded, cross-stratified, and laminated sands with gravel lag beds, and d) indurated, sandy clays interpreted to be a paleosol. Sufficient definition of the surface of this paleosol was obtained to reconstruct the paleotopography of the site, which is distinctly different from the current topography. We interpret this buried surface as a former land surface of early Pleistocene to late Pliocene age.

INTRODUCTION

Recent investigations have documented the presence of periglacial features on the East Coast of the United States farther south than previously thought. The objective of this study was to investigate landforms and subsurface features on the Delmarva Peninsula to determine if they support the presence of a periglacial paleoenvironment as far south as Southern Delaware. Although late Wisconsinan glaciers in Pennsylvania were considered to be separated from evergreen woodlands by no more than 100 km of tundra, recent data indicate that within the coastal plain of New Jersey and Delaware, sandy, well-drained, poorly-vegetated soils may have allowed tundra conditions to extend farther south than formerly thought. French and Demitroff (2001) state that the closed depressions commonly found on the Coastal Plain (sometimes referred to as “Carolina” basins) are considered to be deflation hollows or blowouts formed by strong katabiatic winds originating from the glaciers to the north. These aeolian activities appear to be a significant force in the formation of the landscape. Sand wedges or sand-wedge relicts are described as examples of deep frost action. Cryoturbated soils and polygonal patterned ground are also noted as evidence of periglacial conditions.

Andres & Howard (1998) report wedge casts in the Scotts Corner Formation at the Pollack Farm site in Delaware. They interpret the wedge casts as fossil frost wedges formed in seasonally frozen ground based upon downward warping of adjacent beds.

Investigations of sites in the New Jersey coastal plain indicate that late Pleistocene permafrost extended as far south as 39° north latitude. Wedge casts, referred to as ground wedges, found in the area are interpreted as seasonal frost cracks infilled with loose aeolian frosted sands. Optically-stimulated-luminescence (OSL) dating of the infilled material indicates that the sands accumulated during two separate periods, one during the late Illinoian to early Wisconsinan glaciation (55-66 ka) and another during the late Wisconsinan glaciation (15-22 ka). Based upon the thermal contraction cracking in fine and coarse-grained sands, French et al. (2003) postulated that maximum mean annual air temperatures of <-4 and <-8 °C were common. Dislocation of near-surface ironstone deposits suggests that permafrost in this area reached thicknesses of 10-15 m (French et al., 2003).

Wedges filled with aeolian sand have been documented at two locations in New Castle County, Delaware at approximately 39° 44’ and 39° 25’ north latitude within the Columbia Formation. The Columbia Formation is composed of fluvial sands that accumulated approximately 400 ka with a surface discontinuity that is capped by loess that accumulated approximately 10 to 13 ka. Pollen assemblages indicate that the Columbia Formation accumulated during a transitional period from a cold, glacial stage to a warmer, inter-glacial period. The wedges found are consistently below the loess cap and therefore pre-date the last glacial maximum and are morphologically consistent with the presence of permafrost. A number of other features associated with cold-climates, including dunes, sand sheets and shallow depressions noted in the area, are considered to have formed during the coldest part of the Wisconsinan glaciation (Lemke et al., 2004).

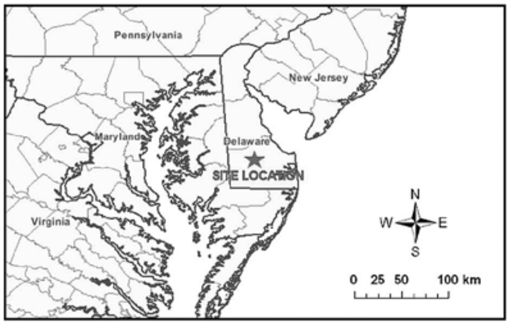

Figure 1. Site Location. The site is located on the Delmarva Peninsula, in the Coastal Plain Physiographic Province of the Mid-Atlantic Region in Sussex County Delaware at approximately 38° 42’ North Latitude and 75° 30’ West Longitude.

The generally-accepted origin of ground wedges or ice-cast wedges in the coastal plain is thermal contraction of perennially-frozen ground with cracks infilled with aeolian sands frosted and deposited by strong katabiatic winds. Modern analogs in high latitudes indicate that surface soil temperatures may have been in the -15 to -20 °C range when this cracking occurred. OSL dating of sands infilling these cracks and forming the wedges suggest a tri-modal formation chronology with wedges forming at >147 ka, again at 50 to 70 ka and a more recent set at 13 to 35 ka. These ages suggest wedge formation of probable Illinoian, early Wisconsinan and late Wisconsinan age. The late Wisconsinan episode likely followed the Last Glacial Maximum (LGM) and may not be associated with significant ground ice growth. It is thought that the post-LGM episode was characterized by thin or discontinuous permafrost or deep seasonal frost. The late Pleistocene-Holocene transition has been described to have been a time of significant aeolian activity dominated by braided fluvial systems with the formation of dunes and deflation hollows on upland surfaces (French et al., 2007).

Murton et al. (2000) discuss the formation of wedge structures by infilling of thermal contraction cracks or ice wedges. These cryogenic sand wedges are reported to occur widely in polar desert and tundra. The fill in these wedges is reported to be either massive or laminated and may contain pebbles and inclusions of the surrounding parent material. Large wedges exceeding 2 m in depth are interpreted as being evidence of continuous permafrost. Many wedges are reported to have been morphologically modified by post-depositional forces such as loading, slope-related movement, glaciotectonic deformation or frost heaving.

Markewich et al. (2009) report parabolic dunes of aeolian origin on the west shore of the Chesapeake Bay that have their origins in the Wisconsinan glaciation. They report a recent episode of significant aeolian deposition that coincides with the period of major growth in the Laurentide Ice Sheet between 35 and 15 ka. Three or more intervals during this time period saw wind as the dominant geomorphic agent in this region. Each of these episodes are reported to have followed rapid incision into crystalline bedrock by the Potomac and Susquehanna rivers between 35 and 30 ka, which would have provided significant quartz as raw material for the deposition of sand across the region.

Periglacial features have been recognized in the northeastern United States for some time. Boulder rings, boulder stripes and rubble on ridge tops are reported in northern Pennsylvania and described as being a result of deep seasonal freeze and thaw during early Wisconsinan glaciation. Estimated frost depths were within 2 to 3 m at the time of formation of these features (Denny, 1951). Clark (1968) described sorted polygonal pattern ground at high elevations in Pennsylvania, West Virginia and Virginia as being periglacial in origin. These features are easily compared with modern analogues at high latitudes, such as those noted in the Devon Plateau of Nunavut in Canada (Ugolini et al., 2006).

Quaternary paleosols in the Arctic that were exposed during glacial periods exhibit relict cryogenic features including sand wedges, ice wedge casts, sand involutions and cryoturbation. Holocene soils in the same area exhibit patterned ground as the most common relict feature. The Wounded Knee Paleosol in the central Yukon, found at elevations of less than 1000 m is considered to be of early Pleistocene origin. This paleosol is strongly weathered and rubefied and exhibits a paleoargillic Bt horizon with thick argillans as well as sand wedges, ice wedge casts and ventifacts. Patterned ground and stone circles are also reported. Taarnocai & Valentine (1989) reported that the rubefication exhibited requires a mean annual air temperature (MAAT) of >7 °C. As this area now has a MAAT of -5 °C, the rubefication is interpreted as being relict.

In northwestern Europe, common Quaternary periglacial features include ice-wedge casts, cryoturbation and patterned ground. Interglacial paleosols commonly exhibit weakly rubefied argillic horizons that are thicker and more enriched in illuvial clays than those formed in the Holocene. Expulsions of air bubbles during thawing are thought to produce large rounded or mamillated pores or vesicles within these paleosols. Quaternary alterations of glacial and interglacial sediments could be stronger in the middle latitudes, resulting in relict features that are more widespread (Catt, 1989). Permafrost degradation is reported to produce thaw consolidation and liquefaction that contributes to a compacted layer at the level of the paleo-permafrost table (French et al., 2009). Paleosols such as these can provide information on past climatic histories. Investigations of loess-paleosol sequences in Southeastern Central Europe and Central China have provided detailed climatic information on portions of the middle and upper Pleistocene. These interpretations must be made carefully, however, as many paleosols are truncated (Bronge and Heinkele, 1989).

Based upon this growing body of information, it is not unreasonable to expect to find evidence of periglacial impact on sites farther south than previously documented. The objective of this study was to identify and document a paleosol and landform features and to determine if their origin is periglacial.

Table 1. Profile log for test pit 1411 described using the USDA system. The Ap and C horizons consist of loose and relatively structureless aeolian sands overlying the surface of the paleosol (2Btg horizon) and lower horizons of varying parent materials. Note the change in consistency starting at the 2Btg horizon and continuing with depth. The plasticity of the 2Btg horizon and the firmness and massive structureless condition of the 3Btg and 4Cg horizons could indicate compaction due to consolidation and liquefaction from degradation of permafrost. The 4Cg horizon is cemented.

Horizon	Depth in inches	Matrix Color	Texture	Structure	Consistence	Boundary	Redox Feature Color	Redox Feature Description	Notes
Ap	0-12	2.5Y4/2	medium sandy loam	coarse weak subangular blocky	very friable	clear smooth			
C	12-27	2.5Y8/4	medium loamy sand	single grain structureless	loose	clear smooth			
2Btg	27-32	10YR5/6	medium sandy clay-loam	medium weak subangular blocky	slightly plastic	abrupt smooth			
3Btg	32-56	Variegated N6/ & 5R5/6	clay	medium strong subangular blocky	extremely firm	abrupt smooth	N6/	matrix	
4Cg	56-72	Variegated N8/ & 7.5YR6/8	medium sandy loam	massive structureless	extremely firm	gradual smooth	N8/	matrix	cemented
5Btg	72-97	Variegated 5PB8/1 & 7.5YR5/6	clay-loam	massive structureless	plastic	clear smooth	5PB8/1	matrix	old lignitic roots to 97"
6Cg	97-105	Variegated 10YR7/1 & 10YR5/8	felspathic heavy medium sandy loam	massive structureless	friable				

REGIONAL SETTING

The site is a 53 hectare (130 acre) tract of land located in Sussex County, Delaware, United States of America at approximately 38° 42' North Latitude and 75° 30' West Longitude (Figure 1). The site is located on the Delmarva Peninsula, in the Coastal Plain Physiographic Province of the Mid-Atlantic Region. The site was a fallow farm field dominated by weeds and surrounded to the north by a young, managed Loblolly pine forest.

Topography is gently rolling, concavo-convex and has very little topographic relief. Elevations in the area range from less than 10 m above mean sea level (MSL) along streams to more than 18 m above MSL at Wilson Hill to the northeast of the study areas.The surface drainage is primarily accommodated by drainage ditches and channelized streams. The site is punctuated by undrained depressions. The site lies along the drainage/watershed divide between the Chesapeake Bay and the Delaware Inland Bays watershed. The site is mapped as being underlain by unconsolidated fluvio-marine sediments of the Pliocene Age Beaverdam Formation (Ramsey, 2008), which overlay Miocene estuarine and marine sediments of the Chesapeake Group (Groot and Jordan, 1999).

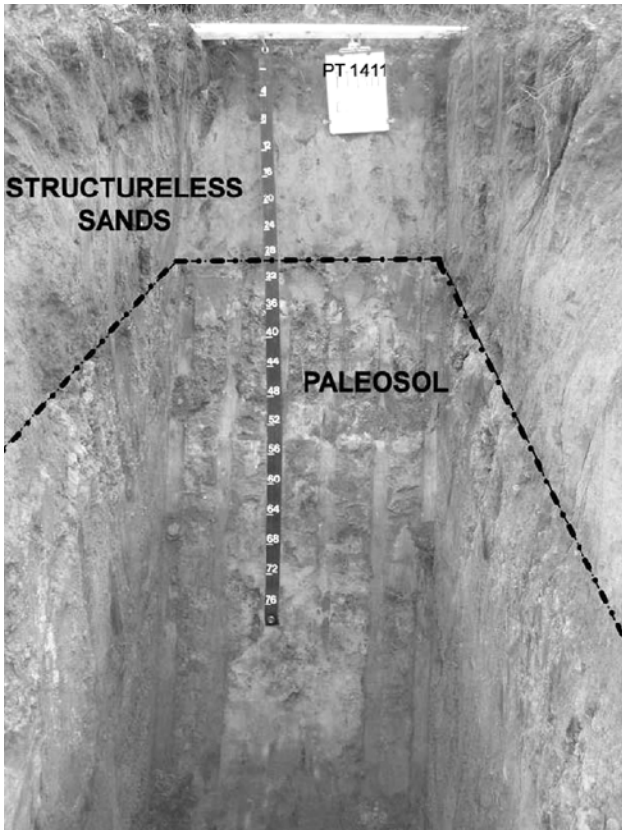

Figure 2. Test pit 1411 showing the distinct boundary between the paleosol and the overlying structureless aeolian sands.

MATERIALS AND METHODS

A preliminary reconnaissance phase consisting of 32 hand auger borings to a depth of 1.5-2.0 m was conducted using a grid pattern of 100 m across the site. The reconnaissance phase was followed by intensive, high-definition soil and hydrogeologic mapping of two areas within the property. The detailed mapping included excavation and examination of 32 backhoe pits to 4-m depth and over 325 hand auger borings at depths of 1.5 to 2.0 m on a 23-m grid pattern across the areas. The soil mapping was coupled with hydrogeologic mapping that included 33 deep probes using a direct-push rig with continuous sampling to depths of 7 to 15 m, as well as 32 deep hand auger borings completed with 5 cm diameter PVC observation wells and 11 shallower wells within the vadose zone. Soil profiles were logged using the USDA and USCS systems. Surface topography and all sample locations were surveyed in Delaware State Plane Coordinates using a combination of a survey-grade global positioning system (GPS) and conventional survey techniques allowing control of both physical locations and topography.

RESULTS AND DISCUSSION

Early examination of the soils exposed in the backhoe pits revealed that the subsurface stratigraphy of the study site was significantly more complex than anticipated based on soils and geologic maps previously published. One soil profile (Table 1) exhibited six different sets of parent materials. The surface soils consisted of relatively structureless sandy loams and loamy

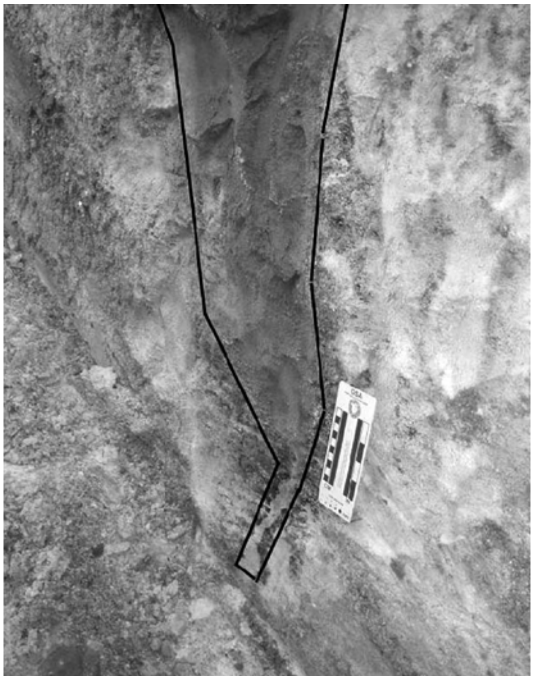

Figure 3. Test pit 1414 exhibiting wedge cast. Material within wedge is friable, massive, medium loamy sand; surrounding matrix is coarse loam to sandy clayloam.

sands that include small sub-rounded gravels overlying the paleosol, which was composed of slightly rubified and, in some cases, gleyed sandy clayloam. The lower horizons included parent materials of apparent structureless clays, lag deposits of possible aeolian pavement, fluvial trough and planar cross-stratified sands, and laminated fine to very fine sands in normal graded sets 30 to 60 cm thick, often truncated by the overlying set of beds (Figure 2). As the paleosol was encountered in nearly every test pit and auger boring, it became a focus of the investigation as it appeared that it could significantly impact subsurface water flow within the vadose zone.

The paleosol was readily recognized in both auger borings and test pits based upon color change, textural change, and induration. Subsequent infiltration testing indicated that the permeability of the paleosol was roughly 30% that of the overlying sands. Double ring infiltrometer (ASTM standard D3385-94) testing yielded an average infiltration rate of 15.86 cm/hr for the shallow soils and 4.62 cm/hr for the paleosol. This dichotomy in permeability rates mirrors initial estimations based upon soil texture, structure and consistence.

The surface of the paleosol occasionally included sub-rounded fine gravels of chert that appeared to be wind abraded. The paleosol was intersected by a number of features of interest. Two instances of apparent wedge casts were observed. The most striking wedge cast (Figure 3) was infilled with a friable, massive, medium sandy loam that was significantly more oxidized than the matrix of the paleosol. The presence of these wedge casts indicate that periglacial conditions with deep seasonal frost or permafrost existed in this region at some time in the past. We interpret these wedges to be similar to the ice wedge casts described by French, et al. (2001, 2003, 2007, 2009) or the cryogenic sand wedges described by Murton et al. (2000). The presence of the gravels at the interface between the paleosol and the surface horizons indicate that the surface of the paleosol was formed during subaerial exposure and was at one time a stable land surface, but experienced

Figure 4a. Lignitized roots are truncated at the surface of the paleosol.

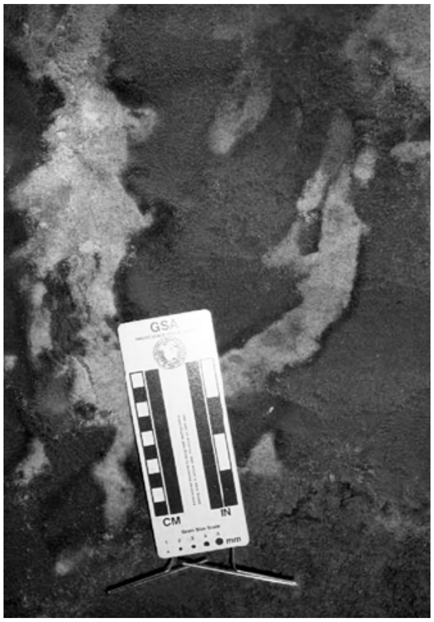

Figure 4b. Macropores in test pit 1444, which are roughly cylindrical in cross section. These could be sand wedges that have undergone post-depositional soft sediment deformation. The resemblance to rodent burrows, however, suggests that these are krotovina of animal origins. Material infilling krotovina is composed of friable, massive, medium loamy sand similar to the sands found in the surface horizons. The surrounding matrix is medium sandy loam to sandy clayloam.

Figure 4c. Macropores of indeterminate origin. These macropores appear to be significant preferential flow pathways allowing groundwater recharge.

differential erosion and loss of all or part of a surface horizon containing gravelly clasts.

Lignitized roots that originated within the paleosol were found at a number of locations (Figure 4a). Future studies could include sampling of the roots to allow for radiocarbon dating. Significant macropores infilled with material differing from the matrix of the paleosol were recognized. The most striking of these was a series of 3 to 6 cm diameter macropores that were infilled with friable, massive white sands similar morphologically to the sands found in the surface horizons (Figure 4b). They were truncated at the overlying contact with the structureless sands and are

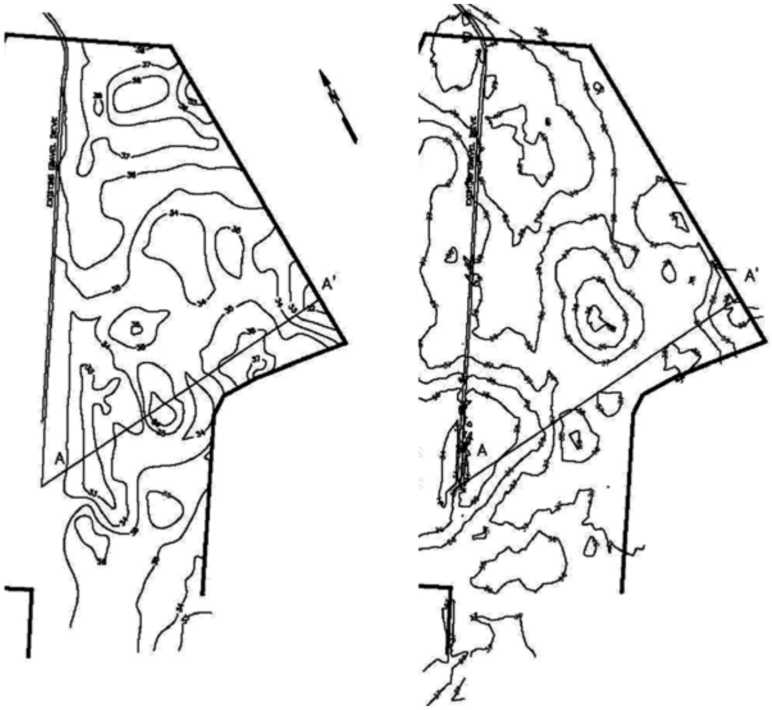

Figure 5. Isopach map comparing current surface topography (right) with paleo-topography (left). Contours are 1-foot intervals.

therefore considered post-depositional and post-date the development of the paleosol. It is possible that these features are sand wedges that have been modified by post-depositional soft sediment deformation. The shape, configuration and placement of these macropores, however, are reminiscent of rodent burrows. We hypothesize that these represent the remains of burrows inhabited by small rodents at the time when the paleosol was exposed and that these burrows were then infilled with aeolian sands as they were subsequently deposited on the site. We interpret these krotovina to be contemporaneous with the mature paleosol environment of a warm interglacial or pre-glacial period.

A number of other, less identifiable macropores were recognized in a number of locations (Figure 4c). These macropores, though their origins are less clear, are likely significant pathways for recharge of the aquifer in this area.

The systematic and detailed nature of the investigation with hand auger borings spaced on a 23-m grid pattern, coupled with precise survey location and the readily recognizable paleosol, permitted the preparation of an isopach map of the top of the paleosol. Taking the known surface elevations at each point on the grid and subtracting the depth to the surface of the paleosol yielded an elevation for the surface of the paleosol (Figure 5). We assume that this paleosol was formed during a lengthy period of subaerial exposure, that it was a stable land surface at one time and that it was subjected to modification on a macroscopic scale by alternate periods of freezing and thawing with both wind generated and fluvial erosion. Our interpretation is provisional, however, and subject to refinement as additional information becomes available. The topography of the existing land surface and the surface of the paleosol were found to differ as illustrated in the isopach map. Figure 6 illustrates the difference in the topographic profile across one area of the site.

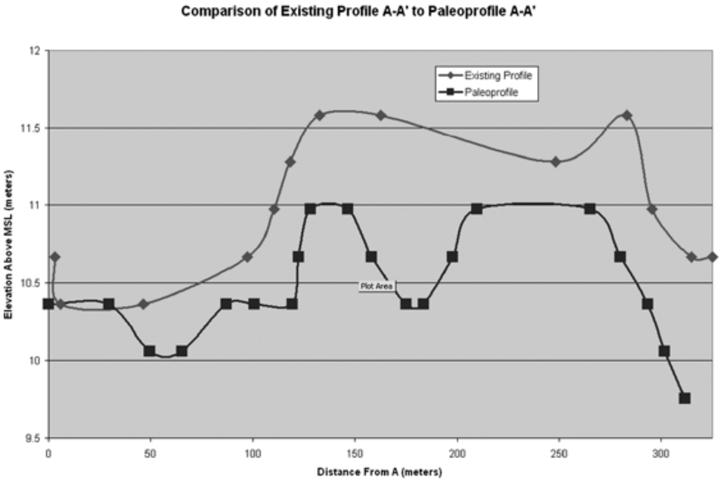

Figure 6. Profile of section A – A' comparing current surface topography with paleotopography.

CONCLUSIONS

The nature of the paleosol recognized at this site indicates that it was formed by a lengthy period of subaerial exposure followed by modification under periglacial conditions. The paleosol was subsequently buried by aeolian sands following, presumably, the last glacial event.

Wedge casts indicate periglacial influences that could be either permafrost or deep seasonal frost. Based upon the findings of French et al., the age of these ground wedges could coincide with one of the three periods of wedge formation which would place the age of the paleosol surface at >147 ka, 70 to 50 ka or 35 to 13 ka. If we assume that the paleosol was a stable land surface, this would place the age of the formation of the surface at a time previous to the latest, but most likely the oldest, glacial period. As the Beaverdam Formation is dated as Pliocene, it is also possible that this paleosol is of Pliocene origin.

The significance of aeolian processes as a result of katabiatic winds in the formation of the landscape of the Coastal Plain has been documented repeatedly by others. The presence of structureless sands with a relative lack of significant pedologic development in the surface horizons is consistent with this model. The wind abraded gravels found within the sands above the paleosol and at the surface of the paleosol support an aeolian origin for the sands resting on the surface of the paleosol. An aeolian origin is consistent with the existing undrained depressions on the site that appear to be formed as deflation hollows. We interpret some of the macropores noted in profiles as the remnants of animal burrows. Some other macropores appear to be krotovina of plant origin or of undetermined origins.

We suggest the existence of a buried landscape that pre-dates the glaciations of the Pleistocene. We further suggest that this landscape was formed under a warmer, non-glacial climate during the Pliocene and remained relatively stable through much of the Pleistocene. This land surface was strongly influenced by periglacial processes including permafrost or deep seasonal frost during episodes of continental glaciations as evidenced by wedge casts. During interglacial periods, this landscape was vegetated and inhabited by fauna as evidenced by the macropores encountered. The land surface was repeatedly impacted by aeolian scouring, sedimentation and modification/alteration due to strong katabiatic winds of glacial origin. These aeolian depositional episodes are likely responsible for burying the area under structureless sands which also infilled the wedges and faunal krotovina creating the gentle topography that exists today.

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