Archaeological site formation in glaciated settings, New Jersey and southern New York


Donald M. Thieme

Department of Geology
University of Georgia, Athens
Introduction

A dense urban metropolis now sits in the area on the eastern seaboard which is immediately north of the last glacial margin. Traces of prehistoric human activity are sparse, although formerly more abundant, having been compromised by the works of modern industry. Archaeological contexts are typically sandwiched between Pleistocene glacial deposits and very late Holocene marsh peat or disturbed land. The area is nonetheless crucial to understanding the retreat of the Laurentide ice sheet, the initial peopling of eastern North America, and the archaeological antecedents of historic tribes.

The following paper will summarize current research in both Quaternary geology and geoarchaeology, with a particular emphasis on the lower reaches of the Passaic and Hackensack Rivers in New Jersey (see Figure 1). The objective is to show some implications of recent geological findings for archaeology and vice versa. Both disciplines currently stress fundamental understanding of the processes which generate stratified deposits. Indeed, many of the formation processes we use to explain the archaeological record are environmental processes which affect noncultural as well as cultural deposits (Schiffer 1987: 199-262).

Chronology of the Quaternary period is another topic of common interest, and radiocarbon dating is still the most widely applied dating method. The recent calibration of the radiocarbon timescale (Stuiver et al. 1998) stretches out the close of the Pleistocene epoch, when the Laurentide ice sheet retreated through the area covered in this paper. The changing climate itself influenced the abundance of $^{14}$C in the atmosphere, and climatic forcing of the carbon cycle continued into the period of known
Figure 1: The glaciated portions of New Jersey and southern New York showing sites discussed in the text
1. Port Washington glacial deposits (Sarkin and Stuckenrath, 1975)
2. Harbor Hill terminal moraine (Cadwell, 1989; Fullerton et al., 1992)
3. Richmond Hill site (Ritchie and Funk, 1971, p. 53-54)
4. Ward’s Point (Ritchie and Funk, 1971, p. 53-54)
5. Hollowell site (Ritchie and Funk, 1971, p. 50-53)
6. Old Place site (Ritchie and Funk, 1971, p. 49-50)
7. Port Mobil and Charlestown Beach (Kraft, 1977a, 1977b)
8. North Bergen Sewer Outfalls (Thieme and Schulentrein, 1998a)
9. Route 21 Corridor Sites 23PA39, 28PA40, 28PA143, and 28PA145 (Thieme, 1997; Tull, 1997)
10. North Arlington Sewer Main (Thieme and Schulentrein, 1996; Thieme et al., 1996)
11. Collect Pond (Schulentrein, 2002)
archaeological cultures (Stuiver et al. 1991; van Andel 1998; van Geel et al. 1999). Episodes of landscape change identified in the stratigraphy of the multicomponent Dundee Canal Site (28PA143) in the Passaic River valley possibly represent responses to such climatic forcing. Correlates identified in other archaeological and geological contexts further support the case for climatic forcing.

**Geoarchaeology and Site Formation Processes**

Geoarchaeology, as defined by Butzer (1982: 35), is the application of earth science methods to archaeological research problems. Earth science methods are employed to provide a regional context for archaeological finds and to determine the lateral and vertical extent of deposits from which significant finds may yet be unearthed. Recent analyses of site formation processes (Nash and Petraglia 1987; Schiffer 1987; Stein 2001) demonstrate the methodological importance of the geoarchaeological approach to the stratigraphy and physical setting of archaeological sites.

Archaeological sites are locations where past human activities took place (Deetz, 1967, p. 11-12; Knudson, 1978, p. 49). The preservation of material traces of past human activities where they were originally deposited by people (*in situ*) is unfortunately rare. Earth science methods must consequently be used to analyze the formation of a site, beginning with its topography and geology prior to occupation.

Glacial geology contributes less frequently to site formation analyses than other earth science subfields. Indeed, Pleistocene glacial deposits in North America are not yet known to
contain prehistoric artifacts \textit{in situ}. On the other hand, materials derived from glacial deposits do commonly occur in archaeological contexts. Derivation of cultural sediment by colluvial and alluvial reworking of glacial till and outwash is demonstrated below in an analysis of the multicomponent Dundee Canal Site (28PA143).

Although glaciation may not have been responsible for site formation processes operating within any period of prehistoric occupation, archaeological contexts did frequently intrude glacial deposits. The formation of these deposits must be accounted for within both regional and site-specific stratigraphic frameworks. Processes observed in the vicinity of active glaciers now play a key role in the analysis of glacial landscapes and depositional environments (Boothroyd and Ashley 1975; Gustavson and Boothroyd 1987; Lundqvist 1989). In the glaciated Northeast, the concept of the "recessional morphosequence" (Koteff 1974; Koteff and Pessl 1981) has proven an effective tool for relating the Pleistocene glacial deposits to one another and to modern analogues.

\textit{Regional Geology and Quaternary Stratigraphy}

The topography of the glaciated portions of New Jersey and southern New York is dominated by north-south trending rifts in the continental crust which first developed during the breakup of Pangea (Isachsen et al. 1991: 50-51). The Laurentide ice sheet advanced over these rifts at least twice during the Pleistocene epoch (Cotter et al. 1986; Stanford 1997, 2000; Stanford and Harper 1991; Sirkin 1986), forming the valleys now occupied by the Hudson, Hackensack, and Passaic Rivers. Most of Long Island and much of Staten Island were deposited as glacial detritus. Sirkin (1982, 1986) assigned the ice-contact deposits on Long Island to early-
and late-Wisconsin advances of at least two lobes of the Laurentide ice sheet. In New Jersey, the older till has been assigned to the Illinoian or pre-Illinoian (Stanford 1997).

Sirkin obtained 29 radiocarbon dates for a section of glacial deposits at Port Washington on the north shore of Long Island (see Figure 1). Mid-Wisconsinan ages from 36-25 ka for shell and 44-35 ka for wood predominate, with pollen spectra further indicating an interstadial warm period (Sirkin and Stuckenrath 1980). Inverted stratigraphy in several of the columns sampled was attributed to folding and thrusting of the sediments as they were overridden by the late-Wisconsinan ice. A date of 21,750±750 B.P. (SI-1590) was obtained for silty sediment capping outwash near the base of the section (~19 m MSL). Sirkin considered this to be a maximum age for the arrival of the Hudson-Champlain lobe in western Long Island.

The terminal moraine for the late-Wisconsinan advance is called Harbor Hill after the ice-contact deposits on this prominent feature in Brooklyn overlooking the Verrazano Narrows. As the ice sheet retreated from this terminal position, it left behind evidence in New Jersey for at least five recessional margins (see Figure 2). The deposits laid down in close association with each ice margin were generated by the local behavior of the ice sheet. Recent models developed for glacial deposits in the northeastern United States (Koteff 1974; Koteff and Pessl 1981; Stone et al. 1998) refer to these genetically related deposits as "recessional morphosequences."

In each morphosequence, the coarsest sediment textures are found at the up-ice head of outwash." Bouldery till or stratified drift are most typical of true "moraines," but each head of outwash should contain material let down in place as the ice was melting. Grain size decreases and landforms are less collapsed in distal parts of a morphosequence, where the stratigraphy typically shows evidence of transport by meltwater (Boothroyd and Ashley 1975; Gustavson and
Figure 2: Late Pleistocene recessional margins in New Jersey (after Stanford, 1997)
Boothroyd 1987). The ice itself was always moving forward at each recessional margin, although the net balance within the sheet reflected more ice lost than gained. The impounded meltwater rose to a level defined by either a glacial lake plane or a valley knickpoint (Stone et al. 1998).

Stepwise northward retreat of the ice sheet through the five recessional margins in Figure 2 resulted in a complex history of lake basins which drained up-ice as well as down-ice or laterally as spillways opened between the bedrock valleys (Stanford 1997; Stanford and Harper 1991). Due to common parent material in Newark Group sedimentary lithologies, the glaciolacustrine sediments from all of these interconnected basins are very similar. Thick winter varves of reddish brown muds alternate with more heterolithic sandy varves deposited as the ice melted during the summer. The apparently uniform lithostratigraphy led to earlier proposals of very large and long-enduring proglacial lakes (Antevs 1925; Lovegreen 1974; Reeds 1925, 1926; Salisbury 1902; Salisbury and Kummel 1893; Widmer 1964).

Lakebed silt and clay accumulations up to 80 m thick are the result of successive meltwater impoundments in the lower reaches of the Hudson, Hackensack, and Passaic Rivers (Lovegreen 1974; Stanford 1997; Stanford and Harper 1991). Independent age constraints from radiocarbon dating and pollen stratigraphy suggest that the last pulse of meltwater occurred sometime prior to 14,000 radiocarbon years before present, or ca. 17 ka cal B.P. (Stanford 1993; Thieme and Schuldenrein 1996; Thieme et al. 1996; Weiss 1974). This predates any known archaeological contexts from either New Jersey or southern New York by several thousand years. Nonetheless, deglaciation did have profound effects upon the physical setting and stratigraphy of archaeological sites located in both the coastal plain and the forested interior.
Within the rift basin valleys, modern river channels are relatively shallow with low gradients due to the subdued topography and clayey glaciolacustrine sediments. Floodplains evolved relatively late compared to the larger and steeper bedrock valleys of the Delaware River (Schuldenrein 1994; Stewart 1991) and the Susquehanna River (Cremeens et al. 1998; Thieme and Schuldenrein 1998b; Vento et al. 1999). The Hudson and Hackensack River valleys were scoured the deepest by glacial ice, and relict floodplain deposits appear to have been submerged during postglacial sea level rise (GRA 2000; LaPorta et al. 1999; Newman et al. 1969; Thieme 2000; Thieme and Schuldenrein 1998a; Weiss 1974). In addition to differences between drainages, sediment texture and bedding characteristics vary within each valley as a result of the depositional history at each recessional margin.

Pleistocene-Holocene Boundary and Early Archaeological Contexts

The chronological boundary between the Pleistocene and Holocene epochs of the Quaternary period of the geological time scale is represented by a stratigraphic contact at the top of the glacial deposits in New Jersey and southern New York. Overlying sediment packages are typically much younger than the arbitrary date of 10,000 years before present which has been assigned to this boundary (Hageman 1972; Harland et al. 1990). The apparent time gap at the Pleistocene-Holocene boundary can be ascribed both to localized erosion by streams choked with glacial meltwater and to a regional hiatus in the delivery of sediment. The "missing" sediment is very much missed by archaeologists working in the glaciated Northeast, since this is where the earliest prehistoric remains typically occur. The most significant beds for
archaeologists are sandwiched between Pleistocene till, outwash, or lacustrine sediment and very late Holocene marsh peat or disturbed land.

This very general stratigraphic framework for identifying the deposits of interest has been employed in several recent projects of geoarchaeological prospection. One such project involved the supervision of geotechnical borings performed for sewer outfalls near North Bergen, New Jersey (Thieme and Schuldenrein 1998a). Organic sediment from a diamicton six meters below surface was dated to 19,400±60 B.P., or ca. 23 ka cal B.P. (see Table 1). The overlying Holocene floodplain facies fines upsection and is capped by a buried soil dated to 4 ka cal B.P. (see Figure 3). These relict floodplain deposits of Penhorn Creek probably continue downstream to its juncture with the Hackensack River, where local collectors have reported prehistoric artifact findspots to the New Jersey State Museum (Artemel 1979; Rutsch et al. 1978). The present land surface rests either on historic landfill or on peat emplaced once this portion of the Hackensack River valley became subject to tidal inundation. Peat from 2.4 m below surface at North Bergen was dated to ca. 1 ka cal B.P.

Calibration of radiocarbon dates using Stuiver et al. (1998) increases the time span for the depositional hiatus at the Pleistocene-Holocene boundary. Calibrated ages older than 10,000 B.P. also result for dates on some deposits which are generally considered to belong to the Holocene epoch. This includes at least one archaeological context from southern New York which produced Late Paleoindian and Early Archaic artifacts. The time span of 8,000-10,000 B.P. assigned to the Early Archaic period based on uncalibrated radiocarbon dates (Ellis et al.
While Paleoindian sites typically provide evidence for human exploitation of animals and plants which went extinct at the close of the Pleistocene epoch (Dincauze 1993; Ellis et al. 1998; Gramly and Funk 1990; McNett 1985), this is not true for sites of the Archaic period.
There is as yet no consensus concerning the implications of using the most recent calibration among Quaternary geologists, but it appears that the Holocene epoch should probably be considered to begin at 11,500 B.P. in calibrated calendar years. The change from Paleoindian to Archaic cultural lifeways would then still coincide with the transition from the late Pleistocene ice age climate to the warm, temperate climate of the Holocene interglacial. Because of "plateaus" in the relationship of radiocarbon to calendar years, it has actually been suggested that changes in regional artifact styles could provide a more precise chronology spanning the transition (Ellis et al. 1998). Age controls can also be obtained from pollen, plant macrofossils, and other biostratigraphic methods (McWeeney 1994, 1999; McWeeney and Kellogg 2001; Peteet et al. 1993; Weiss 1974).

Isolated finds of fluted points and other Paleoindian artifacts are ubiquitous, particularly in southern New York. Excavations in terrestrial settings have unfortunately yet to recover a Paleoindian assemblage from a context which was not disturbed by subsequent prehistoric occupations or geologic processes. Several sites on western Staten Island did clearly have substantial Paleoindian components (Kraft 1977a, 1977b; Ritchie and Funk 1971). At Port Mobil, for example, fluted points, end and side scrapers, and unifacial tools were among over 51 lithic artifacts recovered from a sandy slope between 5 and 15 m above present mean sea level. Fluted points are also among the artifacts found on Charlestown Beach south of Port Mobil.

Four radiocarbon dates ranging from 8-11 ka (cal B.P.) were obtained from contexts at three of the archaeological sites on Staten Island (Ritchie and Funk 1971). Two of the dated
<table>
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<th>Location</th>
<th>Elevation (m b.s)</th>
<th>Generic Lithofacies</th>
<th>Material</th>
<th>$^{14}$C yr B.P.</th>
<th>Calibrated yr B.P. (1-sigma range)</th>
<th>Lab Number</th>
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<td>Richmond Hill</td>
<td>0.50</td>
<td>Cultural sediment</td>
<td>Wood charcoal</td>
<td>9360±120</td>
<td>10570 (10731 - 10295)</td>
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<td>Cultural sediment</td>
<td>Wood charcoal</td>
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<td>9167 (9468 - 9026)</td>
<td>I-5331</td>
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<td>1.25</td>
<td>Cultural sediment</td>
<td>Wood charcoal</td>
<td>7260±125</td>
<td>8092 (8180 - 7944)</td>
<td>I-4512</td>
</tr>
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<td>Old Place</td>
<td>1.40</td>
<td>Cultural hearth</td>
<td>Wood charcoal</td>
<td>7260±140</td>
<td>8092 (8183 - 7884)</td>
<td>I-4070</td>
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<td>3110±90</td>
<td>3350 (3440 - 3212)</td>
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<td>23061 (23450 - 22699)</td>
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<td>Bulk sediment</td>
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<td>3941 (4079 - 3891)</td>
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<td>Tidal marsh</td>
<td>Peat</td>
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<td>1028 (1166 - 966)</td>
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<td>Glaciolacustrine</td>
<td>Bulk sediment</td>
<td>15390±60</td>
<td>18389 (18684 - 18114)</td>
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<td>2140±20</td>
<td>2144 (2302 - 2004)</td>
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<td>Floodplain paleosol</td>
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<td>2207 (2337 - 2150)</td>
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<td>Cultural sediment</td>
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<td>Peat</td>
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<td>5832 (5929 - 5600)</td>
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</table>
sites, Richmond Hill and Wards Point, are at the southern end of the island. Well-preserved Early Archaic components are clearly present at both Wards Point and Hollowell based on the recovery of Kirk, Kanawha, LeCroy, and Stanly projectile points. Hollowell also clearly has a Late Archaic or Early Woodland component based on both the radiocarbon date and stratigraphy reported by Ritchie and Funk (1971: 47).

At the Old Place site just northeast of the Goethals Bridge, charcoal from a hearth was dated to 7,260±140 B.P. in radiocarbon years. This calibrates to ca. 8 ka cal B.P., agreeing with the Early Archaic cultural affiliation of the Stanly, Kirk, and LeCroy projectile points found nearby. Recent geoarchaeological investigation of property on the margins of the site (GRA 1996, 1997) indicates that the best preserved deposits date to the Middle Archaic or Late Archaic cultural periods. The excavators whose findings were reported by Ritchie and Funk (1971: 49) noted several components at the site, with the Early Archaic materials coming from a relatively discrete package that has yet to be relocated.

The Old Place archaeological site is one of many locations in the study area where Holocene terrestrial deposits have been submerged beneath late Holocene tidal marsh. Rapid rates of sea level rise were also characteristic of the late Pleistocene and early Holocene (Bloom 1983; Newman et al. 1969), and many of the locations formerly inhabited by prehistoric hunter-gatherers must consequently have been drowned within New York Harbor and Newark Bay. Such settings could theoretically contain particularly discrete and early archaeological contexts (Emery and Edwards 1966; Stewart 1999; Stright 1986; Thieme 2000). Fieldwork targeting submerged early sites is ongoing, although the studies to date have found extensive reworking during the Holocene transgression (GRA 2000; LaPorta et al. 1999; Stright 1990).
In addition to prospection in underwater and nearshore settings seaward of the extant early contexts, identification of relict freshwater marshes and floodplain settings within the proglacial lake basins is crucial to finding further stratified prehistoric sites. Archaeologically sensitive deposits such as those sealed beneath tidal marsh peat in the Hackensack Meadowlands (Thieme and Schuldenrein 1996, 1998a) are difficult to identify using traditional archaeological techniques. Geological field and laboratory studies help by refining the stratigraphic framework and identifying sedimentological and geochemical signatures for the contexts in which prehistoric cultural materials have been found.

Site Formation Processes in the Route 21 Corridor, Passaic River valley

Large construction projects such as for highways, bridges, or dams sometimes provide archaeologists with the opportunity to study a number of prehistoric sites at the same time. In recent years, it has become common practice to include a geomorphologist or geoarchaeologist on the project team. It is obviously important to develop a generic stratigraphy applicable to the project area, in order to decide where and how deep to dig. Above and beyond such practical tasks, a geoarchaeological study can relate the materials recovered by the archaeologists to the surrounding physical landscape at the time of occupation. Processes in the physical environment often affect the location and integrity of the archaeological contexts, and such "site formation processes" are increasingly of interest to archaeologists working in North America (Nash and Petraglia 1987; Schiffer 1987).
The recent realignment of Route 21 near Passaic, New Jersey (Figure 4) is one such large construction project in which geoarchaeology played a crucial role in the excavation and interpretation of several stratified prehistoric sites. Initial (Phase I and Phase II) investigations were performed by Historic Conservation and Interpretation, Inc. in 1987 and 1988 (Mueller 1987; Rutsch et al. 1988a, 1988b). In 1996 and 1997, URS Greiner archaeologists conducted additional Phase II and Phase III excavations at four prehistoric sites (Scholl and Tull 1996; Tull 1997; URS Greiner 2001). The geoarchaeological studies at sites 28PA39, 28PA40, 28PA145, and the Dundee Canal Site (28PA143) were performed by the author and Joseph Schuldenrein of Geoarcheology Research Associates.

The Route 21 Corridor trends north-south within the Passaic River valley. The large loops in the river at Passaic (Figure 4) and further downstream at the entrance to Newark Bay (Figures 1 and 2) are derangements produced by the ice sheet when it stood at the Culvers Gap-Bloomfield recessional margin (Stanford 1997). Most of the glacial deposits within the Route 21 Corridor were emplaced as the ice sheet retreated to the "Augusta-Mud Pond" margin and then the "Cherry Ridge" margin. The glaciolacustrine sediments were deposited in the proglacial lake Paramus basin (Stanford 1993), which extended for several kilometers to the northeast.

Proglacial lake Passaic was considerably larger, but it spilled to the south into the Raritan River valley (Salisbury and Kummel 1893; Meyerson 1970). The radiocarbon date of 15,500±60 B.P. (ca. 18 ka cal B.P.) for glaciolacustrine sediment from site 28PA40 corroborates Stanford’s model of a relatively small and relatively late impoundment in this part of New Jersey.
Figure 4: Prehistoric Archaeological Sites located along the Route 21 Corridor, Passaic County, New Jersey
Proglacial lake Paramus submerged both this portion of the Passaic River valley and most of the Saddle River valley, which now drains east to join the Hackensack River.

Laminated reddish brown (5YR4/4) medium to coarse glaciolacustrine sand was also encountered in backhoe trenches at site 28PA145, capped by a coarse bouldery diamicton that was deposited in direct contact with the ice (Shaw 1985: 29-46). This appears to be the "Augusta-Mud Pond" till moraine of Stanford (1997), with cobbles and boulders of diabase, gneiss, granite, and metagraywacke up to 50 cm long in a matrix of brown (7.5YR5/4) sand or sandy clay. The sequence also resembles deposits attributed to the "Tappan readvance" by Averill et al. (1980), although a local readvance is fully compatible with the "recessional morphosequence" model of Koteff (1974).

Outwash deposited by melting ice during the retreat of the ice sheet through these recessional margins underlies the bed of the Dundee Canal bordering both site 28PA145 and site 28PA143. Riverward of the canal bed, the late Pleistocene sediments were evidently reworked considerably as a meltwater sluice incised the channel occupied by the modern Passaic River. Basal deposits at the Dundee Canal Site (28PA143) are channel sands and gravels with occasional muddy interbeds representing low-stage slackwater facies sediments of a braided stream (Boothroyd and Ashley 1975; Brakenridge 1988: 141). Bulk sediment from one of these interbeds was radiocarbon dated to 13,860±90 B.P., ca. 16.6 ka cal B.P. This is coherent with the internal site stratigraphy, although regional deglaciation history suggests that the Passaic River was no longer receiving meltwater from the Laurentide ice sheet by this time.
Holocene sedimentation varied considerably moving both laterally away from the river and up- and downstream between the sites investigated. Tributary stream junctures functioned as traps for finer sediments, and one particularly significant trap was located in the immediate vicinity of the Dundee Canal Site (28PA143). Colluvial reworking of till and outwash resulted in new landforms which were composed of much older materials. Sedimentation rates generally increased in the mid- to late-Holocene then slowed after 2 ka when a soil developed on the Passaic River terrace at sites 28PA40, 28PA145, and 28PA143. Subsequent alluviation and historic period landfilling have buried this soil and associated archaeological contexts from 50 cm to several meters below the present land surface.

*Dundee Canal Site (28PA143) Stratigraphy and Sedimentology*

The most important archaeological discovery within the Route 21 Corridor was the Dundee Canal Site (28PA143), the first stratified prehistoric site to be professionally excavated in the Passaic River drainage. Late Archaic through Woodland components were housed in a complex sequence of alluvial and colluvial deposits dating back to the Pleistocene. The Woodland components were particularly well preserved, due to the presence of pit features. The pit features had been dug into a preexisting buried soil. Limited traces of earlier prehistoric activities were found beneath this buried soil.
Figure 5: Stratigraphy of the Dundee Canal Site (28PA143), Passaic County, New Jersey

There were two large blocks of excavation units at Dundee Canal. A deep depression between the two blocks represents the former channel of Weasel Brook. This tributary to the Passaic River was captured during the 19th century to feed a tail race in the Dundee Canal. Weasel Brook would certainly have been an active tributary to the Passaic River during the prehistoric occupations at Dundee Canal. Subsequent to its use for a canal race, the depression was used for the basements of several buildings and then filled with construction rubble.
There were four key packages of sediment common to the stratigraphy of the two excavation blocks (see Figure 5). The basal package consists of cross-bedded channel sand and gravel dated to ca. 16.6 ka cal B.P. At the upper boundary of this package, the laterally accreted gravelly sands give way to fine sand or silt overbank flood deposits. A radiocarbon date of 6,020±50 B.P., or 6.8 ka cal B.P., was obtained for this boundary from a bulk sample of the 2C2 horizon in Block 1. Overlying sediments fine upward to a buried soil, the 2AB horizon in the Block 1 composite stratigraphy (Figure 6).

Figure 6: Composite Stratigraphy for Block 1 at the Dundee Canal Site (28PA143)
The third package of sediment is more variable across the site and results from cultural inputs and colluviation as well as continued episodic flooding of the terrace surface. All of the pit features and most of the artifacts at Dundee Canal were found at the base of a relict plowzone at the top of this package. Capping the Holocene alluvium, colluvium, and prehistoric midden, there was an upper package of municipal refuse and construction debris. The site was used for the Botany Mills lanolin retrieval plant in the 19th century, and most recently for the Passaic town dump.

The footprint of the lanolin retrieval plant actually encompassed most of Block 2, where prehistoric pit features and other archaeological contexts were found by excavating within the plant's concrete foundations. Recent pavement and over a meter of fill were stripped from an area totalling over 80 m² at which point the relict plowzone was recognized as a brown (7.5YR4/4-5/4) fine sandy sediment with slightly darker stains indicating the pit features. Dateable charcoal was not found in good context in Block 2, although ceramics and other temporally diagnostic artifacts were similar for the Woodland components in the two blocks (Slaughter 1997; Tull et al. 2002).

Artifacts of the Woodland archaeological culture (1000 B.C. - A.D. 1500) were directly associated with materials that were radiocarbon dated. Radiocarbon dates of A.D. 1020 and A.D. 1025 in calibrated calendar years (Stuiver et al. 1998) were obtained for charcoal from pit features in Block 1 (see Table 1). Dundee Canal also appears to have been used during the time of the earlier, Late Archaic culture (3000-1000 B.C.). Lamoka and Orient fishtail projectile
points (Justice 1987; Ritchie 1969, 1971) as well as a steatite bowl fragment were recovered from sheet midden and colluvial deposits in Block 2.

Artifacts from the earliest components at Dundee Canal tended to have had the most complex pathways prior to entering the contexts in which they were found. Above and beyond the successive occupations at the site, this points to greater stream power and erosional activity. The sediment textures support this hypothesis in that coarser and more poorly sorted sands

Figure 7: Grain Size Trends in the Block 1 Stratigraphic Column at the Dundee Canal Site (28PA143)
underlie the buried soil dated to A.D. 366 (1690±60^{14}C yr B.P.) in Block 1 (2AB horizon) and to 269 B.C (2250±50^{14}C yr B.P.) in Block 2 (2Ab horizon).

Most of the Holocene sediments of the Passaic River terrace were probably deposited by colluvial reworking of late Pleistocene till or outwash, and this is clearly true of the Block 2 deposits at Dundee Canal. Block 1 was in a unique setting upstream of the mouth of Weasel Brook, and this may partly account for the abundance of fine sand and silt deposited by overbank floods. All ten samples analyzed from the Block 1 stratigraphic column were at least 70 percent sand, but there are two distinct fining-upward trends (Figure 7). The mean grain size decreases (increasing phi) from the 2C1 to the 2AB horizon and from the BC to the Apb horizon. The coarsest sediments are loamy sand in the 2C1 and 2C2, and their mean grain size is also greater on a clay-free basis (Gale and Hoare 1991: 68; Catt 1987: 493).

Sorting, as measured by inclusive graphic standard deviation (Friedman and Sanders 1978: 75), follows opposite trends on a composite as compared to a clay-free basis. This suggests that clay has been translocated into both the Apb and 2AB horizons.

The soil pH is extremely acid (Soil Survey Staff 1951: 235), less than 4.5, for the entire Block 1 stratigraphic column. The pH generally decreases down profile but is slightly elevated in the coarser-textured 2C1 and 2C2 sediments. This may result from lateral groundwater movement along bedding planes in this sediment. The pH could also be buffered by calcium carbonate dissolved off of limestone clasts in the basal till and outwash.

Total "free" iron was analyzed for all ten samples by citrate-dithionite extraction (Birkeland 1999: 90-92; McKeague et al. 1971). Acid-oxalate extraction was also performed
to obtain the "active" Fe fraction complexed in amorphous hydroxides and organic molecules, a significant portion of the total free Fe not included in silicate minerals. The active Fe in ppm is the "ox" region of the graph in Figure 6, peaking in the Apb horizon. A disproportionate increase in the "cd" curve in the upper part of the buried soil (2AB horizon) suggests the presence of more oxidized forms such as hematite or goethite.

Results for Mn, P, and K show relatively little correlation with cultural activity at Dundee Canal but do further elucidate depositional history and pedogenic trends. Manganese increases down the column to a peak in the 2C2 horizon, probably precipitating as a function of water table fluctuation. Phosphorous peaks in the coarse-textured 2C1 horizon, probably occurring as a phosphatic coating on grain surfaces (Birkeland 1999: 137). Potassium tends to follow the clay curve, in this case peaking in the 2AB horizon.

In spite of the continuous use of the property by industry and for disposal of municipal refuse, Dundee Canal provided significant new data concerning prehistoric cultural activity in the Passaic River valley. Both the massive overburden of 19th and 20th century debris and the complex basal contact with Pleistocene glacial deposits are in fact very typical of project areas currently being investigated by archaeologists working in the glaciated Northeast. Previous studies of soil chemistry and particle size in the region (Bilzi and Ciolkosz 1977; Ciolkosz et al. 1993; Foss 1977) suggest that the iron and potassium increase in buried soils is due to the formation of specific soil mineral phases. The effects of parent material and groundwater on the other laboratory results summarized above have also been observed in previous studies.
Conclusions: Site Formation and Regional Environmental Processes

Since the initial proposal of geoarchaeology by Butzer (1971, 1982), and conceivably since the first scientific excavations of prehistoric sites, archaeologists have been aware of the effects of the regional environment on human culture and its material remains. The potential of archaeological excavations to provide significant information about Quaternary environmental change has also been recognized by a few pioneering researchers (Antevs 1948; Haynes 1991; Laville 1975). There have only been tentative efforts at interdisciplinary collaboration, however, between archaeologists and glacial geologists investigating the retreat of the Laurentide ice sheet in eastern North America. The findings presented above will hopefully stimulate further collaboration along these lines and prompt some consideration of the role which glaciation may play in both regional and site-specific phenomena.

The Quaternary period is characterized above all by glaciation, the Holocene epoch being but one of many interglacials in the period (Holliday 2001; Williams et al. 1998: 18). The ice caps which remain at the north and south pole affect atmospheric circulation (Bryson 1966; COHMAP Members 1988; Kutzbach and Guetter 1986), ocean circulation (Broecker 1991, 1994), and thereby the present, past, and future climate of the Earth. It is quite reasonable to hypothesize that regionally synchronous events in the Quaternary stratigraphic record are somehow related to global forcing mechanisms recorded by ice accumulation rates (Dansgaard et al. 1993; Meese et al. 1994; O'Brien et al. 1995; Petit et al. 1990). Many high-resolution records of global climate change have been obtained, for example, from varved lacustrine sediments containing pollen and other environmentally sensitive fossils (Bradley 1999: 324-326; Eicher and Siegenthaler 1976; Maenza-Gmelch 1997; McWeeney 1994; Peteet et al. 1993).
The stratification in glacial deposits, alluvium, and colluvium is much coarser than that in lake sediments. Nonetheless, correlations with external forcing mechanisms can be proposed and rates for some processes can be estimated. One glacial geologist has proposed, for example, that the sediments at a given recessional margin were deposited in a period measured in tens of years (Koteff 1974: 124). If this were true, it would have taken no more than 500 years for the Laurentide ice sheet to retreat through all five of the margins mapped in New Jersey. This is excessively rapid given what is known about deglaciation elsewhere in the Northeast (Muller and Calkin 1993; Ridge et al. 1999), but it is a starting point to compare with the estimates from radiocarbon dating. Dates presented above and by Stanford (1997) suggest that the ice had retreated from New Jersey by 17 ka cal B.P.

The Dundee Canal stratigraphy demonstrates that there are in fact some alluvial deposits in the study area which belong to the interval between deglaciation and the Pleistocene-Holocene boundary. As argued above on both biostratigraphic and archaeological grounds, this boundary should now be placed at 11.5 ka in calibrated years before present. Radiocarbon dates from pre-Clovis contexts at Cactus Hill in Virginia (Goodyear 1999: 435-436; McAvoy and McAvoy 1997) and Meadowcroft Rockshelter in Pennsylvania (Adovasio et al. 1977, 1978, 1999) suggest that humans may have reached eastern North America several millennia before 11.5 ka cal B.P. Laurentide ice was still present in some portions of eastern North America at the time these more controversial sites are inferred to have been occupied. Some Pleistocene glacial deposits may therefore conceivably contain artifacts and other remains of prehistoric cultures, although there have been no in situ finds to date.
The geometry of the basins which held the meltwater from the Laurentide ice sheet resulted in several particularly large, "catastrophic" discharges into both the Gulf of Mexico (Leventer et al. 1982) and the Atlantic Ocean (Broecker et al. 1989; Teller 1990). Recent studies of marine sediment cores (Bond et al. 1996, 1997; DeMenocal and Bond 1997; Marchitto et al. 1998) indicate that meltwater discharges and ice-rafting events caused abrupt changes in the Earth's climate. In particular, the Younger Dryas abrupt global cooling at ca. 12.5 ka cal B.P. can be attributed to a disruption of the production of North Atlantic Deep Water (Broecker et al. 1988). Pollen and plant macrofossil evidence for the Younger Dryas has been found in lake sediment cores from the glaciated Northeast (Maenza-Gmelch 1997; McWeeney 1994; Peteet et al. 1993).

Deposits of Younger Dryas age are of considerable interest to archaeologists because of their potential to contain the remains of Clovis and other Paleoindian cultures. Unfortunately, sites containing Paleoindian materials in good stratigraphic context have yet to be excavated in the study area. Cold intervals in the glaciated Northeast tend also to have been dry in terms of effective precipitation (Webb et al. 1998). This might mean that water tables would have been depressed in the interior, and we know that regional sea levels were still at least 30 meters lower than at present (Bloom 1983; Newman et al. 1969). As suggested by McWeeney and Kellogg (2001), the deposits of archaeological interest in the interior river valleys may very well be a meter or more below the modern water table. The submerged terrestrial deposits in New York Harbor and Newark Bay continue to attract archaeological attention because of their potential to contain discrete, early contexts (GRA 2000; LaPorta et al. 1999; Stright 1986, 1990).
Recent models of the geometry of glacial deposits (Koteff 1974; Koteff and Pessl 1981; Stone et al. 1998) can be used to predict the variation in sediment textures along the downstream axis of river valleys in the glaciated Northeast. In the Passaic River valley, the morainal deposits at the recessional margins stand out because the channel gradient is somewhat steeper and flanked by particularly resistant terrace outcrops (Stanford 1993). This variation along the downstream axis affected the distribution of prehistoric features and cultural materials among the four sites investigated within the Route 21 Corridor. While the relationships were determined after completion of the field investigations, it clearly is possible to use the results of the Quaternary surficial mapping in New Jersey to explain and predict certain processes of archaeological site formation.

The greater stream power and erosional activity evident in the early- to mid-Holocene deposits at Dundee Canal is consistent with paleoenvironmental proxy data from the study area and the glaciated Northeast as a whole. The warmest interval within the Holocene epoch, the Hypsithermal, was locally characterized by abundant precipitation which favored both deciduous forests and freshwater marshes (Rue and Traverse 1997; Webb et al. 1998). Peat dated to 5.8 ka cal B.P. at North Arlington, for example, records the development of an early freshwater marsh in the Hackensack Meadowlands (Thieme et al. 1996). At the Collect Pond on Manhattan Island, freshwater peat accumulated on top of a buried soil which dates to 5.3 ka cal B.P. (Schuldenrein 2000). Farther afield, freshwater marsh replaced closed-canopy forest at Robbins Swamp in northwestern Connecticut at ca. 8 ka (Nicholas 1998). This is approximately the same time as the highstand at Lake Owasco in north central New York reported by Dwyer et al. (1996).
Whereas overbank deposition occurred at Dundee Canal when stream power increased due to greater effective moisture, the buried soil formed during what appears to have been a cold, dry interval in the regional climate. As recently observed by Anderson (2001), the first several centuries of the Woodland period were relatively cold, with two fairly dramatic short term cold events. The radiocarbon dates for the Dundee Canal buried soil are actually nearly a thousand years younger than these proposed abrupt global cooling events at 3.1 ka and 2.8 ka (Baillie 1988; Bond et al. 1997; van Geel et al., 1998, 1999). Perhaps it was really the sequence of rapid oscillations from cool, dry to warm, wet climate modes in the late Holocene which produced the buried soil.

By knowing more about these sorts of regional environmental processes which affect the formation of archaeological sites, we are able to make better decisions about where and how deep to dig in order to save on the costly and tedious labor of hand excavation. For urbanized settings in the glaciated Northeast, this means being able to identify intact Holocene deposits beneath the historic overburden. It also means being able to identify glacial deposits beneath the sediments of archaeological interest. Geoarchaeological knowledge further makes it possible to place artifact assemblages in stratigraphic sequence and relate them to changes in the regional environment. To the extent that we are able to determine the rates at which materials were eroded from or deposited on the land surface, as attempted above for Dundee Canal, we can relate the relative integrity of the archaeological contexts to regional environmental change.
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