**Supplemental Text 1. Coupling Lithic Sourcing with Least Cost Path Analysis To Model Paleoindian Pathways in Northeastern North America**

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These supplemental online materials include two sections. The first, Background to XRF Sourcing Analysis, provides more detailed information on the geology of Normanskill cherts in New York and archaeological evidence for Paleoindian exploitation of Normanskill chert outcrops.. The second section, Notes on Least Cost Path (LCP) Analysis, includes additional discussion of assumptions regarding Paleoindian seasonal mobility in the glaciated Northeast, additional information on our LCP methods, and detailed review of our LCP results, including route descriptions of individual Least-Slope and Tobler's pathways from West Athens Hill to the seven destination sites.

**Background to XRF Sourcing Analysis**

*Geology of Normanskill Cherts, Hudson Valley, New York*

The bedrock geology of the Normanskill cherts and the parent formations that contain them is complex and their mapping is not straightforward. The chert was formed in marine muds and sands as part of slope-rise sediments off the east coast of proto-North America (Isachsen et al. 1991;Fisher 1977; Landing 1988, 2007; Landing et al. 1992; Ruedemann and Wilson 1936). Over the millions of years when they were deposited and displaced, chert formed in the Normanskill mudstones from silica, primarily from the skeletons of radiolaria that were deposited in the bottom of the basin and on the slope-rise. This is why most of the marine Ordovician cherts in the Appalachians (including Normanskill chert), contain the pseudomorph microfossils of radiolaria. These rock formations containing Normanskill chert were later displaced to the west and pushed up and onto older rocks as part of the Taconic orogeny. Most of the rocks that form the Taconic sequence are distributed east of the Hudson River, but some are found west of the Hudson, including the quarry sites of West Athens Hill and Flint Mine Hill (Supplemental Figure 1). Because these rock formations (mostly shales and mudstones today) are out of place, they are referred to as allochthonous.

Mapping the Normanskill group/formation and its subunits (Austin Glen, Mount Merino, and Indian River formations/members) has been a challenge for us because these formations or members have been mapped differently by different geologists and there is disagreement as to how to map them. The bedrock geology mapping for east-central New York (Hudson-Mohawk sheet (Fisher et al.1970) was of considerable use, but the scale was not always amenable to archaeological fieldwork. We also used the GIS layers from the New York State Geological Survey (1999), which were better suited to GPS mapping of the geologic samples. However, the West Athens Hill quarry, for example, is subsumed in the shales of the mapped Austin Glen formation, while Flint Mine Hill is shown as lying in the Mount Merino formation, and the Mount Merino quarry is depicted within a Taconic *mélange* and not in the Mount Merino formation (a mixture of rocks formed by tectonic disruption, which brings disparate rock types together; most of the cherts are in *mélanges*). Resolving these larger geological questions is beyond the scope of this study, but we feel it is important to explain the challenges facing the archaeologist when trying to carry out a proper geoarchaeological sampling of potential members/formations and quarries that contain Normanskill chert.

During our sourcing analysis, we found that the four artifacts from the Michaud site in south-central Maine were manufactured from a rhyolite of unknown origin (Table 1). Review of the total alkali-silica (TAS) compositional diagram (Middlemost 1994) clearly shows that the Michaud artifacts are made of rhyolite (Supplemental Figure 2). The rhyolite represented by these four specimens does not match the geochemistry of rhyolites that we have analyzed from Maine or the greater Northeast (Burke et al. 2014).

*Archaeological Evidence for Paleoindian Exploitation of Normanskill Chert Outcrops*

To date, two outcrops of Normanskill chert – Flint Mine Hill and West Athens Hill – have yielded diagnostic evidence of Paleoindian occupation. At Flint Mine Hill, three fluted points are on record from this large quarry site, including one each from excavations reported by Brumbach and Weinstein (1999) and Laccetti (1989:31). Importantly, both of these studies document that middle Holocene/Late Archaic occupations (represented by broad blade bifaces) appear to comprise the dominant cultural component at Flint Mine Hill. Additionally, multiple surface collections on the Hudson Valley bottom lands surrounding Flint Mine Hill have collectively yielded four scattered fluted points (Funk 2004:129; Jamison 1996:18).

By contrast, New York State Museum (NYSM) excavations at the summit of West Athens Hill (1963-1967, 1969, 1970), revealed three Paleoindian occupation areas containing abundant evidence of (1) quarrying of Normanskill chert, (2) early- through late-stage reduction of this toolstone (including fluted point manufacture and production of uniface tool blanks) and (3) use and discard of resharpened uniface tools of Normanskill chert (Funk 2004). The NYSM excavations at West Athens Hill failed to encounter confirmed Paleoindian hearths or other cultural features, causing Funk (2004:127-128) to question the nature of the Paleoindian encampments at the site (although in retrospect, such features are in fact rarely found on fluted point residential sites in North America [Ellis 2014:5762]). Rather, it is the wide range of tool forms found at West Athens Hill, comparable to that found at residential Paleoindian sites in the Northeast that are *not* proximal tolithic sources, that tells us that Paleoindian chert quarrying and tool manufacture took place during seasonal encampments at the site.

Supplemental Table 1 lists 52 Paleoindian sites in northeastern North America that are *not* associated with Normanskill chert outcrops but *are* reported to contain artifacts of this toolstone. These sites are distributed in all directions around West Athens Hill, at straight-line distances ranging up to 550 km. Most of these sites with Normanskill chert artifacts lie north of the LGM, but a limited number are found south of the glacial maximum as well (Figure 1). In terms of chronology, sites are clearly dominated by Early Paleoindian (circa 13-12,200 cal BP) and Middle Paleoindian (circa 12,200-11,600 cal BP) components, while Late Paleoindian sites (11,600-10,000 cal BP) are much less common. Viewed collectively, these data suggest that Normanskill chert was regionally important for late Pleistocene peoples in the New York region and northeastern North America, and that they transported this toolstone widely across the Northeast.

**Notes on Least Cost Path Analysis**

*Assumptions Regarding Paleoindian Mobility and Movement*

Implicitly or explicitly, most researchers view Paleoindian groups in the Northeast and elsewhere in North America as largely pedestrian foragers, although the specific modes of Paleoindian seasonal travel continue to be debated. Some researchers point to site locations in valley and lowland settings as indirect evidence of Paleoindian use of watercraft on streams and water bodies to facilitate inland or coastal travel (Engelbrecht and Seifert 1994; Ellis and Deller 1990:53; Jodry 2005; Robinson et al. 2018; Schulz et al. 2011).

Assemblage-based evidence for watercraft at Paleoindian sites may be supported by the Mockhorn Island site, an early Paleoindian occupation in Northampton County, Virginia. Stanford et alia (2018) note the presence of bipolar artifacts (functionally interpreted as wedges), as well as unfluted drills with triangular cross sections, and adzes, as potential evidence of woodworking activities at the site. In addition, three heat-reddened cobble tools with adhering black organic residue were noted. Spectroscopic analysis of this residue on one cobble tool detected the presence of copper. Because birch assimilates natural copper from the soil and expels it in the sap, this residue is interpreted as pitch extracted from birch bark. Coupled with the presence of potential woodworking tools, the authors interpret this residue as evidence of these cobbles perhaps functioning as caulking tools for applying birch pitch sealant to birch bark canoes.

In contrast, Morrow (2014) argues that toolstone data on Clovis artifacts in the midcontinent do not support watercraft use in the Mississippi Valley. Using data on toolstone and point provenience, she found that Clovis points were routinely being transported away from their respective toolstone sources and across the upper reach of Mississippi, leading her to propose that northern Clovis populations likely made winter crossings on foot of the frozen northern sections of the upper Mississippi. Further south, in the middle/lower Mississippi Valley (where the Mississippi river was less prone to winter freeze up), she reports that Clovis points were not being transported from toolstone sources across the main channel of Mississippi, suggesting the river may have acted as a barrier to seasonal east-west movement. Morrow (2014) concludes that these patterns indicate Clovis groups in the Midcontinent did not routinely rely on watercraft for crossing or traveling on rivers or water bodies.

Ellis (2008:305, 311) suggests that while northeastern Paleoindians may not have possessed sophisticated terrestrial travel aids such as dog sleds, they may well have used watercraft. He notes, however, that in many instances, documented directions of overland transport of toolstone from source to site “are not consistent with possible water transportation route directions” (Ellis 2008:311). Importantly, Blair’s (2010) model of late Holocene Native Americans in the Canadian Maritimes practicing bulk logistical procurement and transport of unprocessed toolstone by boat is not supported for Paleoindian groups in the glaciated Northeast, where early- through late-stage toolstone reduction was clearly focused at primary lithic sources (e.g., Ellis 2008; Lothrop, Lowery, et al. 2016:226-227). Consistent with this observation, Blair (2010:43) notes that “bulk procurement may not have been an important practice in situations of high residential mobility.”

Others propose that Paleoindian populations in North America may have been accompanied by domesticated dogs (Fiedel 2005), a notion consistent with recent genetic studies on the origins of dogs in the Americas (van Asch et al. 2013). Suggested roles for dogs in Paleoindian societies include travel aids, such as pack animals or pulling sleds or travois, and perhaps hunting (Fiedel 2005; Gramly 2010; Gramly and Funk 1990). For subarctic peoples such as the Innu (Henriksen 2010:28) and Denesuline (Caribou Eater Chipewyan; Sharp and Sharp 2015), prior to the historical adoption of the dogsled for travel, the role of dogs in hunting caribou is uncertain. Binford (1991:38) notes that in the recent past, when the Nunamiut engaged in corporate caribou hunts to intercept migrating herds, all dogs were removed to a location far from the expected migration route, and were staked out and muffled with skin gags so as not to frighten the caribou. Likewise, for Paleoindians in northeastern North America, the potential role of dogs in hunting remains unknown. For the time being, the potential roles of dogs in Paleoindian societies – especially pertaining to seasonal travel – remain speculative.

Based on this review and our sourcing evidence for long-distance transport of Normanskill chert, Paleoindian seasonal movements across the late Pleistocene Northeast may represent a combination of pedestrian travel across terrestrial landscapes and, in winter, on frozen waterways and water bodies, combined with situational use of watercraft for warm season crossings of lakes or downstream travel on waterways.

*Additional Information on LCP Methods*

The LCP study area in northeastern North America extends roughly 900 km north-south and 650 km east-west, encompassing Appalachian Highlands, Piedmont and Coastal Plain provinces. Supplemental Figure 1 illustrates the physiography, major drainages and major Paleoindian lithic sources in this study area.

Here we provide additional information on GIS protocols used to conduct the LCP analysis. Initially, we attempted to reduce LCP analysis error from spatial sampling effects by downloading 1/3 arc-second (approximately 10 m resolution) digital elevation model (DEM) raster files from the USGS National Map website (the highest resolution DEM data available at no cost and encompassing the geographic extent of the study area of approximately 350,000 km2). However, our testing of the ArcGIS Distance Toolset revealed that the file size of the 10 m DEMs required for processing this large an area exceeded the computational capacity of ArcGIS. We then resampled the 10 m DEMs to produce 30 m resolution rasters. This process likely introduced some smoothing error (Herzog and Posluschny 2011) but permitted processing and analysis in ArcGIS.

As noted, in our second LCP analysis, we employed the Tobler’s hiking function algorithm to develop outbound, anisotropic costs from West Athens Hill to each destination site. The validity of this algorithm is supported by empirical testing by Irtenkauf (2014), who compared 120 GPS tracks involving actual pedestrian travel times in four ecoregions in the United States, to GIS-predicted travel times along the same routes using Tobler’s hiking function. Thirty-five percent of the tracks had a Tobler predicted travel time within ± 10% of the actual time. Seventy percent had a predicted time within 25% of the actual time, and 93% had predicted times within 50% of the actual travel time. Accuracy varied between these ecoregion divisions, but the rule performed best in the Warm Continental Regime Mountain ecoregion in New England and northern New York (and located in our study area), with an average difference of only 17% of the actual travel times.

*LCP Results: Detailed Description of LCP Pathways to Destination Sites*

As described in our paper, the Least-Slope pathways emphasize longer valley or lowland routes, while Tobler's solutions follow more direct, often upland paths from West Athens Hill to the seven destination sites (Figure 5). Importantly, Herzog (2014) observes that least-slope LCPs will often follow river channels and thus might require modeling rivers as travel barriers. This is true to an extent in our study where the elevation-distance profiles “flatline” for portions of some of the Least-Slope pathways (Figure 6). Where present, these flatline segments are usually limited to circa 20 km or less of a Least-Slope route. The two most pronounced examples are the Least-Slope path to Vail (following the Hudson north for circa 60 km), and the path to Higgins (tracing the Hudson and Wallkill rivers south for circa 110 km). Based on the assumption that northeast Paleoindians were primarily pedestrian travelers, one could argue that segments of the Least-Slope paths which follow waterways are invalid. As noted above, however, depending on season, routes which follow water could be modeling either cold-season pedestrian travel on frozen rivers or water bodies, or limited warm-season travel via watercraft.

*Vail Site*. The Least-Slope path follows the Hudson Valley northward, ascends Battenkill Valley eastward, traverses the Green Mountains, turns north up the Connecticut Valley, and then crosses the White Mountains before entering the Magalloway Valley (Androscoggin drainage). By contrast, the Tobler’s algorithm route de-emphasizes travel north in the Hudson and Connecticut valleys, while following upland traverses of the south-to-north trending Taconic, Green, and White mountain ranges. Importantly, other Paleoindian sites with reported Normanskill chert (Sundler, Jackson Gore, and Jefferson VI) or confirmed Normanskill chert (Upper Wheeler Dam) lie along both routes (Figure 6;Table 4; Supplemental Table 2). Of note for the Tobler's route to the Vail site is its close proximity to the Jackson-Gore site and an isolated find, the Lesniak point, both located in high elevation settings. Jackson-Gore is situated in the southern Green Mountains, at an elevation of 331 m (1086 ft; Crock and Robinson 2012). The Lesniak point – an isolated find – was found in the Taconic Mountains at an elevation 730 m (2400 ft), making it the highest elevation fluted point on record for New York. This fluted point base (a Middle Paleoindian Michaud-Neponset form [Bradley et al. 2008]), is made of Normanskill chert (based on macroscopic criteria). Both localities could be interpreted as evidence of east-west travel across these mountain ranges. Based on the LCP analysis, however, the locations of both Jackson Gore and the Lesniak point can be viewed as further support for situational upland travel via south-to-north trending ridge crests, and thus consistent with the Tobler's hiking function pathway across the Taconic/Green/White mountains to Vail. Based on these data, both pathways to Vail are plausible.

*Corditaipe Site*. The macroscopic identification of Normanskill chert in the Corditaipe and Potts site assemblages (Funk and Wellman 1984; Gramly and Lothrop 1984) prompted Gramly (1988) and Lothrop (1989) to propose the Mohawk Valley as a logical corridor for the westward transport of Normanskill chert. The Least-Slope LCP solution approximates such a valley-bottom route, leading north up the Hudson Valley, skirting the northeastern front of the Catskill Mountains, and following the Mohawk Valley westward. By contrast, the more direct route of the Tobler's algorithm solution transits uplands across the northern Catskills and higher elevation settings south of the Onondaga escarpment. The identification of probable Normanskill chert in collections from the Toad Harbor site, situated between Potts and Corditaipe on the north shore of Oneida Lake (Lothrop, Beardsley, et al. 2016), further reinforces the notion of westward leading pathways to Paleoindian sites in the upper Mohawk Valley and the Ontario plain. The proximity of the Sundler site to the Least-Slope solution provides limited support for this route.

*Kilmer Site*. After circumventing the northern flank of the Catskills, the Least-Slope path runs westerly, following corridors of the Susquehanna River’s North Branch and its Chemung and Canisteo river tributaries. In terms of other sites with Normanskill chert, Beaver Lodge lies closest at 25 km south of this route, in the adjoining West Branch of the Delaware drainage. Other sites with artifacts of confirmed or probable Normanskill chert, found along the middle and lower reaches of the Susquehanna’s main stem (36SU25, 36LY99, Epler, Saginaw) support the notion of periodic movements by fluted point groups along or near middle and lower reaches of the Susquehanna Valley. Over 90% of the Tobler’s pathway to Kilmer avoids valley corridors: after rounding the northern Catskills, this route runs west-southwest and nearly perpendicular to the north-south grain of the Appalachian plateau landscape. Only the Canoga site (30 km to the north on Cayuga Lake) lies in regional proximity to this pathway. The absence of Paleoindian sites with Normanskill chert artifacts near either route is perhaps not surprising. Recent mapping of Paleoindian sites and isolated point finds in central New York suggests that occupations were more widespread on the Ontario plain compared to the Appalachian plateaus to the south (Lothrop, Beardsley, et al. 2016; Lothrop et al. 2017). Because of the absence of nearby sites with Normanskill artifacts, neither LCP route to the Kilmer site is favored.

*Poirier Site*. Both pathways to Poirier follow similar routes, leading south down the mid-Hudson Valley, then heading southwesterly through the Great Valley via the Wallkill and Paulinskill drainages to the main stem of the Delaware Valley. The lower Wallkill Valley sites of Twin Fields, James Decker, Soon’s Orchard, Dutchess Quarry Cave #1, Zierdt, Plenge and Wolverton all lie within 20 km of each of these routes, suggesting both corridors to Poirier are equally plausible. Importantly, the absence of recorded fluted point sites or isolated finds in the Rondout Valley (paralleling the Wallkill immediately to the northwest) reinforces the notion of the Wallkill Valley vicinity as a key corridor for Paleoindian groups traveling seasonally from the Hudson Valley (Lothrop et al. 2017; Lothrop et al. 2018).

*Higgins Site*. Given the presence of multiple Paleoindian sites in the Susquehanna Valley with reported or confirmed Normanskill chert, we expected that the Least-Slope vector would follow this physical corridor to Higgins. However, both LCP solutions from West Athens Hill avoid the Susquehanna Valley, perhaps because of its lengthy "zigzagging" trace (conversely, one could infer that Paleoindian sites with Normanskill chert in the Susquehanna drainage were associated with seasonal group movements unrelated to the Higgins site). The Least-Slope LCP leads down the middle and lower Hudson Valley, and then turns southwesterly, following the Fall Line along the Piedmont-Coastal Plain boundary, passing within 20 km of the James Decker and the Port Mobil sites. The Tobler's hiking function route takes a more interior track via the Hudson, Wallkill, and Musconetcong valleys, and then turns southwesterly, crossing the Piedmont. This route runs near the Twin Fields, James Decker, Soon’s Orchard and DQC #1 sites in the Wallkill Valley, the Zierdt, Poirier and Snyder Cache localities in the Delaware Valley, and the Plenge and Wolverton sites in the Musconetcong Valley. While both routes have merit, the nine sites with Normanskill chert artifacts proximal to Tobler’s, versus just two sites near the Least Slope path, favors the Tobler pathway.

*DEDIC/Sugarloaf Site*. Both the least-slope and Tobler’s pathways to DEDIC/Sugarloaf ascend the Kinderhook Valley, and then follow an east-northeasterly traverse of the Taconic and Green mountains to the Connecticut Valley. Because there are no recorded fluted point sites with artifacts of Normanskill chert along these pathways, we cannot propose a favored route to this site.

*Bull Brook Site*. Compared to the DEDIC/Sugarloaf pathways, the Least-Slope route to Bull Brook follows a more southerly course, traversing the Taconic and Green mountains, and then following west-to-east-trending sections of the Chicopee, Nashua, Assabet, and Ipswich valleys. Although no recorded Paleoindian sites with Normanskill chert are located along this pathway, the western two-thirds of this trace could have been a viable route to the Neponset and Wapanucket sites in eastern Massachusetts (Figure 6). The Tobler’s solution to Bull Brook nearly matches both LCP pathways to DEDIC/Sugarloaf. From here, the Tobler’s path follows an easterly route through the Millers River valley and across northeastern Massachusetts uplands to Bull Brook. Notably, Gramly (2014:40, 2015) argues for stylistic similarities between fluted points from DEDIC/Sugarloaf and Bull Brook, and he reports a radiocarbon date on calcined bone (Gramly 2014:38, 2015:103) of 10,350 + 50 BP (Lothrop, Lowery, et al. 2016:211). This AMS determination for DEDIC/Sugarloaf compares well with two AMS dates on calcined bone for Bull Brook (Robinson et al. 2009:425-426), yielding uncalibrated ages of 10,410 + 60 and 10,380 + 60 (Lothrop, Lowery, et al. 2016: 211 ). DEDIC/Sugarloaf lies only 3 km south of the Tobler’s route to Bull Brook, suggesting a possible waypoint from WAH. This, plus suggested similarities between Bull Brook and DEDIC/Sugarloaf in age and point styles, supports the Tobler’s solution as the most likely pathway from WAH to Bull Brook.