# CHAPTER 5

# BLUFF TOP SAND SHEETS IN NORTHEASTERN ARCHAEOLOGY: A PHYSICAL TRANSPORT MODEL AND APPLICATION TO THE NEVILLE SITE, AMOSKEAG FALLS, NEW HAMPSHIRE

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Overlook sites from upland settings comprise a significant portion of the archaeological record in the northeastern United States (e.g., Ritchie 1965; Funk 1976; McBride 1984). They range in size from isolated lithic scatters to dense accumulations from intermittent reoccupations. Stratigraphic isolation of cultural components in such settings is rare, owing to the combination of low sedimentation rates and continuous secondary disturbance by biogeochemical processes, which act together to produce complex palimpsests (e.g., Wood and Johnson 1978; Johnson 1990). Although bioturbation is most closely associated with the outward dispersion of artifacts from initially tight clusters, it can also concentrate artifacts into horizons through the effects of particle settling and tree-throw and the development of lag horizons during colluvial transport. Most of these disturbance processes occur within the A and upper B horizons of the soil, where nutrients encourage root growth and animal activity, leading to a network of macropores that control the fate of artifacts.

Burial of this biologically active zone, or even partial burial, can isolate surface archaeological components from subsequent disturbance processes, at least statistically, thereby contributing to the integrity of buried artifact horizons. Lowland contexts—beaches, floodplains, colluvial footslopes, and alluvial fans—are depositional environments where sediment accumulation can outpace bioturbation, at least during extreme events associated with floods and storms. Under normal conditions elsewhere, however, the pace of sedimentation is almost always slower than turbation processes.

West-facing bluff-top settings are an exception to this generalization, providing an additional context where burial can outpace turbation. In this setting, discrete pulses of eolian deposition ranging in thickness from a film of dust to decimeter-thick strata are often associated with geologically short intervals of bluff erosion and exposure. Unlike lowland areas, however, bluff-top deposition takes place on overlook sites that are warmer, drier, and breezier than lowland sites, making them attractive settlement locales, providing not only high visibility of the surrounding terrain, but also access to both riverine and upland resources. Burial of bluff-top archaeological components by windblown sediment from local sources is known from a number of North American sites (e.g., Thorson and Hamilton 1977; Bettis and Hajic 1995; Van Nest 2002:58). Similar settings exist in New England, although they are historically under-recognized (Colby et al. 1953) and are thus largely unreported in the local archaeological literature.

This chapter presents a qualitative model for bluff-top sedimentation that can be applied throughout the northeastern U.S. and adjacent Canada. We begin by introducing a candidate site for this depositional model—the Neville site at Amoskeag Falls, New Hampshire (Dincauze 1976), the type site for the Middle Archaic in New England (Table 5.1 and Figure 5.1), a place where massive beds of "dusty" sand separate its buried, bluff-top, archaeological components.[1] We then develop a physical model for sediment transport and archaeological burial in bluff-top settings. Next we survey the distribution and stratigraphic contexts of northeastern sites, examining their buried sediment horizons with our model in mind, giving special attention to the Neville site. Finally we speculate that the high concentration of Middle Archaic artifacts at the Neville site, the dearth of early artifacts, and the separation of artifact horizons throughout the sequence can all be explained by local conditions associated with bluff-edge retreat that intermittently enhanced the suitability of the Neville terrace for habitation.

## AMOSKEAG FALLS

The Neville site is one of several archaeological sites in the vicinity of Amoskeag Falls, in Manchester, New

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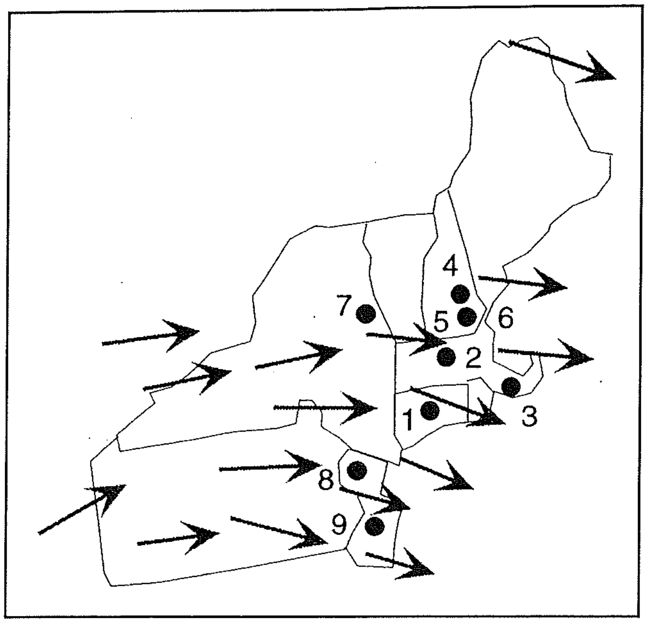


Figure 5.1. Sketch map of the northeastern states showing resultants for sand roses of winds exceeding 6 m sec$^{-1}$. Modified from Wells (1983). Also shown are sites from the region listed in Table 5.1.

Hampshire, which formed after drainage of glacial Lake Merrimack ca. 12,500 years ago (Ridge et al. 2001). Subsequent downcutting of the Merrimack River exposed bedrock at the falls as well as glaciolacustrine and glaciofluvial sediments, most of which are deltaic sands (Koteff personal communication, cited in Dincauze 1976; Koteff 1976). The archaeological importance of this area is demonstrated by the close proximity of three excavated sites to within 0.5 km of the falls—the Neville site (Dincauze 1971, 1976), the Smyth site (Foster et al. 1981), and the Eddy site (Bunker 1992)—and by the large numbers of artifacts recovered from these sites and others, now stored in both private and local historical society collections (Dincauze 1976:1).

The Eddy site lies on the western bank of the Merrimack River, downstream from the falls. Artifacts lie within overbank alluvial deposits and include a basal quartz-dominant lithic industry typologically assigned to the Early Archaic, with associated $^{14}C$ assays dating to ca. 8,000 years ago. Additional vertically discrete artifact layers span the Archaic and Later Woodland Periods. At higher elevation and across the river is the Smyth site, which occurs on top of and within Holocene soil developed on a Late Pleistocene dune overlooking the falls; most recovered artifacts span the Late Archaic through Recent Periods, indicating that eolian deposition continued, at least locally, during late Holocene time.

The Neville site lies on a glaciofluvial terrace above the eastern bank of the Merrimack River at an elevation intermediate between the Eddy and Smyth sites. The terrace tread lies about 10 m above the river under baseflow conditions and well above flood level, precluding a fluvial origin for the archaeological sediments. The tread also lies about 13 m below the upper, dune-draped bluff on which the Smyth site is located. The Neville terrace contains a 3-m-thick, plow-truncated sequence of

Table 5.1. Northeast Sites in Bluff-Top Settings

| No. | Site | Age | State/ Province | References |
|---|---|---|---|---|
| 1 | Red Hills | Unknown | CT | Bellantoni, personal communication (2002); personal observation |
| 2 | WMECO | Middle Archaic–Middle Woodland | MA | Thomas 1980; Dincauze 1989 |
| 3 | Wapanucket | Paleoindian–Recent | MA | Robbins 1980 |
| 4 | Sewall's Falls | Archaic–Woodland | NH | Starbuck 1982, 1983 |
| 5 | Smyth | Paleoindian–Recent | NH | Foster et al. 1981 |
| 6 | Neville | Middle Archaic–Recent | NH | Dincauze 1971, 1976 |
| 7 | Upper Hudson Valley | Woodland | NY | Bender and Curtin 1990; Bender, personal communication (2002) |
| 8 | Rosenkrans Ferry | Woodland | NJ | Cross 1941:132–143 |
| 9 | Abbott Farm | Paleoindian–Early Woodland | NJ | Cross 1956; Stewart 1983 |
| 10 | Barnes Creek | Late Woodland | MI | Larsen 1985 |
| 11 | Knechtel | Late Archaic | ON | Wright 1972 |

sediments, bearing artifacts spanning the Middle Archaic through Recent Periods. The Neville site was excavated in 1968 by Peter Lane, of the New Hampshire Archaeological Society, as a salvage operation prior to destruction of the area for bridge construction. Lane died prior to completion of the final report. Dena Dincauze (1971, 1976) completed subsequent laboratory analysis and reconstruction of site stratigraphy. It was the first stratified and well-dated Middle Archaic (8000–6000 B.P.) site in New England (Dincauze 1971).

Until recently salmon, shad, alewives, and other fish ran Amoskeag Falls to spawn during the late spring, providing a predictable, seasonal resource that likely provided the primary attraction for human settlement in the area; native populations were observed to congregate at the falls in spring well into the 17th century. Although faunal remains are not preserved, concentrations of iodine and mercury within sediment recovered from subsurface strata of the Neville site are consistent with the processing of anadromous fish (Dincauze 1976) throughout much of the Holocene time, which is likely responsible for the dense archaeological accumulations there. The repeated and concentrated human activity at the falls has obscured reconstruction of individual occupations (e.g., Dewar and McBride 1992) as well as social, political, and refuse-related phenomena, which often leave no discernable archaeological trace.

## TRANSPORT MODEL

Owing to the importance of wind erosion and desertification, the literature on eolian sedimentation is extensive and highly quantitative. Empirical field and laboratory research, largely from engineering, focuses on the shear coupling (traction) between the airstream and the ground (fluid mechanics), the properties of sedimentary grains (density, shape, sorting, size, etc.), the mechanics of particle transport (creep, saltation, suspension, and variants thereof), and the role of roughness in causing flow separation. Simplifying assumptions associated with flat beds, uniform roughness, and spherical sediment grains are usually made to render the problems mathematically tractable. Forested bluff-top settings, however, depart from such idealized conditions largely due to the contrast in roughness associated with the forest edge (and the bluff face), the compression and acceleration of the airstream in response to the topographic constriction, the frictional loss of wind energy by chaotic processes associated with leaf and branch motion, and the mixed sediment texture of bluff-top deposits (particle-size ranges, generally 0.05–0.5 mm).

For simplicity, we restrict our bluff-top site-formation model to inland, forested terrace edges overlooking broad lowlands filled with glaciolacustrine, glaciomarine, and glaciofluvial sediments. Although mantling less than 15 percent of the Northeast by area, these waterlain deposits are widely distributed throughout the region, are associated with all important valleys (Lakes Erie and Ontario, and the Hudson, Connecticut, Merrimack, and Penobscot Rivers, etc.), and co-occur with thousands of known archaeological sites. We do not consider the case of unforested bluffs, because forest has been present during the entire human occupation interval. (An early and abrupt arrival of *Picea* and *Pinus* in the Northeast roughly coincides with the Bolling-Allerod transition (Interstade 1), dated to 12,900 B.P. [Gaudreau and Webb 1985].) We also restrict our model to settings where lake or river levels have risen and fallen through time, rather than to coastal settings where sea level has risen monotonically; in these circumstances bluff erosion and sedimentation take place during rare but dramatic geological events such as hurricanes, meander shifts, valley avulsion, and lake flooding. Finally, our model deals only with the eastern sides of major valleys, downwind from the sedimentary basins that provide both a source for sedimentary particles as well as a broad fetch along which the wind may intensify (Figure 5.1).

### Boundary Conditions

We begin by considering the problem in two dimensions along a line parallel to the wind direction (Figure 5.2). Three topographic locations are considered: the *fore-bluff* of infinite width, refers to the lake, estuary, or alluvial valley below the bluff in question; small scarps may be present. The *bluff face* is a relict topographic step facing into the wind (terrace, shoreline, cliff, etc.) that was created initially by downcutting, and which is intermittently steepened by lateral erosion; the angle of the topographic step varies during steepening events, but generally remains close to the angle of repose for uncohesive sands and gravels (typically 31–37$^{o}$). Steeper slopes are present only during a transient phase of lateral erosion; gentler slopes having the downhill convex-concave profile of humid, creep-dominated slopes occur during much longer intervals of soil development. The *bluff top* is the original subhorizontal terrace tread; its level is stationary but its front may erode backward during increments of bluff erosion.

Wind energy, which diminishes progressively in a downstream direction from the lowland, is lost at five different transport levels. Level 1: Topographically lowest is the distal, downwind limit of the fore-bluff, here assumed to be an unvegetated bar or beach below the bluff face; wind moves parallel to the surface. Level 2: The bluff face is both the site of sediment entrainment and a back-facing escarpment that forces convergence of

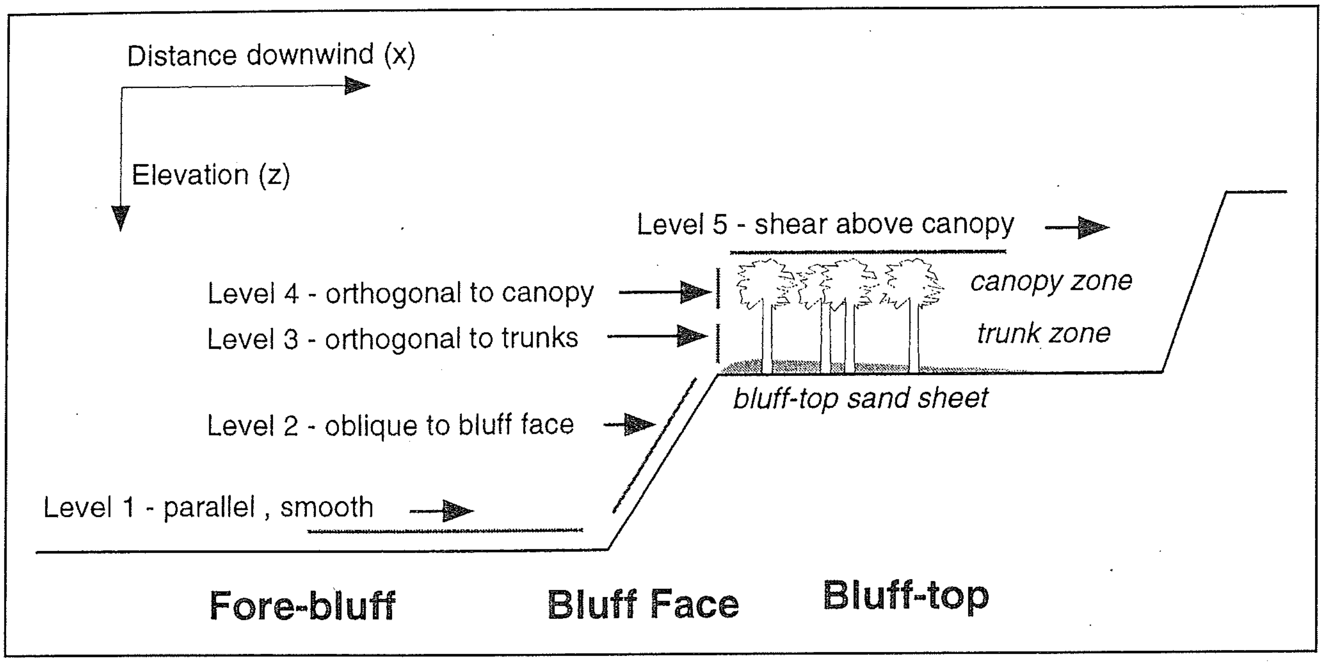


Figure 5.2. Geographic terms used in this chapter. Transport levels are defined in the text.

the airstream; this topographic step includes the height of the forest if the trees are thick enough to block the wind, but otherwise it does not include the forest. The third and fourth levels comprise the vertical front of the forest on the bluff face. Level 3, the trunk zone, is defined only when the understory is thin enough to allow wind to blow above the soil but beneath a raised canopy; in this setting, the trunks of the trees act as a comb for the wind stream moving through the canopy zone above and the surface of the bluff below. Level 4, the canopy zone, is effectively a barrier to the wind, because easier passage lies below (in the trunk zone of Level 3) and above. Level 5 is the aerodynamically rough, subhorizontal surface of the canopy; there the energy loss takes place at the base of the airstream.

## Physical Processes

The processes (Figure 5.3) increase in complexity from the simplest (horizontal traction on a uniform bed) to the most complex (interactive effects from five levels).

*Wind Profile on a Uniform Bed; Levels 1 and 5*

On aerodynamically rough surfaces, the wind speed above the ground under steady-state conditions is given by the Prandtl-von Karman equation (Thwaites 1960)

$$U/u^* = 1/k^* \ \ln (z/z_0)$$

where U is the velocity at height z, u* is the velocity gradient shear velocity, k is a constant, $z_0$ is the characteristic roughness displacement height, the point at which velocity is effectively zero. On smooth surfaces, $z_0$ ranges from 0.5 to 10 x $10^{-4}$ m with d, the predicted displacement height, being negligible. For grass 0.25 to 1-m high, $z_0$ and d rise to 0.04 to 0.2 m and < 3 m, respectively. For forest (average value for deciduous and coniferous), however, $z_0$ and d rise to between 1.0 to 6.0 m and < 25 m, respectively. In other words, beneath a continuously forested landscape, the wind effectively blows at treetop level on a very rough surface, and the velocity is effectively zero near the forest floor.

*Forest Edge with No Other Topographic Change: Contrast Between Levels 1 and 5*

Consider an abrupt increase in the roughness such as that along the edge of a continuous, dense forest. Here the velocity profile is displaced upward, becoming

$$U/u^* = 1/k\ [(z\text{-}d)/z_0]$$

Under limiting conditions in which the forest is completely impermeable to wind, all of the kinetic energy is displaced upward, where it flows over a much rougher surface on top of the canopy, an action that lowers the shear velocity faster than on unforested ground, enhancing sedimentation. In this case, the forest edge effectively acts as a vertical bluff with a soft, tapered edge. Wind, forced upward, must accelerate over the forest edge at the front of the canopy. The transition from

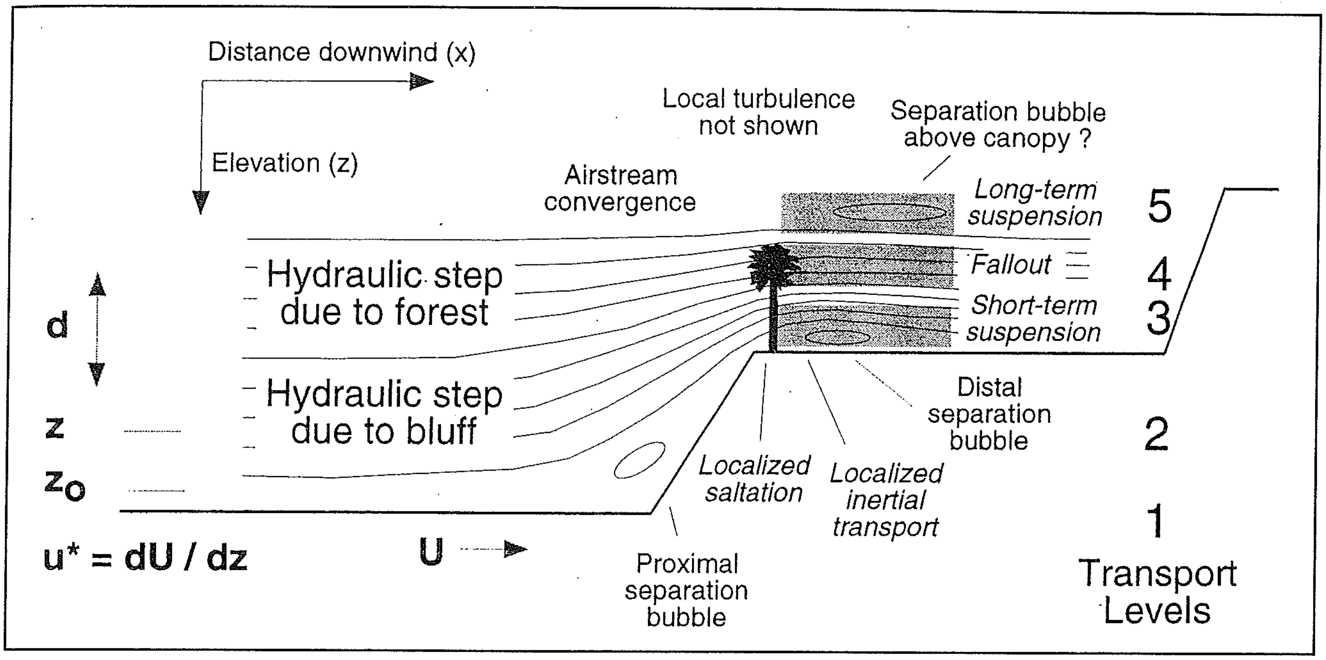


Figure 5.3. Simple hydraulic factors associated with deposition of bluff-top sand sheets. Letters indicate terms in equations 1 and 2. The hydraulic step caused by the forest is present only when the forest is thick. Separation bubbles (or low-velocity zones) form above the bluff when the forest is thin or when the canopy is either raised or very dense. Italicized terms identify sediment transport processes to the bluff-top sand sheet.

smooth bed to rough bed is not simple. The addition of a few roughness elements (trees) may actually increase local entrainment and enhance transport, because the wind is funneled around objects, causing flow separation and the formation of turbulent eddies. Above a critical concentration of trees, however, the addition of roughness elements uniformly diminishes the rate of sediment transport.

*Leaking Forest Edge; Levels 3 and 4*

Under normal circumstances, however, some of the wind energy is lost as it blows inward to the forest from its exposed edge. If the forest edge is thin enough (gallery forest), an outlet for the wind in a downstream direction will exist, and the wind will blow through, rather than above, the forest, especially in Level 3. If the bluff-top band of forest is thick, however, there is no outlet for wind forced horizontally into the trees, causing wind that enters to be ventilated upward through the canopy. The total kinetic energy of the wind ($E_{kt}$) is given by

$$E_{kt} = E_{kl} + E_{kc} - E_p - F$$

It must equal the sum leaking into Levels 3 and 4 ($E_{kl}$) and that being displaced upward to canopy height ($E_{kc}$), minus the frictional losses (F) associated with swaying and fluttering of forest components and the small gain in potential energy ($E_p$) associated with wind being lifted to canopy height.

*Flow Separation at Topographic Breaks at Levels 2 and 3*

When a viscous fluid (such as air) encounters an obstacle, it experiences flow separation, creating what are known as separation bubbles (or rollers for the two-dimensional case). The most familiar separation bubbles are stationary eddies—whirlpools—which exhibit local reversals in flow direction. In the case of bluff edges, there are two separation bubbles. The proximal bubble lies at the base of the bluff and diminishes in importance as the slope angle declines. The distal bubble originates at the bluff edge, and, if the wind is strong enough, reattaches downwind; the shape of the resulting sediment body depends on many factors, primarily the viscosity of the fluid, the velocity, and the roughness (Hetu 1992:Figure 9A). In addition to creating a permanent distal separation bubble, the bluff also acts as a constriction for the wind, forcing the horizontal flux through a smaller cross-sectional area. As a consequence, the airstream is deflected upward and increases in velocity (which lowers the pressure through the Bernouli effect). Separation is straightforward above an unforested vertical bluff edge or under conditions when a dense forest with uniform canopy essentially raises the height of the bluff. More realistic and complex, however, is the case where the forest is "permeable" to the wind (Level 3). A highly permeable Level 3 merely complicates the flow separation process, rather than eliminates it. An impermeable Zone 3 forces flow separation to take place largely above the canopy. Under normal circumstances bluff-top flow separation is present, but weakly expressed.

*Sediment Source*

Sediment entrainment by wind is negligible on continuously vegetated surfaces, hence a loss of vegetation cover by erosion is required. Rarely, slumping of a bluff edge can expose a surface to deflation. Normally, however, the bluff must be undercut by water; the loss of support then propagates upward, destabilizing the entire bluff face. On sand and gravel, the slopes quickly ravel to angle of repose slopes. Maintenance of the unvegetated bluff requires continuous undercutting. Sediment may be entrained either from the beach or floodplain or from the bluff itself. Erosion is limited by the threshold shear velocity ($U_{*t}$), which is given by

$$U_{*t} = A \, [(\rho_p - \rho_a) \, g \, D \, / \rho_a]^{0.5}$$

where $\rho_p$ and $\rho_a$ are the particle and air densities, respectively, and A is an empirical coefficient related to surface roughness and grain characteristics, and D is the particle-size diameter. Note that the threshold velocity is related to the square root of the particle diameter. Once motion is initiated by creep, the movement of grains enhances local turbulence and their momentum is transferred on impact, causing rapid sediment movement called saltation. Dust liberated will be carried forward by other processes.

Sediment sources on the bluff are maximized when the bluff is high (maximum contact with the deflating wind and maximum constriction of the airstream), uniformly weak in composition (smooth, continuously raveling surface without secondary roughness), and oriented favorably with respect to prevailing wind direction. Sediment sources on the lowland are maximized when the fetch is broad and the surface smooth and when waves or floods prevent the formation of a lag horizon.

*Sediment Transport*

Three principal modes of transport—suspension, surface creep, and saltation—are largely a function of particle size. Suspension can be divided into long-term suspension characteristic of dust storms, acting on particles generally < 20 μ (0.020 mm) and short-term suspension, a complex but widely present transport mechanism restricted to coarse silt and fine sand at shear velocities of 50–200 cm $sec^{-1}$. Creep involves the rolling and pushing of large particles (> 500 μ; 0.5 mm) by the bombardment of saltating particles. Saltation refers to the movement of particles of intermediate size by a series of shorts leaps or bounces. Regardless of process, particle concentration decreases hyperbolically with increasing height (z) above the ground. Bluff-top dunes, especially when eolian bedforms are present, indicate saltation as a dominant process. A thin layer of fine dust, which would eventually lead to the accumulation of loess, is dominated by long-term suspension.

Most bluff-top sand sheets are neither dunes nor loess accumulations per se but are more complex in origin. In New England they have been referred to as the "eolian mantle" (Hartshorn 1976; Thorson and Schile 1995). Similar "mixed-source" eolian deposits are common components of geoarchaeological models in early and mid-Holocene deposits throughout North America (Bettis 1995). Hetu (1992) presents an extreme case in which a sheet of windblown coarse sand and granules composed largely of shale chips (mean thickness of 11.4 mm; area of 1,200 $m^2$) which was deposited by a single storm.

*Bluff Retreat*

Implicit in the model of the exposed bluff is the idea that the bluff top retreats incrementally backward, sometime after erosion at its base (Figure 5.4). Conditions might arise, however, when erosion is restricted to the base of the bluff. Alternatively, erosion near the bluff top might lag behind that at the base, leading to slumps. Regardless, sediment entrained from the lowland or from the base of the bluff may be blown up into vegetation on, rather than above, the bluff edge, complicating the model.

*Soil Development*

Holocene soil formation dominated by the accumulation of organic matter, biogeochemical changes in the parent material, and bioturbation, takes place continuously, with a small addition of eolian dust. Pulses of sediment, if rapidly deposited, isolate soil horizons from the surface action.

## Time Steps

Three time steps take place in sequence on a forested surface in which mature trees have raised canopies (Figures 5.3 and 5.4).

*Step 1.* Background conditions ($10^2$–$10^4$ years) consist of times when net sedimentation is limited to dust influx from distant source areas. Bioturbation and pedogenesis take place under continuously forested conditions.

*Step 2.* Bank erosion ($10^0$–$10^2$ years) associated with high lake levels, extreme floods, channel avulsion, or

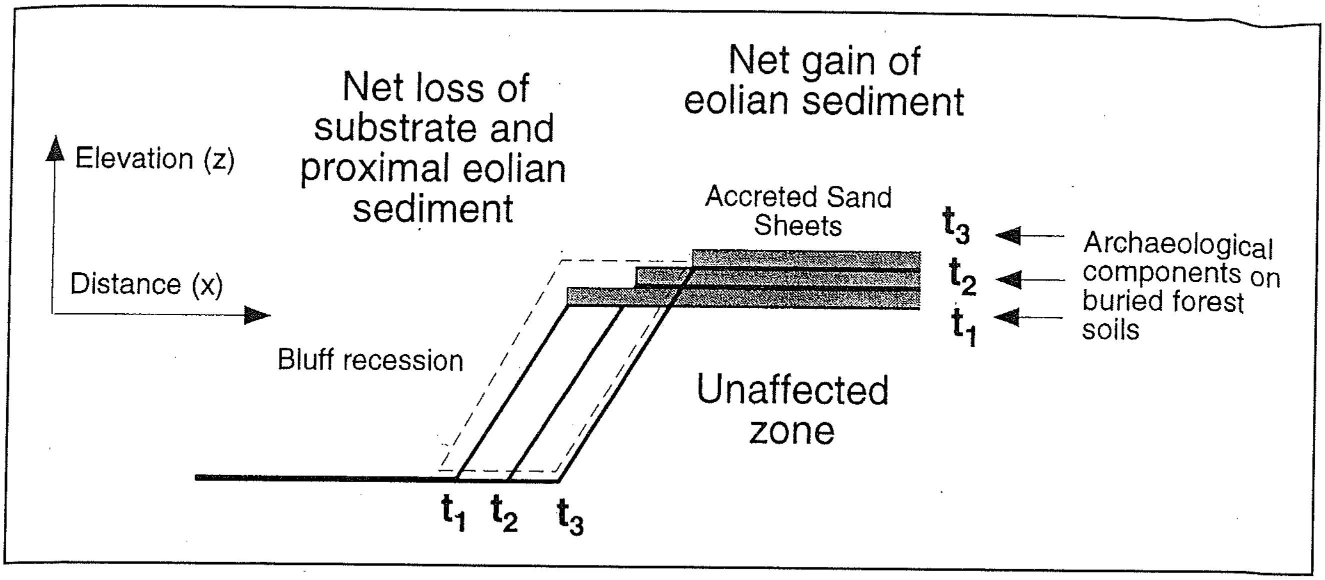


Figure 5.4. Schematic model emphasizing temporal component of bluff-edge sand sheet accretion. Pulses of erosion $t_1$ through $t_3$ lead to parallel retreat of the bluff face (dark lines), during which enhanced sediment transport and local entrainment lead to the deposition of bluff-edge sand sheets (gray). Note that erosion also removes part of the sand sheet. Artifacts are most likely to be deposited during the transition from exposed to forested conditions.

meandering shifting leads to destabilization of the slope. After the instability has propagated upward to the bluff top, an increment of erosion may take place. An exposed bluff provides a source area for deflation, or it may merely provide an aerodynamically smooth surface through which sediment entrained from the fore-bluff (Level 1) may occur. The sedimentation pulse consists of three basic facies.

Sand saltating up the bank can be accelerated into short-term suspension near the top of the bluff and be deposited immediately leeward of the bluff edge. Normally the sand will simply fall from short-term suspension into the proximal part of the separation bubble, where it is mixed with finer material blown up by other processes. In the rare cases where the sand flux is high, however, saltation can continue beyond the bluff edge, forming a true bluff-top dune the upper surface of which must conform to the local airstream; as the dune grows it usually assumes a parabolic (blowout) form with the separation bubble migrating downwind. Such dunes typically form only locally where sediment flux is maximized by bluff-parallel topography and a lack of vegetation cover.

Sand moving in turbulent gusts up the bluff face within short-term suspension carries well past the bluff edge, falling over a broad area perhaps 2–10 m wide for a thick, raised-canopy forest. Owing to inertial effects, the coarsest sand is restricted to the edge. This process is enhanced when the canopy is high, allowing fine sand to be carried in suspension through the trunk zone, forming a deposit that gradually diminishes in thickness. Sediment transport diminishes through normal fallout processes, both because the wind flux is diminished through upward loss, and because the wind shear is diminished by frictional losses from the ground and from the base of the canopy. Canopy structure will largely determine how far inland this facies penetrates.

Very fine sand and silt carried to the top of Level 4 in suspension (front edge of the canopy) will move subhorizontally in Level 5 above a weak separation bubble. Enhanced roughness consumes wind energy forcing the deposition of material being carried low in the wind stream. Deposition may be direct to the forest floor or indirect through the rain washing of leaves. Sedimentation is supply limited, its rate dependent on bluff-face conditions.

Excluding parabolic bluff-top dunes, the shape of the sediment body resulting from these processes will likely be tabular. In theory, the body will thicken away from the bluff edge, because inertial forces force the maximum flux several meters inland from the bluff edge then thin away from the zone of maximum concentration through normal fallout processes. Bedforms and discrete beds will be absent, because traction cannot take place on a rough surface that probably remained continuously vegetated during the pulse of sediment deposition; at normal sedimentation rates, bioturbation is dominant. The bulk texture will be poorly sorted because several processes are at work. Importantly, the eolian nature of these deposits may not be apparent. If thick enough, and deposited fast enough, the bluff-edge sand sheet can isolate a former ground surface producing a buried paleosol.

*Step 3.* Stabilization ($10^2$–$10^3$ years). Eventually, the fore-bluff and the bluff face will become stabilized, cutting off the sediment supply, and inaugurating a phase of soil development. The bluff face, being xeric and deficient in organic matter, must experience a transient phase of ecological succession before forest can be reestablished on the bluff face. Hence a transient phase will exist when the bluff top provides ideal conditions as an overlook, because an unobstructed valley view is available from a shaded, well-drained vantage point. Therefore we should expect archaeological occurrences to lie at or near sediment interfaces or incipient soil horizons.

Our model refers to the unrealistic two-dimensional situation where there is no component of sediment motion oblique to the bluff edge. Yet any curvature of the bluff face will influence sedimentation patterns. For example, wind is often funneled up small gullies, resulting in irregular, bluff-top dunes. Sand blowing obliquely on the slope will be focused inland to the bluff top where the curvature of the scarp is toward the fore-bluff. Erosion of the bluff top by lateral processes often leaves the dense mat of roots intact; they can drape the upper edge of the bluff face, either enhancing (by macroscale smoothing) or minimizing (entrapment) sand transport. Blowdown by trees, which may be concentrated at the bluff face, will locally complicate the scenario.

Assuming the human occupants use the bluff as an overlook, the maximum concentration of artifacts will lie a short distance inland from the bluff edge. Loss of integrity to components includes three processes. The first is pervasive bioturbation, which fractionates artifacts generally downward. Second is human disturbance, which can take many forms, including trampling, site maintenance and secondary disposal, feature excavation, development of anthrosols, etc. (Schiffer 1987). Third is frontal erosion of the bluff, in which the artifacts are permanently lost to the bluff-top environment. The absence of artifacts from the lowest layers of a bluff-top site may reflect frontal erosion, rather than the absence of occupation. The artifacts may not be permanently lost from the system but may be buried in the colluvial wedge below.

## APPLYING THE MODEL

Given the apparent preferential past occupation of river terraces, and the number of recent regional surveys that have focused upon major river valleys (e.g., Snow 1980; Kenyon and McDowell 1983; McBride 1984; Bender and Curtin 1990; Funk 1976), this model should be applicable to a number of sites in the Northeast. Table 5:1 presents a preliminary list of 11 such sites, in both fluvial and lacustrine contexts, from a brief review of the published literature; the model may not apply equally to all of them.

Eolian deposits and artifacts co-occur in the Connecticut Valley at the Red Hills area and the WMECO site complex in Gill, Massachusetts. The Neville, Smyth and Sewall's Falls sites in the Merrimack Valley all preserve archaeological deposits in windblown sediment on bluffs or terraces upstream of major waterfalls. A number of candidate sites exist in the Upper Hudson Valley, along the Hoosic and Battenkill Rivers where bluff-top sites are known, and eolian sedimentation suspected (S.J. Bender, personal communication 2002). Bluff-top eolian sedimentation occurred at the Rosenkrans Ferry site in upstate New Jersey, along the Delaware River and near the southern limit of the last glaciation. The Abbott Farm site complex rests on redeposited glacial outwash ("Trenton Gravels") from which fines were winnowed and blown onto the overlying bluff tops.

Climate-driven fluctuating lake levels may expose fine-grained lacustrine sediment during low lake stands, with subsequent entrainment by wind burying stable land surfaces. Examples of this from the Great Lakes region are recorded by Larsen (1985) for the Barnes Creek site and likely apply to the Knechtel 1 site as well. Smaller lakes may also provide sufficient wind velocities for eolian reworking of beach deposits. The various sites at Wapanucket occur within a large dune at the northern edge of Lake Assawompsett, Massachusetts. The dune appears to have undergone a continual process of net aggradation accompanied by localized erosion. Strong winds blow off the lake, and the adjacent bluff is undercut by wave action today (Robbins 1980). Artifacts from the Paleoindian to Recent Periods occur in the sediment, although little cultural stratigraphy has been preserved due to both the intensive (re)occupation of the site in the past and extensive looting.

We propose that the Neville site was occupied during intervals of bluff-face erosion and restabilization because of (1) the fact that grain-size coarsens upward, suggesting an increasingly proximal sediment source, such as that provided by a progressively retreating bluff edge, (2) the coincidence of high sedimentation rates with periods of intense occupation, suggesting a correlation between sediment availability and settlement suitability, and (3) the location of major occupation floors at or immediately below strata interfaces, indicating a correlation between occupation and change in sedimentary regime.

### Stratigraphy

After a period of subaerial exposure, a ~6-cm-thick bed of alluvium was deposited upon the weathered surface of the original terrace tread. Subsequent deposition was of windblown sediment (Stratum 5B-2). Strata were divided both on color and textural differences as well as artifact type and density. Stratum 4 is described as a "typical greasy, black midden soil" (Dincauze 1976:19), while Strata 2 and 1 are a plow zone and 19th-century construction debris, respectively.

The 1.14-m depth marks a significant change in the site's history.[2] The Neville terrace appears to have been occupied most frequently below this depth (the Middle Archaic occupation), which also coincides with a period of increased sedimentation rates relative to the overlying strata (Dincauze 1976; 1989:3). We believe that our model provides an explanation for this co-occurrence, which may be due in part to changes in the local environment driven by a warmer, drier interval of the Holocene.

### Grain-Size Analysis (Figures 5.5 and 5.6)

Sediment samples were taken at 15.2-cm intervals from a soil monolith approximately 12 m from the terrace edge (Dincauze 1976:10–12). Samples below 1.14 m (Neville 2, 3, and 4) coarsen upwards (increase in the "C" fraction of medium to very fine sand), whereas those above Stratum 4B exhibit little compositional change (Neville 5 and 9). Although the winnowing of fines by wind cannot be ruled out, this coarsening-upward sequence is consistent with an erosional retreat of the terrace edge (Time Step 2), resulting in an increasingly proximal sediment source. The bulk of the material at the Neville site is not well sorted; this, and the absence of recorded sedimentary features, is consistent with our depositional model. The bulk texture is also similar to the eolian mantle found throughout much of New England (e.g., Thorson and Schile 1995:753; Hartshorn 1967).

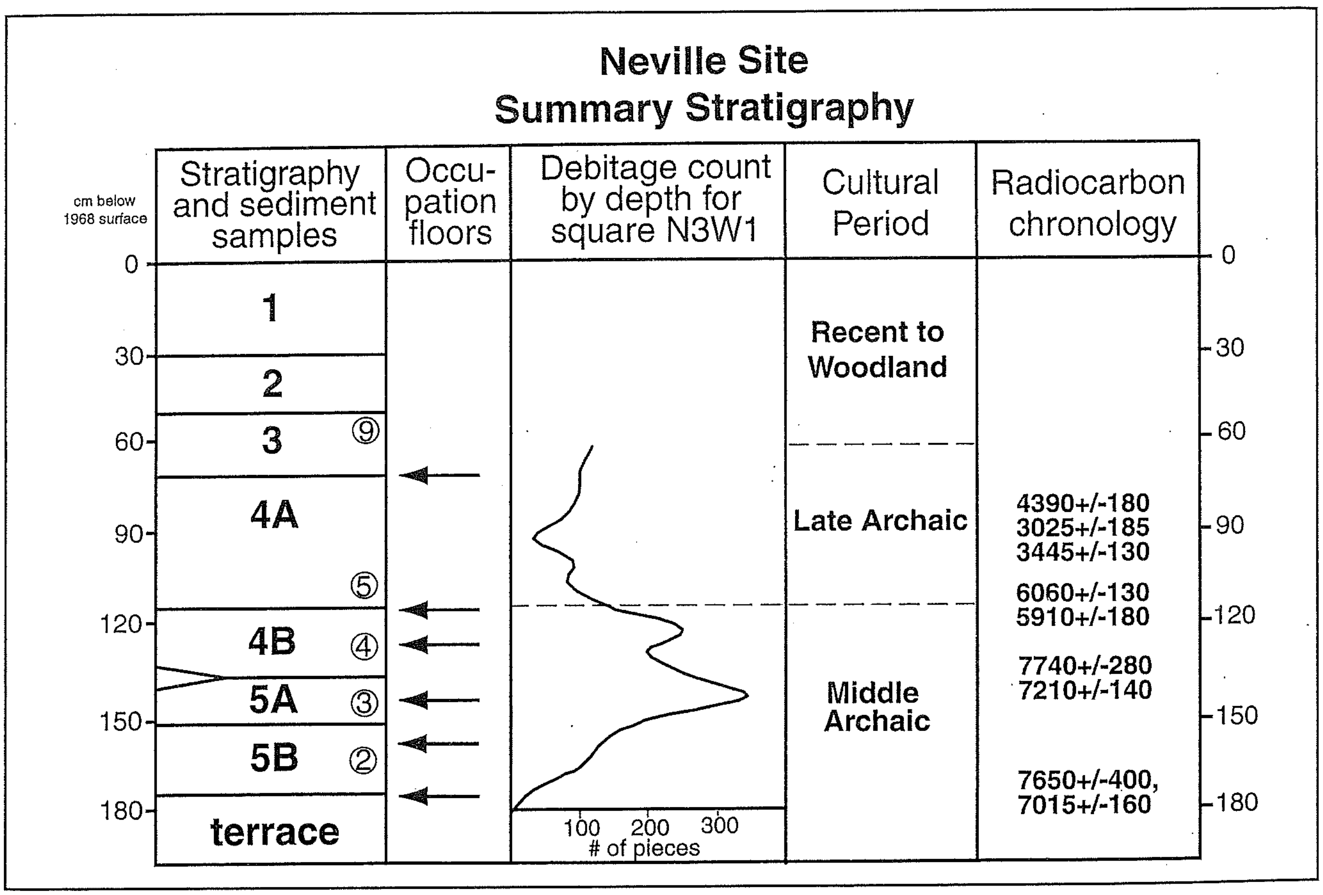


Figure 5.5. Schematic stratigraphic summary of the Neville site, adapted from Dincauze (1976). Included are locations of sediment samples (circled numbers) plotted in Figure 5.6, location of horizons of high artifact density ("occupation floors," see text for discussion), and selected radiocarbon dates plotted by depth, using a half-life value of 5570, before A.D. 1950. Debitage count modified from Dincauze (1976:Figure 7).

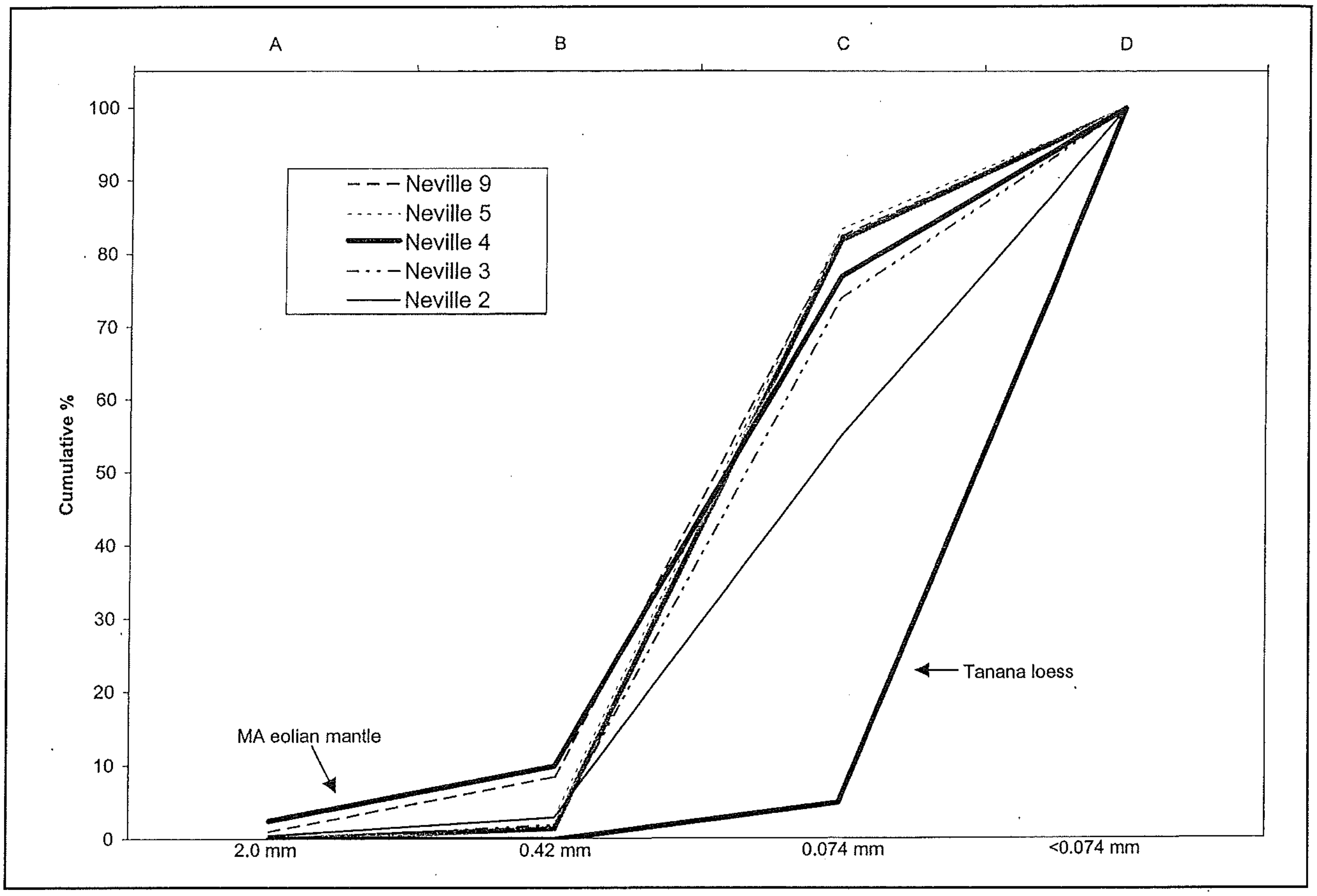


Figure 5.6. Grain-size distribution of selected samples from the Neville site, compared with a representative sample of the Massachusetts "eolian mantle" (Hartshorn 1967) and loess from the Tanana Valley, Alaska (Thorson and Hamilton 1977). Vertical axis records cumulative percentage; size fraction on the upper horizontal axis following that from the Neville site (Dincauze 1976).

## Sedimentation Rates (Figure 5.5)

Comparison of sediment thickness to radiocarbon chronology suggests that Strata 5B–4B (the Middle Archaic occupation) accumulated at a much higher rate than did the overlying strata (ca. 1 cm/24 yr vs. 1 cm/52 yr) (Dincauze 1976, 1989:3). Occupation of the terrace was apparently both more frequent (as measured by the number of occupation floors, see below) and more intense (as measured by debitage density) prior to the deposition of Stratum 4A. This suggests a preferential use of the terrace when it was most subject to eolian deposition, that is, when the edge and bluff face were relatively clear of vegetation, providing good visibility, as well as a source of sediment. Strata above 1.14 m contain fewer artifacts and a single occupation floor; lower sedimentation rates and apparent terrace stability indicate the predominance of our Time Step 1 (background conditions).

## Occupation Floors (Figure 5.5)

Several "occupation floors," consisting of thin, dense concentrations of artifacts, occur throughout the stratigraphic sequence of the Neville site. Such concentrations in unconsolidated sediment may result from postdepositional processes, as several artifact-refitting studies have shown (e.g., Cahen 1978; Villa 1982), although no such data is available for the Neville site. These debitage concentrations are associated with strata interfaces, which suggest formerly stable land surfaces. Successive major "occupation floors," at or immediately below these stable surfaces (Dincauze 1976), suggest a link between occupation and sedimentary regime. We interpret this as occupation during Time Step 3 (stabilization), a period following the major pulse of sedimentation (diminished amounts of windblown dust), but prior to complete reappearance of obscuring vegetation on the bluff face.

## Climatic Effect?

The Middle Archaic occupation of the Neville terrace occurred during an interval of the Holocene both warmer and drier than the present (e.g., COHMAP 1988; see also papers in Bettis 1995), and climatic changes may be broadly responsible for the higher rates of sedimentation and apparent terrace instability at the Neville site during this period. Proxy records in the Northeast document lowered water tables in small lakes and bogs (Thorson and Webb 1991), an increase in pine pollen (Davis 1983), and reduced effective soil moisture (Webb et al. 1993) during ca. 8000–5000 B.P. The response of fluvial systems is variable and complex and remains unresolved (e.g., Knox 1983). Although we can only speculate on the climatic effect at the Neville site (increased frequency of floods and bank undercutting?), a generally warmer and drier climate would tend to extend the duration of Time Step 2 (erosion), prolonging sediment availability for wind transport prior to restabilization due to possible changes in the vegetative screen or a loss of cohesion of terrace sediment.

# DISCUSSION

The Neville site conforms to our model of terrace-edge retreat and incremental burial of archaeological components by windblown proximal sediments, because (1) the site is located on a west-facing terrace above the flood level of a major river; (2) the bluff face fronting the site could have been destabilized by episodes of fluvial bank erosion; (3) fine-grained sediment suitable for entrainment by wind is widely available; (4) Holocene eolian deposits are widespread in the area (Koteff 1976); (5) sediment texture and structures at the site are consistent with an eolian origin; and (6) the alternative of colluvial transport is generally precluded by the low slope on the terrace tread.

Direct evidence for bluff-edge retreat is seen in the coarsening upward sequence of sediments preserved at square N0E1, located some 8 m from the bluff edge. Inertial effects dictate the settling of larger particles first; this signal is interpreted as increasingly proximal sediment source provided by the retreat of the terrace edge.

Most compelling, however, is the presence of five discrete archaeological horizons within 75 cm of sediment that apparently formed in ca. 1,500 years; each archaeological horizon occurs at or immediately beneath the interfaces below Strata 5B–4B. Although pedogenetic and bioturbative processes can result in artifact burial, stratification, and secondary concentration (e.g., Johnson 2002; Van Nest 2002), we interpret the stratigraphic separations as due principally to increments of eolian sedimentation followed by occupation during Time Step 3 of our model (stabilization), a period following the major pulse of sedimentation (diminished amounts of windblown dust), but prior to complete reappearance of the obscuring vegetation on the bluff face.

Reliable sedimentation rates cannot be calculated for the Neville site deposits. This is based on theoretical grounds (Ager 1981; Anders et al. 1987; Van Andel 1981) as well as the impact of soil formation and cultural disturbances at the site. However, comparison of the available radiocarbon chronology to sediment thickness at the Neville site suggests increased sediment availability and deposition during the Middle Archaic occupation of the site. Thus the ~75 cm of Strata 5B–4B accumulated in ca. 1,500 radiocarbon years, whereas age estimates for the 1.14 m of Stratum 4A-1 indicate some 6,000 years of accumulation. We argue that this is significant because the Middle Archaic dates to a warmer and drier interval of the Holocene, which may have increased the incidence of bluff-edge destabilization and eolian transport.

Our bluff-edge retreat model may also account for the scarcity of Paleoindian and Early Archaic artifacts. Dincauze (1976:118) interprets the few artifacts from these periods as curios brought to the site by later inhabitants, suggesting that, with the Amoskeag Falls not yet formed, there was little in the way of a persistent environmental attraction (anadromous fish) to drive continued, frequent occupation of the area (Dincauze 1976:9; 1993:17; personal communication 2002). Although we cannot rule out such cultural and historical explanations, the simplest explanation for the absence at the Neville site is that the earliest occupations were concentrated along a bluff edge that has since been eroded away.

Our model suggests that terrace edges will be most frequently selected for occupation following rare erosive events and subsequent bluff-face restabilization, the frequency of which may be controlled by broader regional environmental conditions. Occupational hiatuses at a regional scale may be due, in part, to an incomplete understanding of the geological processes that lead to the formation, burial, and ultimate recovery of archaeological remains (e.g., Petersen and Putnam 1992; Van Nest 1993; papers in Bettis 1995).

Future testing of our model will require excavation of a multicomponent archaeological site in an upwind-facing, bluff-top setting. Excavations will be required along a transect perpendicular to the bluff face, which will provide an opportunity to examine and sample the gradients in bulk texture, sedimentary structure, and pedogenic modification from proximal-to-distal local wind regimes (e.g., Thorson and Hamilton 1977)

## END NOTES

1. Artifact concentrations ("occupation floors") at or immediately beneath strata interfaces suggest a formerly stable surface, although soil development may have been quite weak.

2. This corresponds to the 45-in depth noted by the excavators; all measurements converted to metric.

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