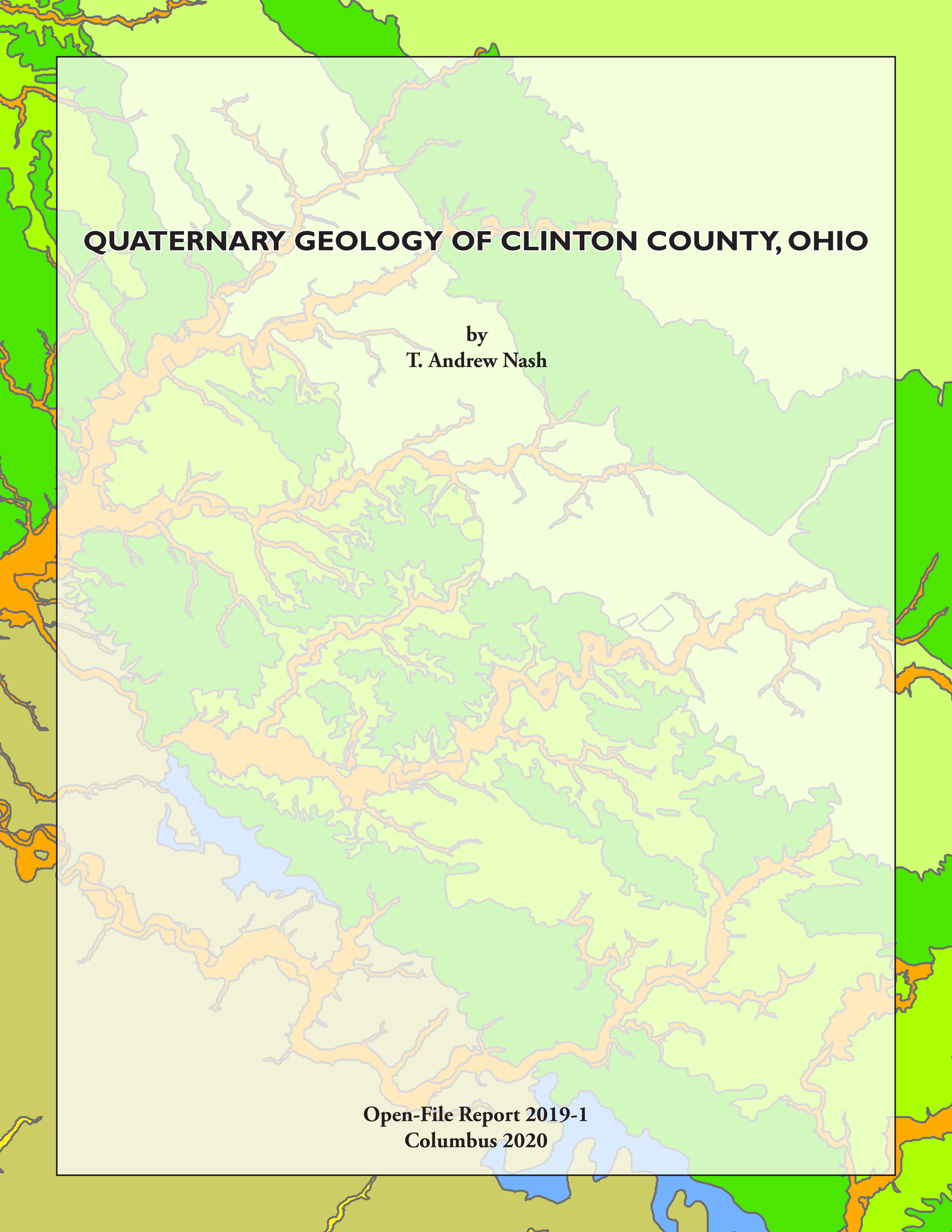

QUATERNARY GEOLOGY OF CLINTON COUNTY, OHIO

by
T. Andrew Nash

Open-File Report 2019-1
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ABBREVIATIONS USED IN THIS REPORT

Units of Measure

Feet . . . ft
Miles . . . mi
Grams . . . g
Liters . . . L
Millimeters . . . mm

Other

Light Detection and Ranging . . . LiDAR
Digital Elevation Model. . . . DEM
Optical Stimulated Luminescence . . . OSL
Accelerator Mass Spectrometry . . . AMS
Geographic Information Systems. . . . GIS
State Route. . . . SR
Mean Sea Level . . . MSL
Thousands of Years Before Present . . . ka
Millions of Years Before Present. . . . MYA
Last Glacial Maximum . . . LGM

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ABSTRACT

The detailed study of Quaternary-aged sediments in Clinton County is vital to the continued growth of the county's population and economy. Understanding the lithologies, thicknesses, and distribution of these sediments is needed for land-use planning, groundwater studies, septic system installation/remediation, natural resource extraction, and hazard mitigation. These sediments have not been studied at the county level in more than 50 years. Since that time, new technology and ideas have emerged that have changed how glacial geology is studied. Therefore, this report describes a new high-resolution (1:62,500-scale) map of Clinton County's Quaternary geology. This map utilizes chronostratigraphic principles and surficial geology data to reinterpret the glacial landforms preserved at the surface, which tell the story of multiple advances and retreats of the Laurentide Ice Sheet (LIS) into the county. New data from Light Detection and Ranging (LiDAR), water well logs, geotechnical logs, soil surveys, soil borings, field observations, radiocarbon dates, and textural analysis were compiled into a geographic information system (GIS) to interpret the deposition of surficial sediments across the county. Through this interpretation, a depositional framework of multiple glacial till deposits was constructed for the county. This framework, coupled with chronologic control through radiocarbon dating, was the basis for the interpretation of the Quaternary history presented in the detailed county map. Improved mapping has helped identify a new glacial moraine, the Sabina Moraine, in northeastern Clinton County and better defined the inner and outer Cuba and Vandervort Moraines into the Cuba Moraine Complex. Improved mapping has also organized outwash deposits into a framework of contemporaneous till deposition, linking outwash sediments with the construction of other concurrent glacial landforms. Overall, this new mapping effort resulted of increased understanding in the Quaternary history of Clinton County.

INTRODUCTION

Clinton County, in southwestern Ohio (fig. 1), is located centrally between the metropolitan areas of Columbus and Cincinnati. As of the 2010 census, the county had a population of 42,040 people (U.S. Census Bureau, 2012). With a 1990 population of 35,415, the countywide population has grown by roughly 16% over the past two decades (U.S. Census Bureau, 1992). During these two decades, the county diversified its economy, moving from a primarily farming community to aerospace, logistics, health care, and manufacturing sectors. The development of these industries is reliant, in part, on the interstate transportation corridors (Interstate 71; U.S. Highways 68 and 22) and Wilmington Air Park. These industries require aggregate and construction materials to maintain the high-quality infrastructure needed for future economic growth. Therefore, detailed mapping of the Quaternary geology is crucial to better understand the availability of natural resources in the county and provide regional planners and policy makers with enough data to sustainably extract these resources for future economic development and maintenance of existing infrastructure.

Geologic forces have shaped the landscape of Clinton County over millions of years. These landscape-altering processes left behind landforms that help geologists identify the specific forces that acted on the surface of Clinton County. The deeply dissected valleys of Todd Fork, East Fork Todd Fork, Cowan Creek, and others are indicative of erosion by rivers, while the arcuate ridges which stretch across the valley are indicative of deposition by continental ice sheets. These features are best visualized by a Digital Elevation Model (DEM; fig. 2), which is interpolated from elevation points collected by Light Detection and Ranging (LiDAR). The 2.5-ft resolution raster shows that the total relief in Clinton County is 416 ft, with a maximum elevation of 1,200 ft above MSL and a minimum elevation of 784 ft above MSL.

Clinton County contains two distinctly different geologic regions, marked by glacial deposits of different ages preserved at the surface. Ice advanced into the county at least twice, during the Illinoian and Wisconsinan Glaciations. Sediments from the last glaciation, known as the Wisconsinan Glaciation, are exposed at the surface of the northeastern two-thirds of the county. Most of these Wisconsinan-aged sediments were deposited by the Scioto Sublobe (fig. 1, inset map). However, the adjacent Miami Sublobe also deposited some sediments in Clinton County (Pavey and others, 1999). Sediments from the Illinoian Glaciation cover the southwestern third of the county. The county is almost entirely covered by Quaternary-aged deposits, except for areas where Holocene stream erosion has uncovered the underlying Paleozoic bedrock. The thickness of these Quaternary deposits is variable across the county but generally, Wisconsinan deposits are thicker than the underlying Illinoian deposits. The topography in the Illinoian region is typically more dissected than the Wisconsinan region as the Illinoian deposits are older and have been subjected to erosion by surface waters over a longer period. However, some of the most dissected areas of the county occur along Todd Fork (fig. 1) and its tributaries because the Wisconsinan and Illinoian deposits are both thin within this watershed and the surface topography is controlled by the pre-Quaternary erosion of the underlying bedrock.

Clinton County contains a variety of glacial landforms and deposits from multiple glaciations. These landforms, such as ground moraines, end moraines, outwash plains, outwash terraces, and paleolake beds, generally control the topography of the landscape and are recognizable in the field and on topographic maps. The end moraines of Clinton County are looping, arcuate ridges that act as drainage divides for surface waters in the county. These end moraines are easily distinguished from the surrounding flat ground moraines by their hummocky topography and ridge morphology.

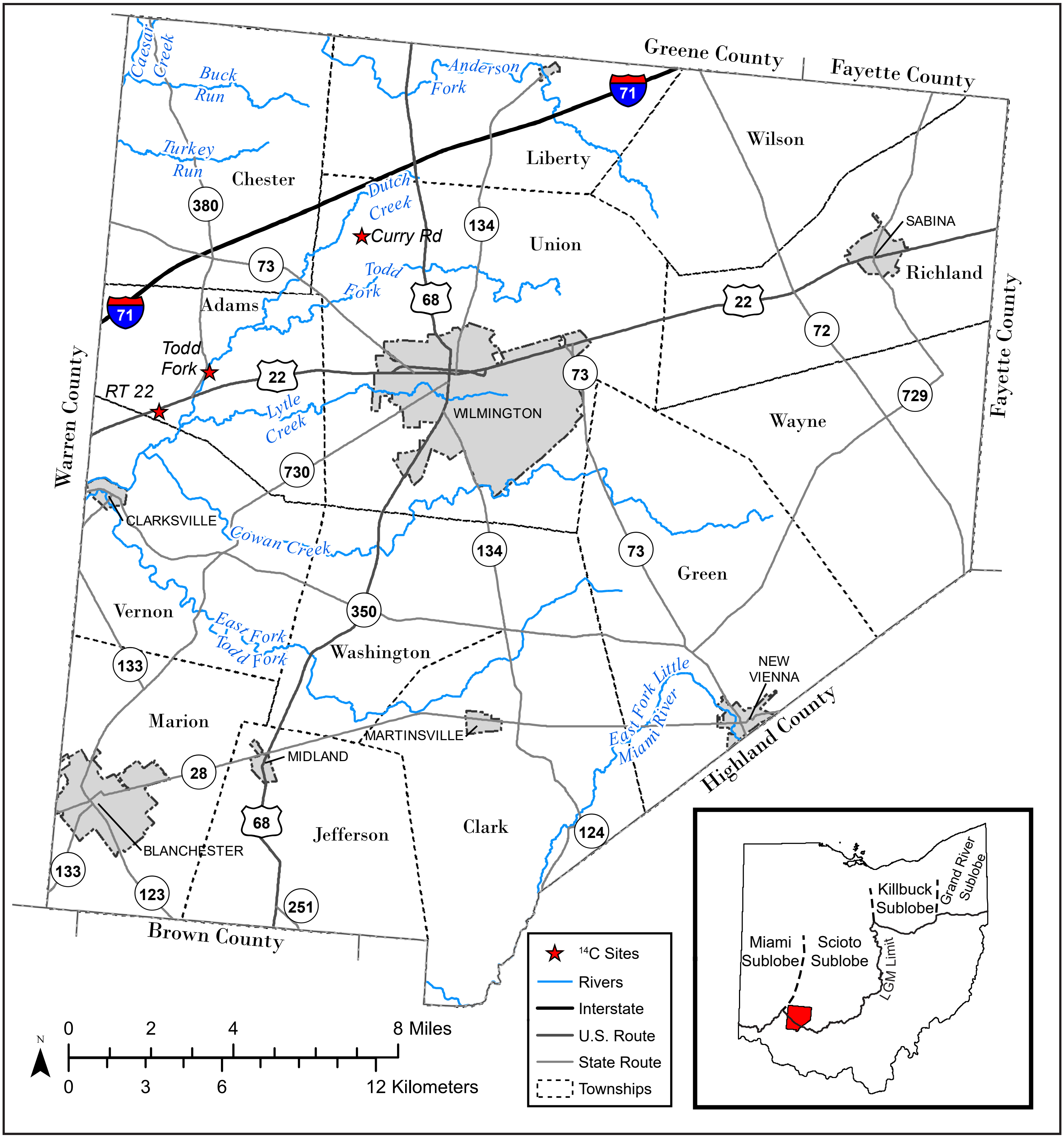

FIGURE 1: Map depicting the locations of major roads, rivers, townships and cities within Clinton County. Red stars indicate sites where organic material was collected for radiocarbon dating. The inset map depicts the location of Clinton County (red) in relation to the sublobes of the Laurentide Ice Sheet within Ohio; LGM = Last Glacial Maximum.

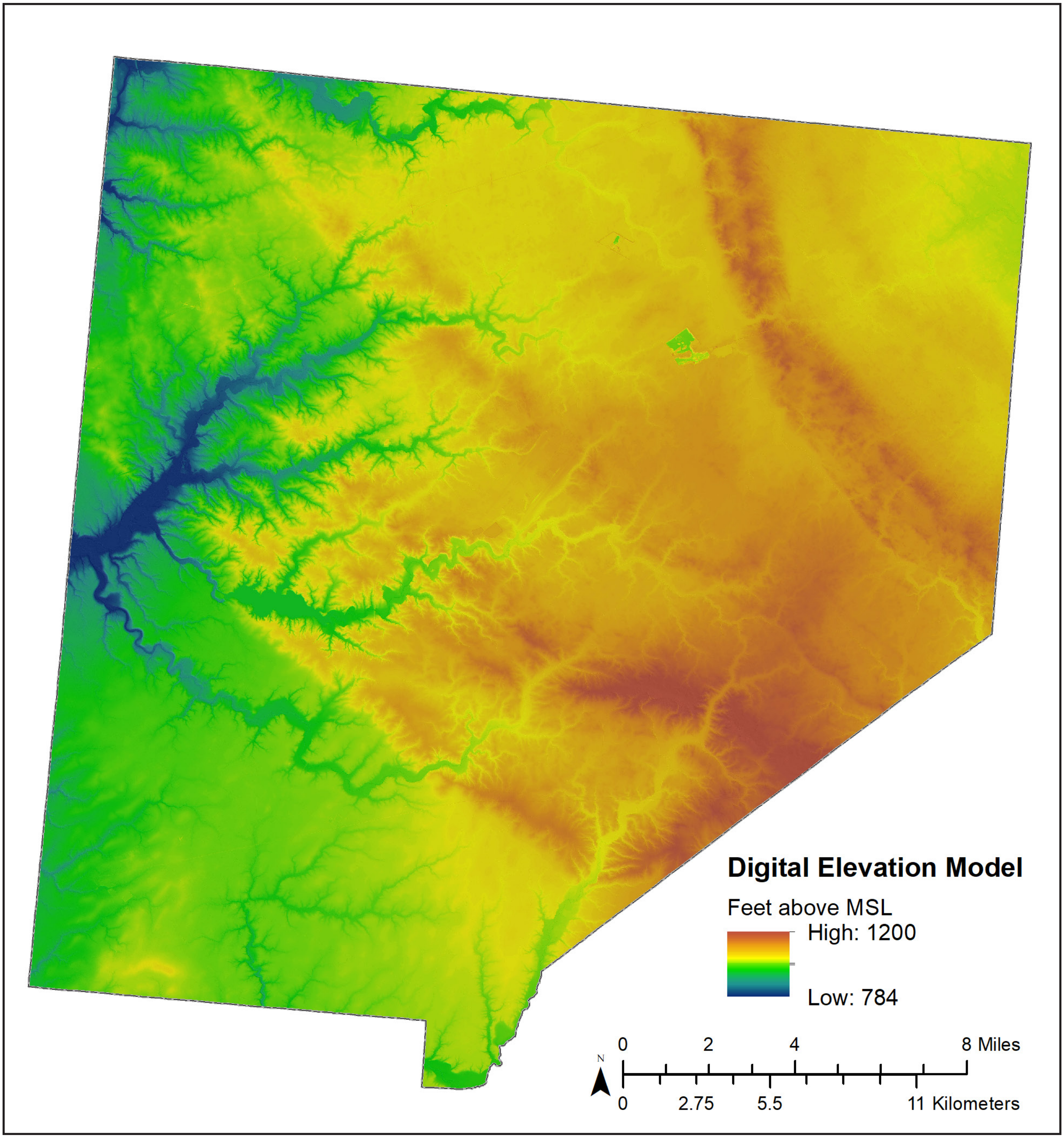

FIGURE 2: DEM of Clinton County, Ohio.

Previous Studies

The glacial geology of Clinton County has been studied in varying levels of detail since Hussey's initial descriptions of the geology of the county (Hussey, 1878). One section of his report focuses on the glacial geology of the county but is too generalized to be useful with modern standards of precision (Hussey, 1878). Shortly after this initial report, Chamberlin first described, but did not name, the Reesville Moraine (Chamberlin, 1883). However, he wrongly stated that this was the terminal position of the Early Wisconsinan glacier (Chamberlin, 1883). This work was superseded by Leverett in his famous 1902 monograph where he defined the Cuba Moraine as the terminal position of the Wisconsinan glacier (Leverett, 1902). The broad regional nature of this monograph means that little detail was reported about the glacial deposits in Clinton County. Austin (1930) published a report detailing significant geologic findings including moraines, terraces, and buried features. These initial attempts to characterize the surficial glacial sediments served as a framework for modern researchers to build upon.

These earlier studies were first expanded on by Teller's (1964) thesis on the glacial geology of Clinton County. This work led to the first published county-scale glacial geology map of the county (Teller, 1967). This work was the first to define the Wilmington Moraine and presented a detailed glacial history of the county. Part of this detailed glacial history was the presentation of two hypotheses for the retreat of ice from its maximum position at the Cuba Moraine during the Wisconsinan Glaciation; the first being the "Early Wisconsin Hypothesis" and the second being the "Wilmington Retreat Hypothesis" (Teller, 1964). In the Early Wisconsinan Hypothesis, Teller (1964) postulated that till was deposited during the early Wisconsinan and then was overridden by late Wisconsinan ice, constructing the inner and outer Cuba Moraines. The Scioto Sublobe then hypothetically retreated from the inner Cuba Moraine to the Wilmington Moraine position. This contrasts the Wilmington Moraine Hypothesis, which suggested that the Scioto Sublobe retreated to the Wilmington Moraine before the construction of the inner Cuba Moraine. Ideas about the Quaternary history of the Laurentide Ice Sheet have shifted since this study, rendering any early Wisconsin deposition within Clinton County improbable (Eyles and Westgate, 1987). The mapping of surficial boulders, soil parent material, silt depths, and glacial till-matrix grain size were important methodological advancements that helped better define the surficial geology of the county (Teller, 1964). Teller's (1964) study built upon the foundation of the glacial history of Clinton County that was initiated by the previous generation of geologists working in the region. However, even Teller's work left certain questions to be answered by future geologists, namely the chronologic history of ice movement in the county.

The Cuba Moraine and its chronological history has been the source of study for more than half a century (Goldthwait, 1958; Dubois, 1996). Early attempts at defining the age of Cuba Moraine construction hinged on just a few radiocarbon dates (Goldthwait, 1958). Dubois (1996) recognized the complex lithofacies preserved within the Cuba Moraine and found that one radiocarbon date was not sufficient to define the complex advance and retreat cycles that characterized the construction of the Cuba Moraine. Ultimately, Dubois compiled 51 radiocarbon dates from across Clinton, Highland, and Ross Counties to accurately define the chronologic history of moraine construction (Dubois, 1996). Dubois' (1996) work better characterized the construction of the Cuba Moraine in modern terms and led to a more complete understanding of glacial processes along the edge of the Scioto Sublobe. However, the detail-oriented nature of this study did not allow for a broader discussion of glacial history within Clinton County specifically.

Recent reconnaissance mapping in Clinton County completed by the Ohio Department of Natural Resources (ODNR), Division of Geological Survey and Division of Water provided higher resolution detail of the surficial geology, bedrock topography, and derivative mapping products (Schmidt, 1995; Brockman and others, 2005; and Fugitt and others, 2016). These new maps are lithology based and provide details on the basic lithologies and thicknesses of sediments across the county. However, these maps do not provide the context and glacial history that are shown on traditional Quaternary geology maps. A more recent statewide compilation of Ohio's Quaternary geology, mapped at 1:500,000, relied heavily on work done by Teller (1967) but is too generalized to be useful for municipal or site-specific planning purposes (Pavey and others, 1999).

Preglacial Landscape

The uppermost bedrock in Clinton County is mostly composed of Ordovician- and Silurian-age carbonates (fig. 3). These rocks were deposited in both shallow and deep marine environments on the eastern edge of the Cincinnati Arch about 460–425 MYA. Most of the bedrock in the county is buried beneath Quaternary-aged sediments, except for some exposures along the streambeds. The most notable exposures of bedrock in the county are along Buck Run just west of SR-380. The Ordovician-age limestones and shales exposed along Buck Run are from the Whitewater and Liberty Formations (Slucher and others, 2006; Schumacher and others, 2013). These are the same formations exposed at the Caesar Creek spillway, a renowned site for the collection of Upper Ordovician fossils (Shrake, 1992). The Silurian-age Cedarville Dolomite subcrops in the northeastern portion of the county and is an important source of aggregate. This unit is only mined where glacial deposits are sufficiently thin enough to make recovery of the material profitable.

The initial ice advances into Clinton County during the early Pleistocene Epoch would have encountered a much more rugged topography than the modern landscape. Erosion of the relatively stable land surface occurred over tens of millions of years during the Tertiary Period. This erosion was controlled by fluvial processes and left behind a dendritic pattern of valleys to be buried by multiple advances of ice in the county. The deposition of glacial materials on this preglacial landscape has obscured the exact position and flow-direction of these paleorivers.

A large buried valley was first recognized by Austin (1930) and was then known as the Great Central Valley. Austin (1930) used a total of 246 bedrock elevation observation points to interpret the preglacial land surface in Clinton County. The depth of the Great Central Valley was mostly based on just three deep wells which terminated in bedrock. An oil-and-gas exploration well, drilled on the farm of Randolph Clevenger, is said to have hit the top of bedrock at a depth of 400 ft (Austin, 1930). However, no records or log of this well existed even in the time that Austin was conducting his research (Austin, 1930). The apparent word-of-mouth delivery of this bedrock elevation data makes this a relatively unreliable point to base the elevation of a major buried valley, especially when no other data suggested bedrock depths were more than a few hundred feet (Austin, 1930).

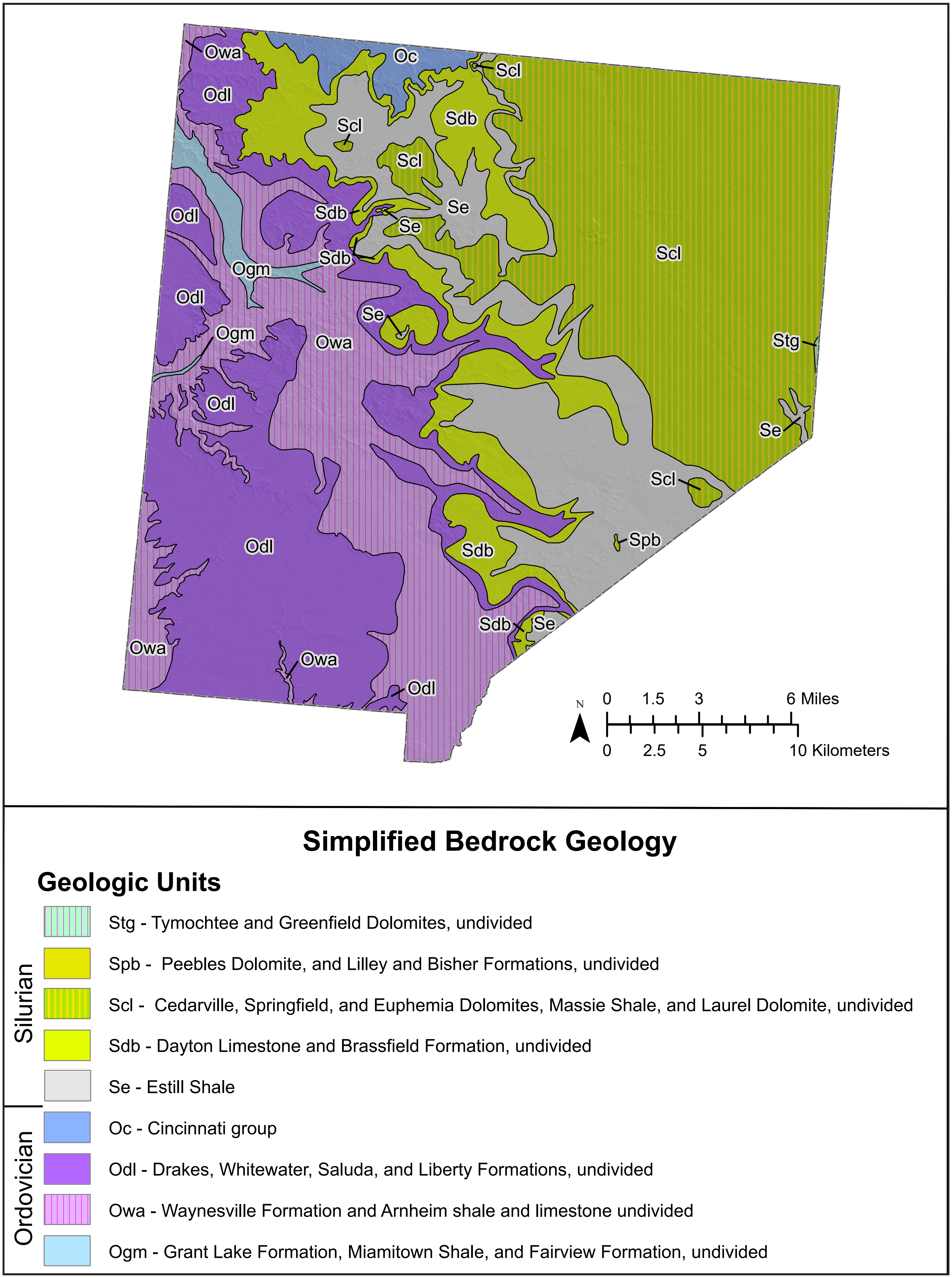

FIGURE 3: Generalized bedrock geology of Clinton County, Ohio. Modified from Slucher and others, 2006.

The mapping of this valley was later refined by Stout and others (1943) during the study of groundwater throughout Ohio. Stout and others (1943) agreed with Austin's (1930) interpretation that surface waters were flowing to the southwest. They defined this valley, which was formally named Monroe Creek, as a tributary to the Hamilton River. Liberty Township, the northern half of Chester Township, and western portions of Wilson, Richland, and Wayne Townships were cut off from Monroe Creek by a drainage divide that loosely follows the contact between Ordovician and Silurian-aged rocks in southwestern Ohio. According to mapping by Stout and others (1943), surface waters east of this divide would have flowed north-northeast into the Teays River.

Teller's (1967) interpretation of the bedrock topography of the county showed a dendritic network of buried valleys that began near the border between Highland and Clinton Counties and flowed to the northwest, with the main trunk valley exiting Clinton County near Caesar Creek Lake. This interpretation was different from previous work by Austin (1930) and Stout (1943), which showed a more southwestern direction of flow for surface waters. Contours by Teller (1967) range in elevation from 650 to 1,100 ft above sea level across the county.

Modern mapping efforts by the ODNR Division of Geological Survey generally agree with Teller's findings of a primarily northwestern-trending flow of surface water before Pleistocene glaciations (Brockman and others, 2003). The statewide 1:500,000-scale bedrock topography compilation map shows bedrock elevation ranging between 300 and 1,500 ft across the state, with variations between 595 and 1,102 ft in Clinton County (Brockman and others, 2003). In Clinton County, this bedrock topography map depicts a dendritic trunk valley sloping towards the northwest corner from the center of the county (Brockman and others, 2003). Northeastern and southwestern Clinton County show a predominately flat upland surface with minimal dissection by surface waters (Brockman and others, 2003). The development of topography on this bedrock surface occurred over millions of years by erosional forces of the northwest-flowing rivers. However, the 200-foot resolution is too coarse for more detailed subsurface studies that require raster surfaces of bedrock topography (Brockman and others, 2003).

A new bedrock topography map for Clinton County improves upon previous iterations (fig. 4). A total of 1,240 control points from located water well logs, geotechnical borings, and bedrock surficial exposures were used to interpolate the new bedrock topography raster with a 10-foot cell size. This new, high-resolution raster surface also shows a large dendritic valley system with a northwest trending gradient as described in Brockman and others, 2003. The range of bedrock elevations for the new raster surface is 598–1,120 ft, which is similar to previous mapping efforts (Brockman and others, 2003). Besides the increased the resolution between the two interpolations, the main difference between the two maps is the increased precision in defining the geographic position of the valleys. The inclusion of new water wells and geotechnical borings with highly accurate and verified locations has increased the confidence of defining the location of these valleys.

In addition to interpolating a new, high-resolution bedrock topography map, a new high-resolution drift thickness map was calculated for Clinton County. A 10-ft resolution drift thickness raster was calculated by subtracting land surface elevations (DEM) from bedrock elevations (bedrock topography raster). The original calculation of drift thickness in Clinton County ranges from 0 to 361 ft, with the thickest drift located in a buried valley in the northwest section of the county (Powers and Swinford, 2004). The updated drift thickness in the county ranges from 0 ft (bedrock exposed by stream erosion and mining) to 367 ft. While the increased resolution of the drift thickness mapping did not drastically alter the range of thickness values, the interpolation is more precise and is a better tool for small-scale subsurface investigations.

Purpose and Scope

The primary goal of this study is to better define the Quaternary stratigraphy of Clinton County and produce a new county-scale map (plate 1). Data was incorporated from previous mapping efforts and new data was collected in the field to better understand the complex glacial stratigraphy. Minimal correlation of units was attempted across county boundaries (primarily Highland County) but no formal attempt was made to characterize all sediment of the Scioto Sublobe or the adjacent Miami Sublobe under a unified stratigraphic context. Future mapping and research will be necessary to make any of these formal correlations. This work should serve as a starting point to build a regional stratigraphic framework.

No detailed countywide Quaternary mapping of Clinton County has been done since the publication of Teller's (1967) *Glacial Geology of Clinton County, Ohio.* After more than 50 years of technologic development, the amount of geologic data available to supplement county-wide mapping has increased substantially. Chronologic control on key glacial features can now be attained by Accelerator Mass Spectrometry (AMS) radiocarbon dating (which requires smaller sample quantities and produces results with minimized errors relative to traditional radiometric techniques), or by Optical Stimulated Luminescence (OSL) methods (which extend the absolute dating range into the Illinoian Glaciation). Laser diffraction particle size analysis instruments increase the precision, accuracy, and efficiency of grain size measurements. LiDAR is used to create DEMs that better display the land surface compared to traditional topographic maps. Large amounts of spatial data are compiled in a GIS and allow more efficient comparisons between geographically referenced data. The inclusion of these technologically advanced methods into map creation leads to detail-oriented, precise products that are of higher quality.

In this study, a new high-resolution (1:62,500-scale) Quaternary geology map is presented. Through these mapping efforts new glacial features preserved on the land surface have been identified and described, the chronology of glaciation in Clinton County has been better defined, and new interpretations of the glacial history have been made.

METHODS AND RESULTS

Field Mapping

Investigations of spatial relationships between glacial sediments were primarily made by detailed descriptions of lithologies and the observations of their stratigraphic positions along with the nature of those contacts. Lithofacies types were interpreted based on analogues to modern glacial and periglacial environments (Eyles and others, 1983; Brodzikowski and Van Loon, 1987). Field work was conducted in the summers of 2018 and 2019. A total of 89 outcrop exposures, most of which were located along the banks of streams, were studied in detail. Hand auger borings were made in ground moraines, outwash plains, and paleolake basins where exposures of the glacial sediments were unavailable.

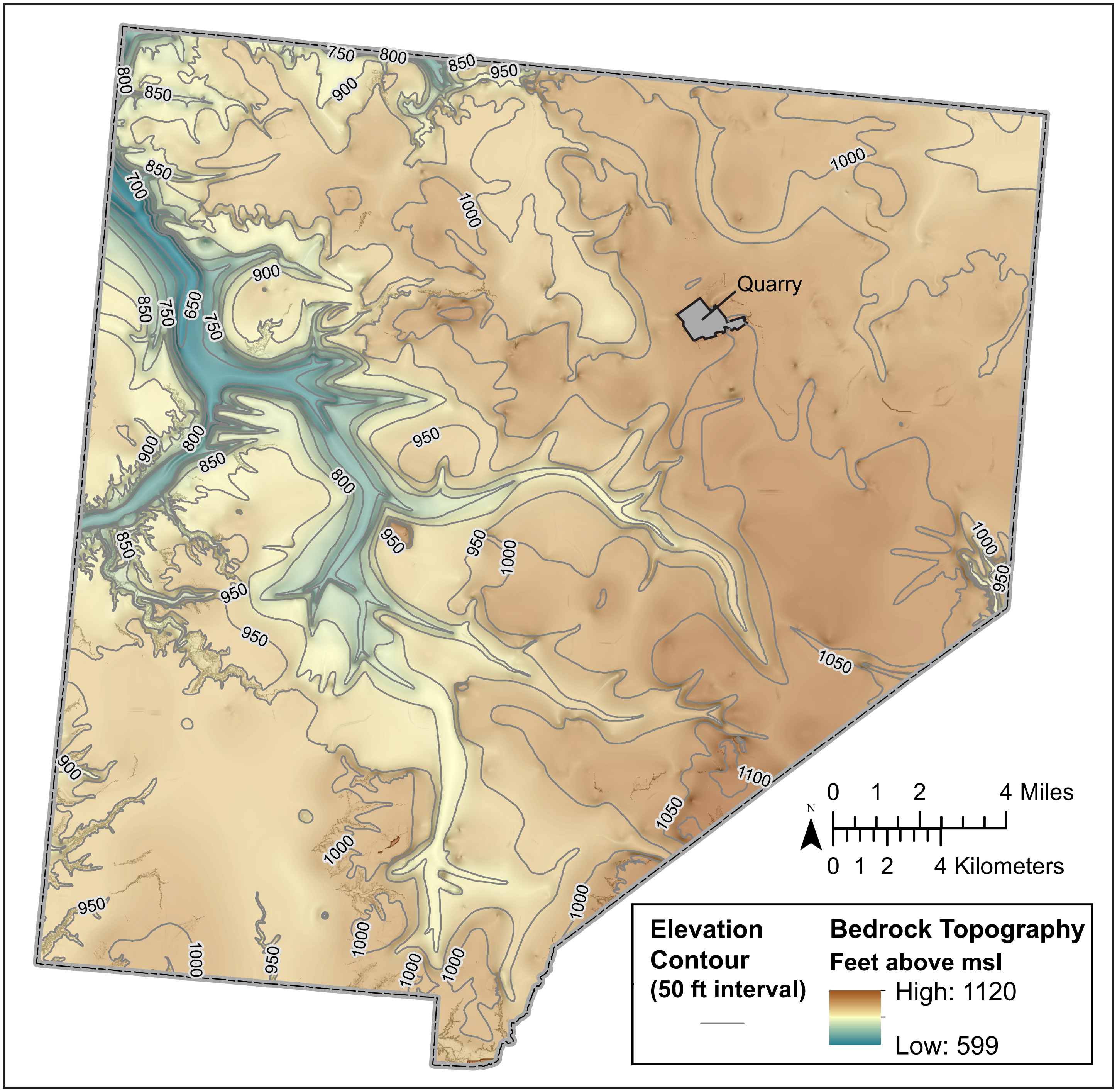

FIGURE 4: New bedrock topography map of Clinton County, Ohio.

All lithologic field descriptions included comments on texture, structure, color, contacts, and leaching. Texture evaluations were made based on a variety of field tests used to estimate the ratios of sand, silt, and clay in a sample. The primary structural distinction made in the field was the classification of bedded (stratified) versus massive units. The relative abundance of joints and faults were also noted when describing sediments in outcrop. Wet sediment samples were compared to a Munsell color chart to accurately describe the hue, value, and chroma of each sediment. Dilute hydrochloric acid was used to test the leaching depth of soil profiles.

Base map elevation data was derived from a statewide LiDAR survey completed in 2007 (OGRIP, 2006). This LiDAR data was used to produce a statewide DEM with 2.5-ft resolution. Geomorphic contacts were delineated using this seamless DEM base map. This base map improves the visualization of elevation data of USGS 7.5-minute topographic maps.

Radiocarbon Dating

Chronologic control on sediment deposition is necessary in order to interpret the glacial history of Clinton County. To date, there have been 19 individual radiocarbon dates made on materials preserved in Clinton County sediments (Dubois, 1996; Higley and Norris, 2020). Of these 19 dates, only three have been published (Goldthwait, 1958; Deevey and others, 1959; and Ogden and Hay, 1967). The remaining 16 unpublished dates have recently been compiled by Higley and Norris (2020) through personal communication with principle researchers and radiocarbon labs. Fourteen of the nineteen radiocarbon dates were made on wood, two dates were made on moss, one date was made on peat, and the remaining two dates were made on unknown materials. No new material has been analyzed for radiocarbon dating in Clinton County since the mid-1990s (Higley and Norris, 2020). The spatial distribution of these dates is primarily limited to the Cuba Moraine, where more detailed study of glaciogenic processes were studied (Dubois, 1996). These radiocarbon dates are insufficient to fully interpret the history of glaciation in Clinton County.

New material for radiocarbon dating was collected to gain a better chronologic control on the deposition of glacial sediments in Clinton County. Two new sites and one previously studied site were selected based on amounts of organic material available for radiocarbon dating, relative ease of access, and to fill gaps left by previous studies. The two new sites provide radiocarbon dating on the Wilmington (Curry Road Site) and "Vandervort" Moraines (RT-22 Site) which previously had no chronologic control. Materials dated included spruce needles (Todd Fork Site), dryas leaves (RT-22 Site), and peat (Curry Road Site). The inclusion of material from Todd Fork for radiocarbon analyses was made to verify previous results that are now over 50 years old and represent data collected from a less precise era of radiocarbon dating.

Twelve samples (four from each site) were analyzed using the W.M. Keck Carbon Cycle Accelerator Mass Spectrometer (KCCAMS) at the University of California Irvine (table 1). These samples were first pretreated with an acid/base/acid treatment to remove contamination. Then, samples were combusted at 900^0C to isolate the carbon within a stable CO_2 gas. The purified CO_2 gas was then reduced to graphite via chemical reaction to further purify and isolate the carbon atoms. These graphite samples were then ionized and ratios of $^{14}C/^{12}C$ atoms were measured via accelerator mass spectroscopy.

Results from the analysis (table 1) indicate the maximum age of sediment deposition and can be used to interpret the Quaternary history of the county. Organic material preserved within till units came from living plants which incorporated ^{14}C atoms from the atmosphere and trapped these atoms within their cellular structure after death. It was only after the death of these plants that they were preserved within the Quaternary-aged sediments on the surface of Clinton County today. A potential source of error in dating these materials is the unknown amount of time between the death of the plant and the burial within sediments. The preservation of stumps within their growth position along the Cuba Moraine suggests that this time was minimal and these materials represent that earliest age that ice could have advanced to each site (Dubois, 1996).

GLACIAL FEATURES

Glacial landforms such as end moraines, hummocky moraines, ground moraines, and outwash plains/terraces control the topography of the land surface across Clinton County. The Wisconsinan end moraines act as the primary drainage divides in the county and form large arcuate ridges that can be traced across the county. Some have been recognized as significant geologic features before the availability of topographic maps (Chamberlin, 1883). Technologic improvements such as LiDAR and GIS make it easier to delineate glacial moraines and examine their cross-cutting relationships to one another. In this section, Clinton County's prominent glacial features and their properties will be described in detail.

Illinoian Ground Moraine

The Illinoian Ground Moraine covers about a third of the county, southwest of the Cuba Moraine (plate 1). The ground moraine is a partially dissected plain of thin till over mostly Ordovician-aged and some Silurian-aged bedrock. The gentle rolls and hummocks of the ground moraine's surface are a result of erosion and are not a primary depositional characteristic. The increased levels of dissection are a qualitative proxy for the relative age of the deposit, compared to the low-level dissection on younger Wisconsinan-aged ground moraines.

The drift thickness of the ground moraine varies greatly, from just a few feet up to as much as 125 ft thick. The thickest drift is confined to a 13 mi^2 area south of Martinsville which infills the

Table 1: ***Samples analyzed at the KCCAMS***

UCIAMS #	Sample name	Material Dated	Fraction Modern	±	$D^{14}C$ (‰)	±	^{14}C age (BP)	±	Cal Year (BP)	±
221205	TF19B	spruce needles	0.0421	0.0004	-957.9	0.4	25,450	70	27,590	270
221206	TF19D	spruce needles	0.0418	0.0004	-958.2	0.4	25,500	80	27,650	310
221207	RT2219A	wood	-0.0001	-0.0003	-1000.1	-0.3	>59,600		>60,000	
221208	RT2219B	dryas leaves and stems	0.0007	0.0003	-999.3	0.3	58,100	3500	>60,000	
221209	RT2219C	wood	0.0000	-0.0003	-1000.0	-0.3	>59,600		>60,000	
221210	RT2219D	wood	0.0004	0.0003	-999.6	0.3	>55,500		>60,000	
221211	CR19A	peat	0.0314	0.0006	-968.6	0.6	27,810	150	29,620	350
221212	CR19B	peat	0.0438	0.0007	-956.2	0.7	25,130	140	27,220	360
221213	CR19C	peat	0.0416	0.0006	-958.4	0.6	25,540	130	27,780	450
221214	CR19D	peat	0.0306	0.0006	-969.4	0.6	28,000	170	29,920	540

headwaters of a buried preglacial bedrock valley. Outside of this area, the Illinoian drift deposits are typically around 10–30 ft thick. The topography of the ground moraine is predominately drift controlled, except for some areas such as the East Fork Todd Fork and East Fork Little Miami valleys, which have cut through the ground moraine after deposition. The bedrock valley south of Martinsville shows no expression on the surface suggesting the entire preglacial drainage network of bedrock valleys was filled during the Illinoian Glaciation.

Landforms associated with subglacial processes are uncommon across the regional Illinoian till plain. Teller (1967) mapped a solitary kame near the intersection of US-68 and Lazenby Road, about 2 mi south of the town of Cuba (39.331618, -83.895414). This elliptical feature has a northeast–southwest-trending long axis that is 400 ft long and a perpendicular short axis that is 225 ft long. The feature has a maximum elevation of 1,010 ft and is about 15 ft tall. No other similar features are found on the Illinoian ground moraine of Clinton County.

Cuba Moraine Complex

The Cuba Moraine has been recognized as the terminal moraine of the Wisconsinan Glaciation for over 100 years (Leverett, 1902). Shortly after its initial recognition, the moraine was delineated as a single ridge feature, with minor associated moraines occurring on the stoss side of the Cuba Moraine (Austin, 1930). These moraines were later grouped together and recognized as a moraine with two distinct ridge systems (Teller, 1967). However, a portion of Teller's (1967) Cuba Moraine was split into a new moraine designated the Vandervort Moraine. In adjacent Highland County, the two ridges of the Cuba Moraine were split into an Inner Cuba Moraine and Outer Cuba Moraine (Rosengreen, 1974). In Rosengreen's (1974) map of Highland County, the Mount Olive Moraine correlates with the furthest extent of the Cuba Moraine in Clinton County (see fig. 14; Rosengreen, 1974). This inability to agree on the simple delineation and correlation of the multiple ridges at the terminus of Wisconsinan-aged sediments leads to inconsistences and general confusion regarding the interpretation of the glacial history.

To combat this confusion, the Cuba Moraine is currently described as a morainal complex, formally the Cuba Moraine Complex. This is supported by lithofacies investigation along the moraine that determined it was constructed by at least three distinct advances over a period of a few thousand years (Dubois, 1996). The moraine complex is composed of at least three subparallel, dissected, arcuate ridges characterized by crests about 2–3 mi long. Two distinct crests can be delineated in the Cuba Morainal Complex at the border between Clinton and Highland Counties (39.314167, -83.701262). The innermost crest splits into two distinct crests just east of where East Fork Todd Fork bisects the morainal complex (39.362367, -83.752751). From here, three crests can be correlated across multiple cross-cutting streams until the Cuba Morainal Complex abuts the Hartwell Moraine of the Miami Sublobe (39.553780, -83.975406).

Stream dissection near Todd Fork, Caesar Creek, and Cowan Lake had developed into a mature dendritic drainage pattern before the Last Glacial Maximum (LGM) construction of the Cuba Moraine Complex. Thinly draped till and associated glaciogenic deposits are blanketed onto this dissected landscape and do not effectively bury or flatten the landscape. The landscape associated with these deposits exhibits characteristics of bedrock-controlled topography, where ridges and valleys maintain near constant drift thickness and changes in surface elevation are controlled by the elevation of the underlying bedrock. The glacial deposits flanking these hillsides tend to be partially eroded and thinner than deposits on stable ridgetops. The till deposited on these flanks of the ridge exhibits characteristics of gravity-fed colluviation, most notably exhibiting weakly-developed soils and mixing of various lithologies such as loess and till.

Wilmington Moraine

The Wilmington Moraine was first recognized by Teller (1964) as an arcuate, thin belt of hummocky topography that extends nearly continuously from the border between Clinton and Highland Counties at Scissorville Road (39.352407, -83.636448) to the border between Greene and Clinton Counties at Ingle Mill Road (39.566107, -83.923313). The single crest is weakly developed, except for the portion of the ridge bordering Highland County. A new delineation of the moraine based on LiDAR data shows that the width of the moraine is more variable than previously thought (Teller, 1967). The moraine averages about 2 mi in width, with a maximum width of 4.25 mi and a minimum width of 0.75 mi. The crest of the Wilmington Moraine is about 30–60 ft higher in elevation than the surrounding ground moraine and has a maximum elevation of 1,125 ft. The ridge is dissected by Anderson Fork (Greene County), Buck Run, Dutch Creek, Todd Fork, and South Fork Lees Creek. The drift thickness along the moraine averages about 50 ft thick and is thickest at the headwaters of the preglacial bedrock valley, where drift is up to about 175 ft thick.

The hummocky topography, weakly developed crest and margins, and concentrations of sorted sediments of the Wilmington Moraine are all indicative of a recessional moraine. The hummocks on top of the moraine are typically circular with diameters of roughly 200 ft. These hummocks are smaller, more tightly packed, and more regularly spaced than those preserved on the Reesville Moraine. The crest of the moraine is generally weakly developed, except for the southeastern-most portion of the moraine in Clinton County. A weak crest could be due to a lack of active ice processes at the snout of the Scioto Sublobe (Bennett, 2001). The margins of the moraine are gradational between the surrounding ground moraine. This gradational margin can be explained by a gradual settling of the sediments in an ablation terrane. This passive, decaying-ice hypothesis is supported by the inclusion of sorted sediments interbedded within glacial till. Observations of sand and gravel, lacustrine, and peat deposits within the glacial till and between hummocks indicate that multiple depositional environments, including variable conditions of water-lain deposition, were present within close proximity to each other at the ice margin while the Wilmington Moraine was constructed.

Reesville Moraine

The Reesville Moraine was the first end moraine recognized in Clinton County (Chamberlin, 1883). The distinct scarp at the moraine front made it easily recognizable even before the existence of topographic maps. Originally, Chamberlin (1883) believed that the Reesville Moraine marked the terminal advance of Wisconsinan ice of the Scioto Sublobe. Later mapping by Leverett (1902) and Teller (1967) dispelled this theory and recognized the Cuba Moraine as the Wisconsinan terminal position.

The Reesville Moraine is an arcuate belt of hummocky topography with a well-defined double crest and abrupt margins (plate 1). The moraine loops from the triple junction of Clinton, Highland, and Fayette Counties (39.382921, -83.590781) to the area where Interstate 71 enters Clinton County (39.553956, -83.727474). The width of the moraine varies slightly between 1.5–2 mi. The crests of the moraine reach an elevation of up to 1,125 ft above MSL, about 70 ft above the surrounding ground moraines. The depth to bedrock along the moraine is typically between 70 and 100 ft; however, portions of the moraine near the eastern edge of Clinton County exhibit depths to bedrock between 30 and 40 ft (fig. 5).

The Reesville Moraine crosscuts the Wilmington Moraine about 1.4 mi southwest of the intersection of SR-72 and SR-729 (plate 1). The front edge of the Reesville Moraine overrides the back edge of the Wilmington Moraine. This relationship between the two moraines indicates that the Reesville Moraine is younger than the Wilmington Moraine and provides more evidence that the Reesville Moraine was constructed by an advancing ice sheet.

Sabina Moraine

An arcuate ridge of hummocky topography standing 10–30 ft above the bordering ground moraine extends throughout northeastern Clinton County. This ridge runs parallel to the Reesville Moraine about one to two miles to the northeast. The ridge extends from the Clinton County line at Greenfield-Sabina Road (39.468825, -83.583332) to the triple junction of Clinton, Fayette, and Greene Counties (39.550333, -83.670145) The village of Sabina sits directly on top of the ridge. Previous investigations into the glacial geology of the county failed to recognize this feature as a moraine. Teller (1964) provided data on surficial boulder concentrations across the county but could not explain higher concentrations of boulders northeast of the Reesville Moraine. The comparison between Teller's boulder data and the new delineation of the geomorphology show a distinct relationship between boulder concentrations and this ridge.

This study designates this feature as a glacial moraine based on the boulder concentrations, hummocky topography, and arcuate morphology (plate 1). The name Sabina Moraine is proposed for the moraine. The subtle height, lack of well-defined crest, and the gradational nature of moraine boundaries indicate that this moraine had a similar recessional construction to the Wilmington Moraine. The hummocks on the Sabina and Wilmington Moraines are of the same magnitude, justifying the conclusion that each moraine formed by similar recessional processes. The extent of the Sabina Moraine is limited to Clinton County as the moraine pinches out in Fayette County to the north and east.

Cuba Outwash

Outwash associated with Cuba Moraine Complex construction is preserved in terraces along the East Fork Todd Fork and East Fork Little Miami valleys (plate 1). Cuba Moraine Complex outwash was presumably also deposited along Todd Fork; however, younger valley train deposition associated with the construction of the Wilmington Moraine imprinted its own history on top of previous outwash deposits, obscuring topographic characteristics of previous outwash deposits. Outwash deposits along these valley systems are composed of sand and gravel with high concentrations of well-rounded dolomite and igneous/metamorphic erratics. Valley train deposits deposited in both valleys were sourced from outwash plains at the heads of their respective rivers, between the inner and outer crests of the Cuba Moraine Complex (plate 1). Additionally, an outwash plain developed on the Illinoian ground moraine along US-68 at the frontal edge of the Cuba Morainal Complex, likely preceding the development of outwash plains between moraine crests. This earlier outwash plain supplied sediment directly to East Fork Todd Fork.

Previous mapping of outwash terraces in Clinton County used outdated time distinctions and did not tie terraces directly to outwash events associated with different moraine-building events (Teller, 1964). Teller (1964) identified two distinct terrace elevations along East Fork Todd Fork, one belonging to the Early Wisconsinan and one belonging to the Late Wisconsinan. Outwash deposition during the Early Wisconsinan would not have been possible in Clinton County because correlation to the marine isotope record and reinterpretation of glacial sediments in Canada led to the conclusion that the Laurentide Ice Sheet was not large enough to advance past the Great Lake Basins (Eyles and Westgate, 1987).

Previous investigations of outwash terraces along the Scioto and Hocking River Valleys have used elevation correlation graphs to determine relative ages of outwash deposits and correlate ages of terraces (Kempton and Goldthwait, 1959). Outwash terrace elevations along East Fork Todd Fork and East Fork Little Miami exhibit similar gradients; however, they have different elevation profiles (fig. 6). Terrace elevations range from 1,100 to 832 ft above MSL, decreasing in elevation with further distance from the outwash plain sources. When plotted along a distance profile, the terrace gradients from both valleys are almost indistinguishable (fig. 6). The points have a correlation coefficient (R^2) of 0.95 along East Fork Todd Fork and 0.93 along East Fork Little Miami. A second visual trend is seen in the terrace elevation data along East Fork Todd Fork, which probably represent a relic in valley gradient from before the capture of a prior Todd Fork Tributary into an ice marginal channel (fig. 6; plate 1). Outwash sourced from the Cuba Moraine Complex was deposited concurrently along East Fork Todd Fork and East Fork Little Miami because of the proximity of valleys and outwash sources, similar composition of deposits, and similar valley train gradients.

Wilmington Outwash

Outwash associated with Wilmington Moraine construction is preserved in terraces along the Cowan Creek, Lytle Creek, and Todd Fork Valleys (plate 1). These rivers crosscut the Cuba Moraine Complex and have their headwaters at, or near, the Wilmington Moraine. Therefore, surficial outwash deposits in these valleys likely were sourced from the Wilmington Moraine. However, below these surficial outwash deposits are likely sediments from an earlier outwash deposition stage related to the construction of the Cuba Moraine Complex. Later deposition of outwash during the Wilmington Moraine imposed new gradients on valley train deposits that are distinct for each valley train system.

The three valley train systems along Cowan Creek ($R^2 = 0.91$), Lytle Creek ($R^2 = 0.96$), and Todd Fork ($R^2 = 0.87$) all exhibit good internal correlation between terrace elevations along distance profiles (fig. 7). Changes in the underlying bedrock topography affect the elevations of these different valleys systems, meaning they cannot be directly correlated between valley systems by elevation. In other words, valley train outwash sediments that were deposited concurrently might not necessarily have been deposited at the same elevation, as one would expect for other geologic systems such as lacustrine basins. Overall, outwash terrace elevations are similar to those established during Cuba Moraine Complex deposition with elevations between 1,040 and 825 ft above MSL. The valley train gradient along Lytle Creek is the steepest of the three because of the relatively shorter distance along this route from the Wilmington Moraine to the intersection of the valley with the Todd Fork valley, which sets the base level for Lytle Creek. The gradient on Todd

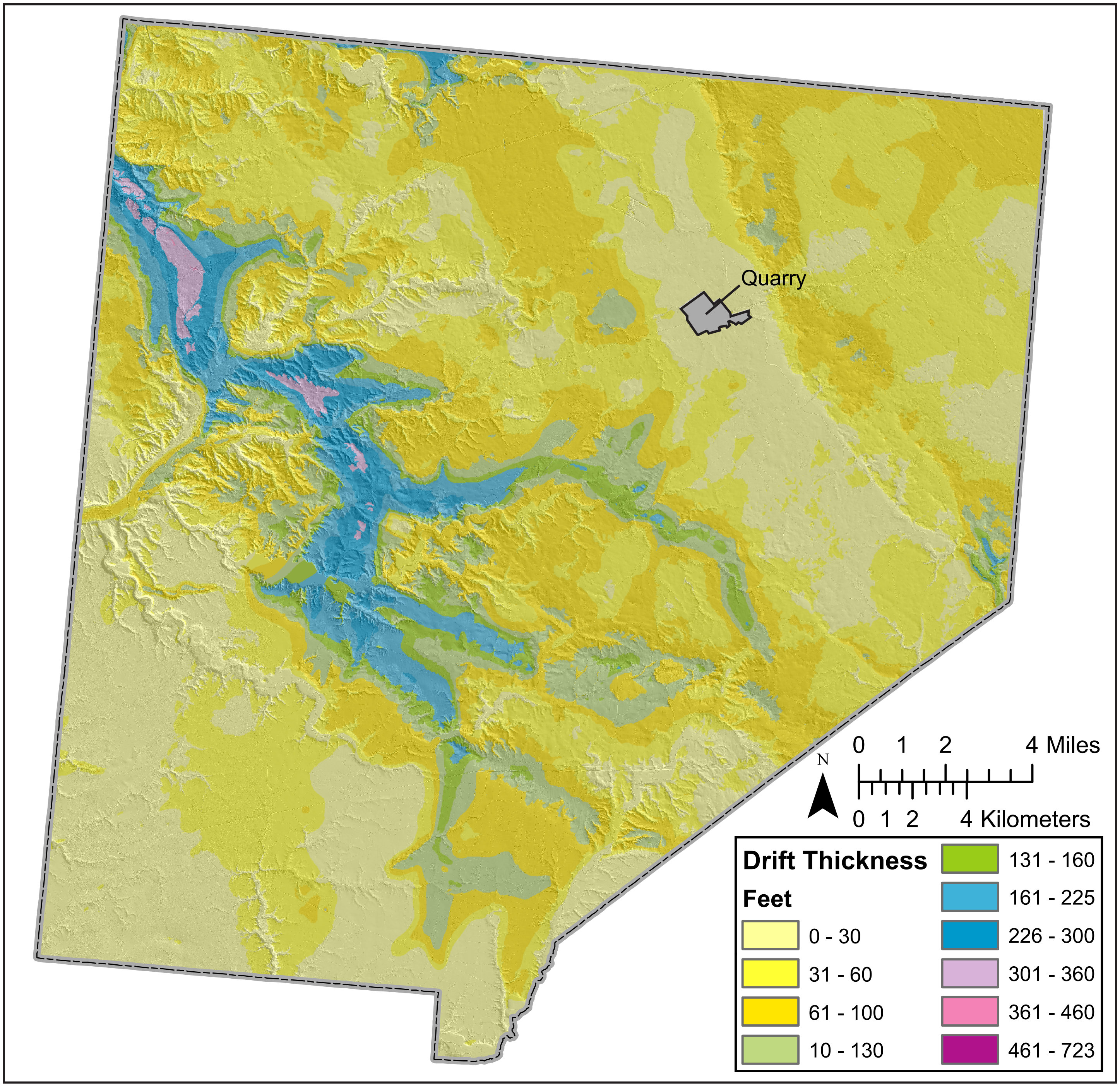

FIGURE 5: New drift thickness map of Clinton County, Ohio.

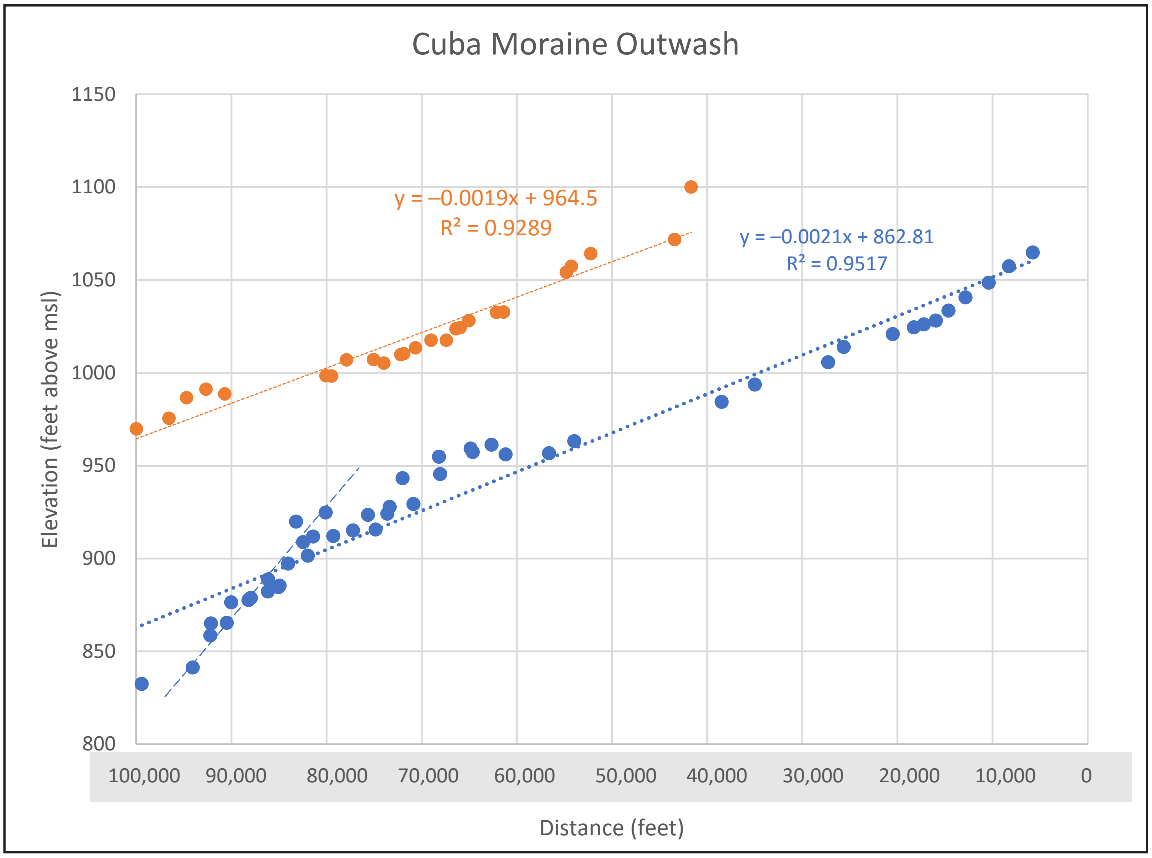

FIGURE 6: Elevation profile of Cuba Moraine outwash terraces along the East Fork Todd Fork (blue) and East Fork Little Miami Valleys (orange) in Clinton County, Ohio. The blue dashed line follows a visual trend in the data that represents a previously steeper drainage pattern imprinted on the bedrock from before the full capture of East Fork Todd Fork by ice marginal streams, when the valley was a smaller tributary of Todd Fork.

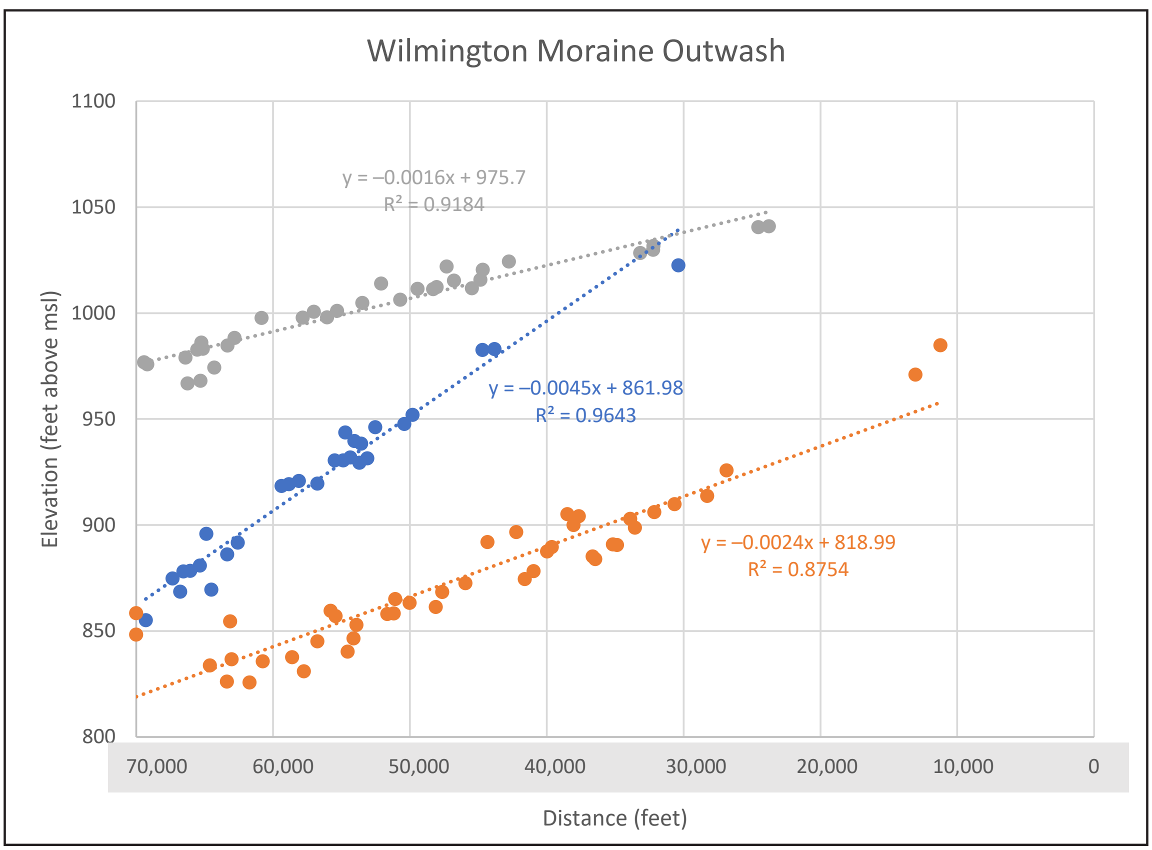

FIGURE 7: Elevation profiles of Wilmington Moraine outwash terraces along Cowan Creek Valley (gray), Lytle Creek Valley (blue), and Todd Fork Valley (orange) in Clinton County, Ohio.

Fork is similar to the gradient observed at East Fork Todd Fork and East Fork Little Miami River, which could imply that outwash deposition was minor during the construction of the Wilmington Moraine, leaving the primary valley train gradient intact. This is supported by a seemingly steeper slope near the head of Todd Fork indicated by outwash terrace elevations which are higher than the expected trend based on downstream terrace elevations.

Reesville Outwash

Outwash associated with Reesville Moraine construction in Clinton County is preserved in terraces along the Anderson Fork and Caesar Creek Valleys (plate 1). This outwash is sourced from an outwash plain abutting the Reesville Moraine between I-71 and US-22 (plate 1). This outwash plain exhibits a fining upwards sequence within the upper 5 ft moving from cobble-rich outwash sediment to sandy-loam glaciolacustrine sediments. Sediments preserved in terraces along Anderson Fork are cobble-rich, well-rounded gravels with a mix of dolomite, limestone, and igneous/metamorphic lithologies. The elevation of these outwash terraces along the Anderson Fork and Clinton County portions of Caesar Creek range between 1,025 and 861 ft above MSL (fig. 8). This elevation range is comparable to both Wilmington and Cuba Moraine Complex outwash terrace elevation ranges. Therefore, outwash terraces in Clinton County were not be distinguished based solely on elevation, but rather mapped in detail based on lithology, valley headwater locations, and drainage divide positions.

Boulder Belts

The concentrations of boulders along the surface of Clinton County was studied by Teller (1967), which showed an increase in boulder concentrations along the Reesville and Cuba Moraines. This original data was georeferenced and digitized in a GIS and reinterpreted with the modern delineation of moraines in the county (fig. 9). Surficial boulders in Clinton County are generally correlated with the glacial moraines, especially the Cuba Moraine Complex and the Reesville Moraine. It is still unclear whether the increase in boulders are a primary depositional feature or an erosional feature. The deposition theory posits that ice-dynamic processes work to concentrate boulders during enhanced periods of ice "conveyor belt" movement throughout moraine construction. The erosion theory posits that, along the steeper slopes of moraines, more potential energy exists to erodes finer sediments through gravity-fed or water-fed processes; however, larger boulders are not able to be eroded leaving higher concentrations of boulders. Regardless of processes, it is important to map concentrations of boulders, where significant, because they impact the engineering and hydrologic properties of the glacial tills.

COUNTY STRATIGRAPHIC FRAMEWORK

A spatial and temporal framework that relates the deposition of till and associated glacially derived sediments is needed to understand the complex cycles of glacial advance and retreat. Currently no such framework exists to relate all Quaternary-aged sediments in Ohio. In order to advance towards a state-wide framework, regional and county frameworks must first be developed. The first iteration of this stratigraphic framework follows below and is summarized by a correlation diagram (fig. 10).

The physical and chemical properties of tills and their spatial distribution can be used to build these smaller frameworks. Tills can be correlated at varying scales using chronostratigraphic principles and formalized into formations and groups. On plate 1, tills are divided into three chronologic units: Rainsboro Till (ra-), Caesar Till (ca-), and Darby Till (da-). Modifiers for ground moraines (-g) and end moraines (-m) are used to distinguish different geomorphic landforms composed of the same till. For example, a Caesar Till end moraine (i.e., the Wilmington Moraine) would have the abbreviation 'cam' and Rainsboro Till plain would be abbreviated 'rag.' Outwash, lacustrine, and loess sediments deposited concurrently with till units

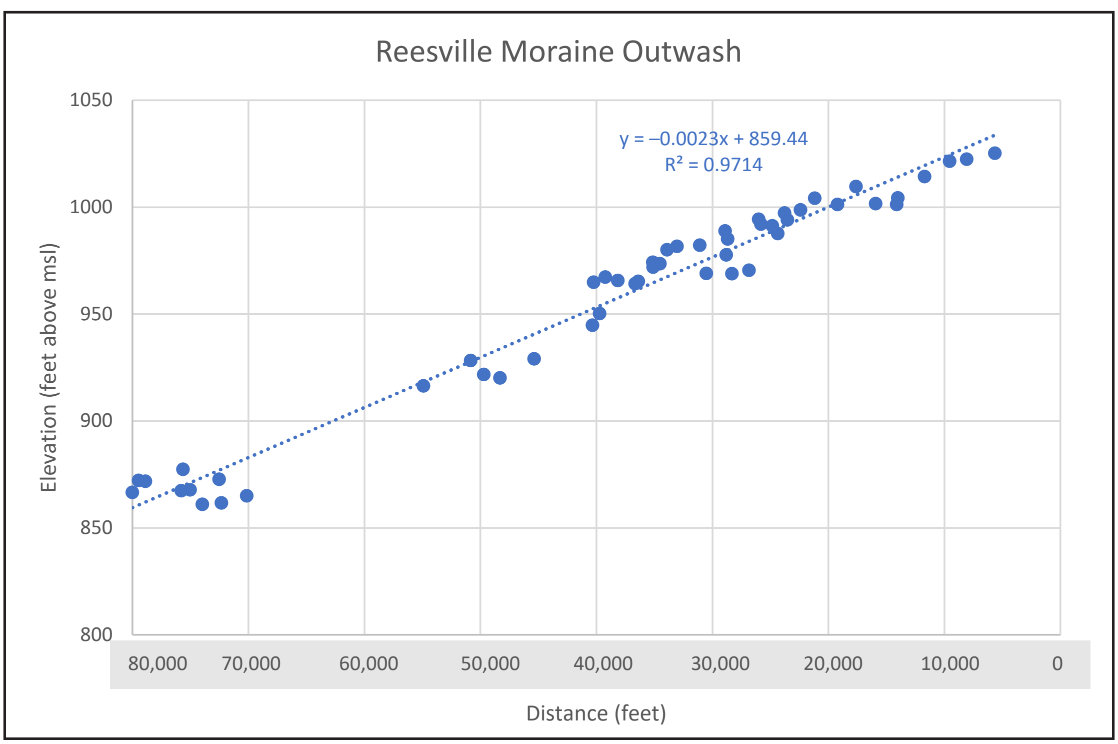

FIGURE 8: Elevation profile of Reesville Moraine outwash terraces along Anderson Fork valley in Clinton County, Ohio.

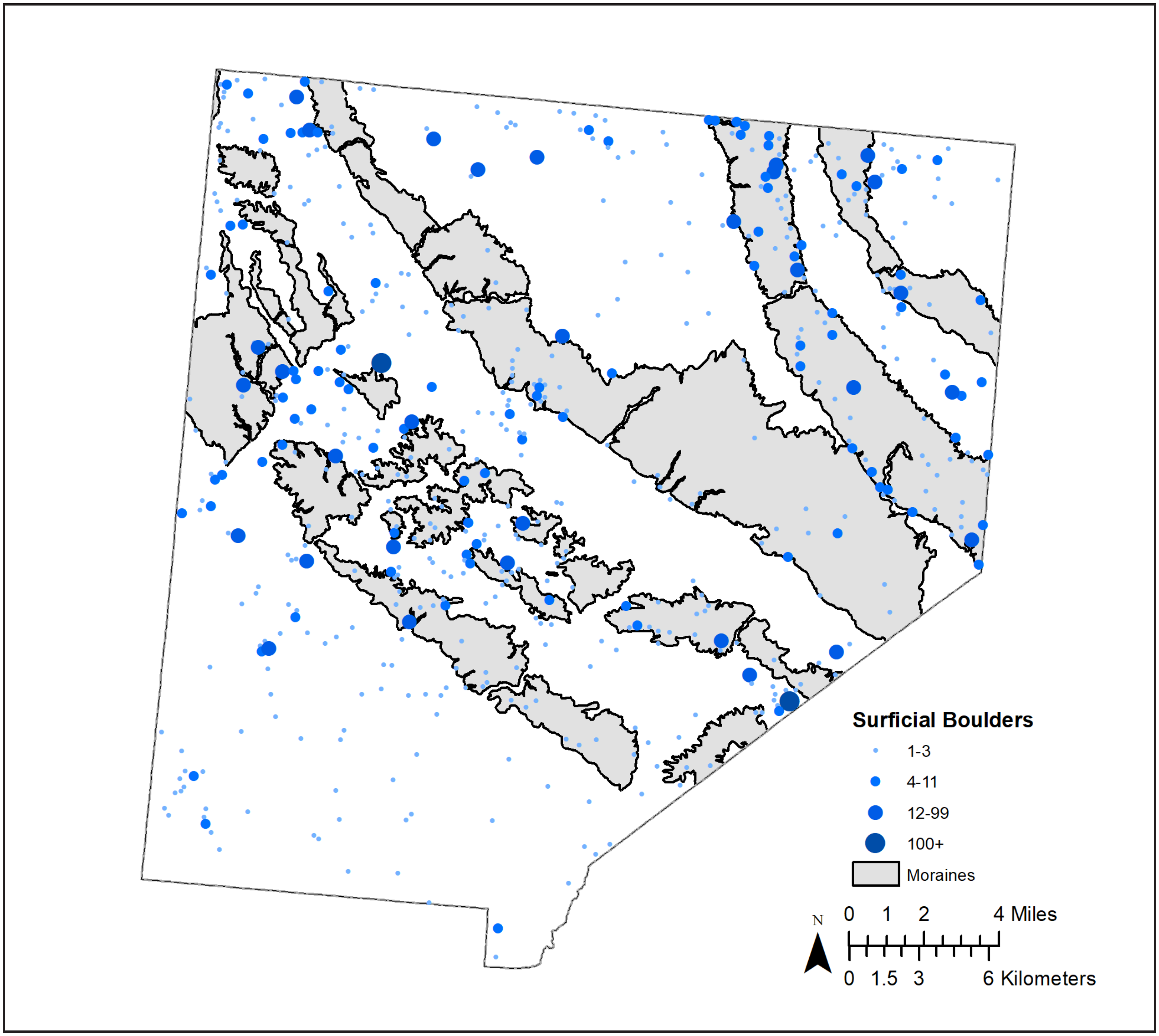

FIGURE 9: Surficial boulder concentrations in Clinton County, Ohio, modified from Teller, 1967. Each point represents the number of boulders greater than 1 ft in diameter within a quarter square mile area.

Age	Primary Till Units	Contemporaneous Units
Holocene (10–0 ka)	—	alluvium
Late Wisconsinan (28–18 ka)	Darby Till	Reesville Moraine Outwash
	Caesar Till	Wilmington Moraine Outwash
		Cuba Moraine Outwash Cuba Moraine Proglacial Lake Cuba Moraine Colluviated Till
Illinoian (160–125 ka)	Rainsboro Till	Illinoian Outwash

FIGURE 10: Correlation of Quaternary-aged mapped units.

should share geochemical and lithologic signatures that can be used to relate multiple glaciogenic facies within chronostratigraphically-distinct units. These contemporaneous features also modify two-letter abbreviations of associated moraines to create a three-letter code for mapping. These modifiers are: Outwash in valley train terraces and plains (-o), intermorainal and proglacial lakes (-l), and thick loess deposits (-e). For example, an outwash terrace formed contemporaneously with the Reesville moraine is abbreviated 'reo' and proglacial lakes which abut the Cuba Moraine Complex are abbreviated 'cul.' In the future, this correlation might also be made across sublobe boundaries, with the assumption that sublobes are moving in unison (Ekberg and others, 1993; Lowell and others, 1999).

Rainsboro Till

The Rainsboro Till is a dark-gray (10 YR 4/1), massive, loamy diamicton deposited during the Illinoian Glaciation. The surface of the till unit is deeply weathered and leaching depths of more than 6 ft are greater on average than younger Wisconsinan-aged tills. Generally, the Rainsboro Till is also generally more compact than younger Wisconsinan-aged tills. The Rainsboro Till exhibits nearly vertical and evenly spaced sets of joints when observed at outcrop-scale. These joints are well documented within the Rainsboro Till across the region (Rosengreen, 1974; Weatherington-Rice and Bingham, 2006). The loess mantle on the Rainsboro Till in Clinton County ranges from 2–4 ft on average.

Pebbles preserved in the Rainsboro Till are generally sparse. When pebbles are found in near-surface tills, they are heavily weathered and are colloquially referred to as, "rotten pebbles." Rotten pebbles in the Rainsboro Till often break easily under low pressure. The pebble lithology is predominately dolomite and limestone, which reflects the local bedrock source of the till. The till unit also has minor amounts of Canadian-sourced igneous and metamorphic pebbles and minor amounts of Ohio Paleozoic sandstone and shale.

Surficial exposures of the Rainsboro till are limited to areas southwest of the Cuba End Moraine and cover 21.1% of the county today. These regions are mapped on plate 1 with the abbreviation ra- These sediments were deposited near the end of the Illinoian Glaciation when the ice sheet was nearing its maximum extent. One Illinoian-aged outwash terrace along the Todd Fork valley is associated with the Rainsboro Till. No absolute age dating on Rainsboro Till and outwash sediments in Clinton County has been attempted in the past or herein.

The Rainsboro Till is commonly associated with the Clermont and Westboro soil series (Luhct and others, 2005). Combined, both soil series cover 13.8% of the Clinton County land surface, with other minor soils covering the remaining portion of the Rainsboro Till plain (Luhct and others, 2005). These soil associations extend across southern Ohio through Brown, Adams, and Clermont Counties indicating a fairly consistent Rainsboro Till parent material composition throughout the region (Luhct and others, 2005).

Caesar Till

The Caesar Till is a gray (10YR 5/1), massive, loamy diamicton deposited during the Wisconsinan Glaciation. This till unit exhibits a well-developed prismatic structure and is sparsely pebbly. The dominant pebble lithologies are dolomite and limestone with minor proportions of igneous/metamorphic and shale/sandstone lithic fragments. Caesar Till units are typically leached of carbonate within the upper 3–4 ft of the profile and contain a 2–3.5-ft-thick loess mantle. Large outcrops of Caesar Till often include thick interbeds of outwash between deposits of Caesar Till (Quinn and Goldthwait, 1985).

Glacial advances often destroy or truncate geologic records of interstadial events. In these cases, the Caesar Till is distinguished from the underlying Rainsboro Till by the lack of, or significant decrease in, vertical joints and the lower degree of compaction and cohesiveness. The Caesar Till also appears to a have a slightly lighter blue tint relative to the underlying Rainsboro Till and overlying Darby Till.

Surficial exposures of Caesar Till occur between the Cuba and Reesville Moraines, including the Wilmington Moraine (plate 1). Deposits of Caesar Till cover 56.7% of Clinton County today. The Caesar Till was deposited as the Scioto Sublobe reached its maximum extent, around 24 ka, in Clinton County. Outwash associated with the Cuba and Wilmington Moraines were deposited concurrently along mainly Todd Fork, East Fork Todd Fork, Lytle Creek, East Fork Little Miami, and Cowan Creek.

The Caesar Till is associated with the Fincastle, Reesville, Treaty, and Xenia soil series in Clinton County (Luhct and others, 2005). Combined, these soil series cover 39.2% of the Clinton County land surface, with other minor soils covering the remaining portion of the Caesar Till plain (Luhct and others, 2005). Confusingly, the Reesville soil is not found on the Reesville Moraine, but mainly within the Caesar Till ground moraine between the Wilmington and Reesville Moraines in the northern half of Clinton County (Luhct and others, 2005). The Crouse and Miamian soil series in Clinton County are associated with higher slopes and slightly colluviated Caesar Till deposits (Luhct and others, 2005).

Darby Till

The Darby Till is a dark-gray (10YR 4/1), massive silt loam diamicton deposited during the Wisconsinan Glaciation. This till unit exhibits a prismatic structure and is pebbly. The dominant pebble lithologies are dolomite, limestone, and shale/sandstone with minor proportions of igneous/metamorphic lithic fragments. The Darby Till typically has a 0–2 ft loess mantle and is leached of carbonate within the upper 3–4 ft of the vertical profile. The Darby till is typically darker than the underlying Caesar Till, contains more sandstone/shale pebbles, and exhibits more vertical jointing in outcrop.

Surficial exposures of Darby Till occur northeast of the Reesville Moraine, in Clinton County, and extend north to the Powell Moraine in Delaware County. Deposits of this age cover 15.2% of Clinton County today. Darby Till was deposited during the construction of the Reesville and Sabina Moraines.

The Darby Till is associated with the Celina, Crosby, and Kokomo soil series (Luhct and others, 2005). Combined, these soil series cover 13.5% of the Clinton County land surface, with other minor soils covering the remaining portion of the Darby Till plain (Luhct and others, 2005). The soils are characterized by higher percentages of clay in their parent material and thinner loess mantles relative to those soils associated with the Caesar Till (Luhct and others, 2005). These patterns correlate geographically with the Reesville Moraine, forming a pseudoboundary between these soil associations (Luhct and others, 2005).

QUATERNARY HISTORY

Sediments preserved at the surface of Clinton County, as described in the previous section, indicate that glaciers covered varying portions of the county at least twice during the Pleistocene Epoch. These sediments can be correlated to those deposited in the Atlantic Ocean during distinct stages marked by fluctuations in oxygen isotopes recorded in marine foraminifera (Railsback and others, 2015). Glaciers concentrate ocean water that has lower ^{16}O values, due to the preferential evaporation of the lighter oxygen isotope (Dansgaard, 1964). This leaves the seawater with higher relative values of ^{18}O isotopes that organisms use to precipitate calcium carbonate ($CaCO_3$) shells. When these organisms die, some are buried and preserved in ocean sediments. The burial and archival of these organisms has been nearly continuous throughout the Pleistocene, which allows researchers to create detailed time series of change in seawater chemistry, which is a primary proxy record for the size of terrestrial ice sheets (Railsback and others, 2015). Radiocarbon and OSL dating can be used to correlate terrestrial glacial sediments with global sea level and water chemistry changes (fig. 11). The Wisconsinan Glaciation peaked during Marine Isotope Stage 2 (MIS 2) and the Illinoian Glaciation reached its height during MIS 6a. The history of glaciation can be interpreted through the context of these stages using the lithologic properties of these sediments in conjunction with the age of organic material preserved within and around them.

Pre-Illinoian Glaciation (MIS >19?)

The earliest advances of ice into Ohio during the Quaternary Period occurred in the pre-Illinoian glaciation. However, no sedimentological evidence for a pre-Illinoian glaciation exists at the surface of Clinton County. Pre-Illinoian glacial sediments exhibit reversed magnetic polarity in other portions of the state, indicating deposition before MIS 19 (Szabo and Chanda, 2004). The presence of some pre-Illinoian till deposited in adjacent Highland County suggests that pre-Illinoian ice did advance across Clinton County (Rosengreen, 1974).

Although no surficial pre-Illinoian sediments exist in the county, it is likely that sedimentation occurred during this period and was then eroded during subsequent glaciations. Pre-Illinoian deposits have been reported buried beneath Illinoian deposits in adjacent Highland County (Rosengreen, 1974). Ice flow indicators, such as striations on bedrock surfaces, show that for subsequent glaciations ice probably flowed through Clinton County to Highland County (Illinoian Glaciation), or sediments were deposited concurrently in both counties (Wisconsinan Glaciation). Without further evidence, it can be reasonably assumed that ice would have flowed in a quasi-southernly pattern during the pre-Illinoian glaciation. Some pre-Illinoian sediments could

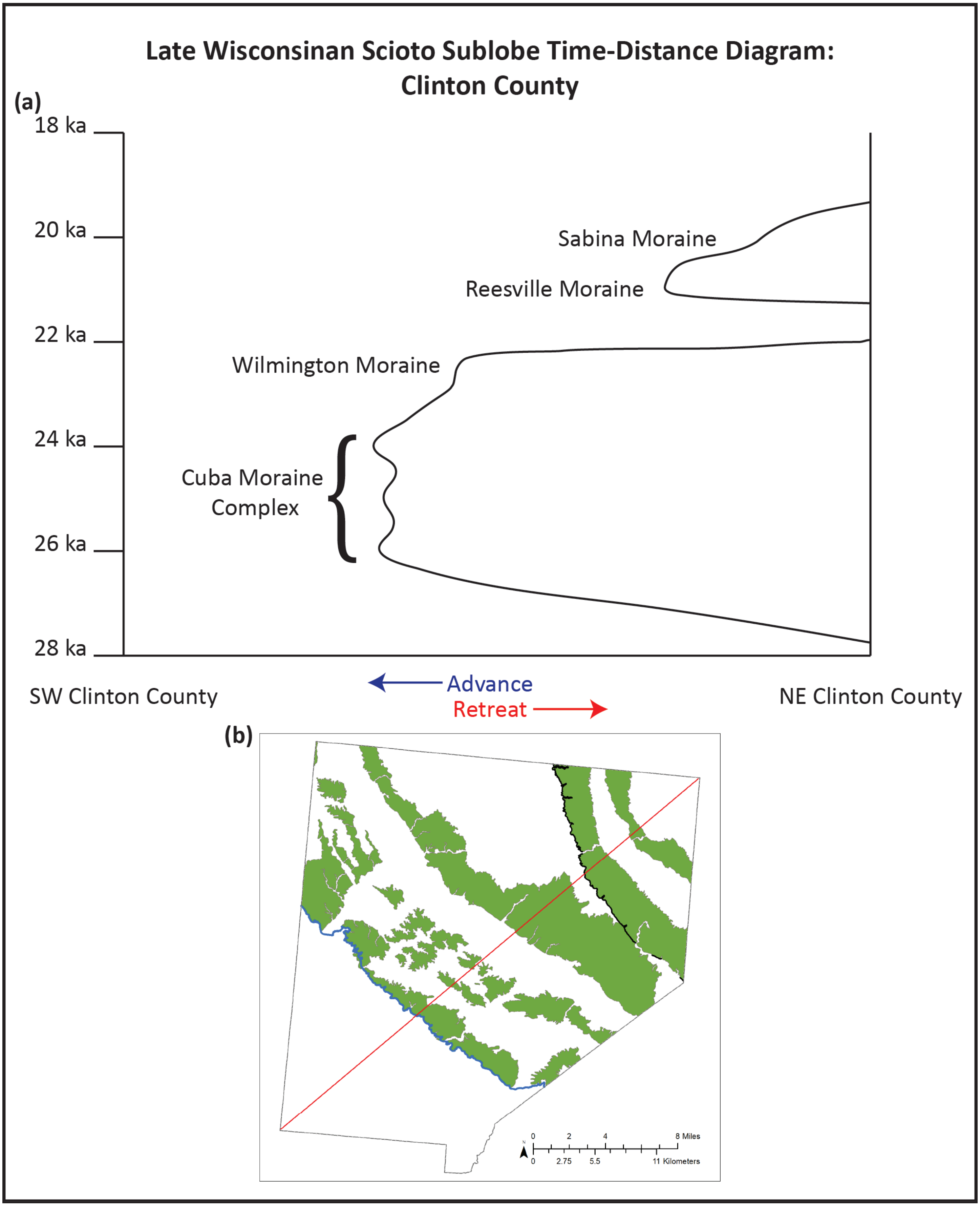

FIGURE 11: (a) Time distance diagram showing the advance and retreat history of the Scioto Sublobe in Clinton County, Ohio, during the Late Wisconsinan Glaciation. (b) Inset map showing the x-axis of the time-distance diagram (red line) and the LGM boundary (blue). The limit of the Reesville advance is marked by a thick black line and thin black lines represent moraine boundaries.

be preserved at the base of the preglacial bedrock valley, but no subsurface investigations have been conducted to search for these sediments.

The first advance of ice into the county likely had a large influence on the surface drainage in the county. The preglacial bedrock topography shows a large dendritic drainage system that drained most of the county's surface waters to the northwest (fig. 4). These surface waters eventually flowed into the Teays River (Stout and others, 1943). Pre-Illinoian glaciers dammed the Teays drainage system creating Lake Tight, which began the deposition of lacustrine sediment, formally named the Minford Silt (Tight, 1903). There are no records of Minford Silt in Clinton County, which could indicate that the entire area was covered by pre-Illinoian ice.

During the pre-Illinoian Glaciation, the flow of Todd Fork reversed from a northwestern course to a southwestern course. Glacial meltwater breached the drainage divide at a col about three mi southwest of Clinton County. The reversal of the Little Miami River also occurred during the pre-Illinoian glaciation, possibly after the reversal within Todd Fork depending on the pattern of pre-Illinoian ice retreat. Todd Fork and Little Miami River have maintained these southwestern drainage patterns throughout subsequent glaciations and the Holocene.

Illinoian Glaciation (MIS 6)

The first sedimentological record of ice advance into the county comes from the Illinoian Glaciation. Deposition of the Rainsboro Till establishes the area that was overrun by Illinoian-aged ice (fig. 12). Clinton County was entirely covered by ice during the Illinoian Glaciation as Rainsboro Till extends across the entire southern border of the county and into adjacent counties. The till was deposited over a vast ground moraine that covers the area southwest of the LGM boundary, an area that represents about a third of

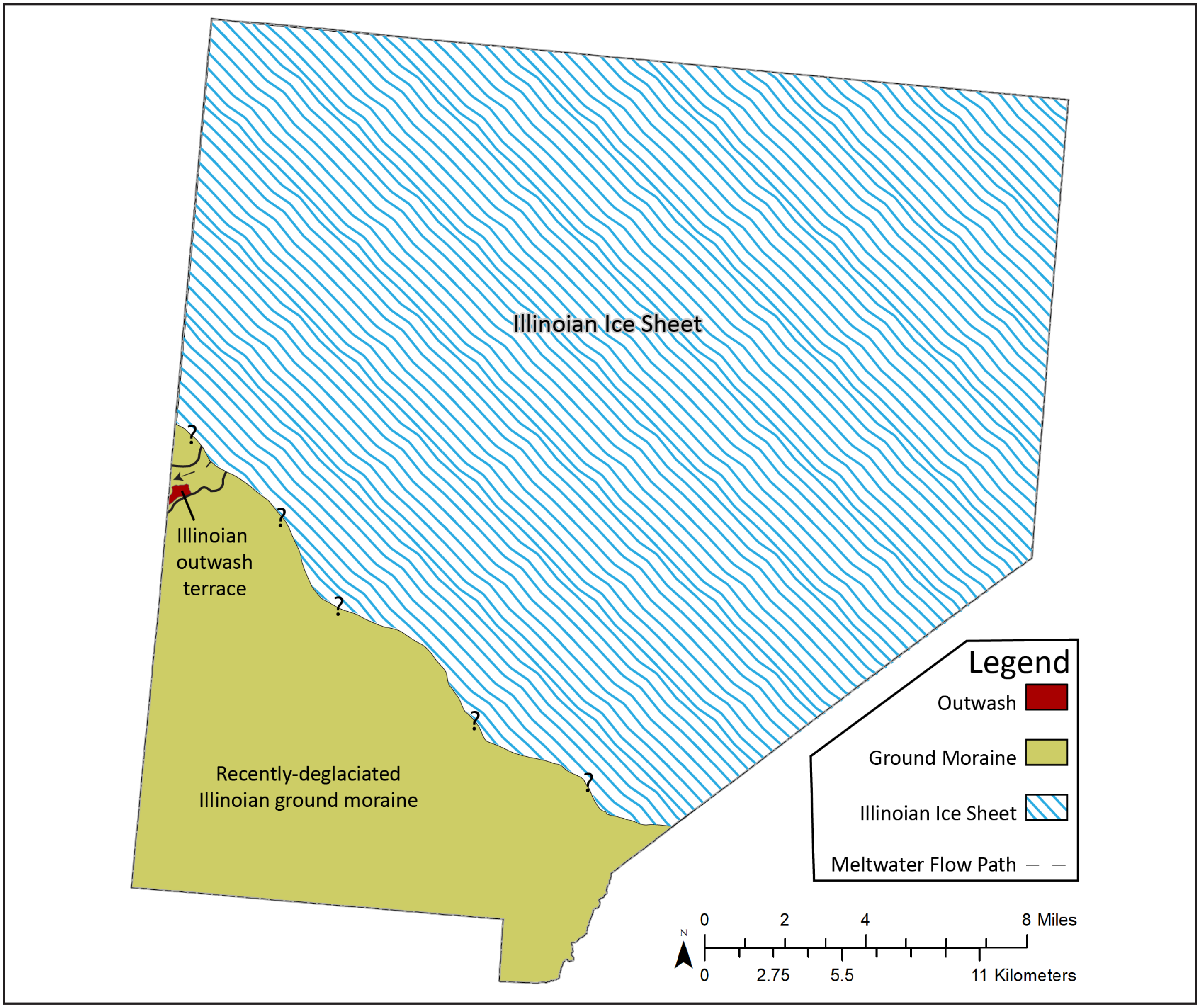

FIGURE 12: Theoretical Illinoian ice margin during MIS 5/6 transition and deglaciation of the Illinoian Laurentide Ice Sheet in Clinton County, Ohio. The ice margin depicted is theoretical (denoted by question marks) because any morainal evidence of ice margin positions either did not exist during the Illinoian or was destroyed by the deposition of Wisconsinan-aged sediments. However, the presence of Illinoian outwash stratigraphically above Illinoian Rainsboro Till stranded in a terrace along Todd Fork indicates the deposition of outwash during Illinoian deglaciation, after the development of a ground moraine.

the county (plate 1). Deposits of Rainsboro Till on the ground moraine are generally thin (fig. 5), with and average drift thickness of 20–30 ft. The thin till sheet could be indicative of a single, relatively fast advance to its terminal margin. The dissection of the ground moraine is caused by post-glacial fluvial processes, which are responsible for the greater relief relative to the Wisconsinan-aged ground moraines.

The Illinoian till plain of Clinton County is generally lacking in glacial landforms that can be used to infer ice sheet conditions and processes. The solitary Illinoian kame originally mapped by Teller (1967) south of the East Fork Todd's Fork Valley, near the intersection of U.S. Highway 68 and Lazenby Road, is a single exception. The small size and surficial till lithologic composition of the feature led to the decision not to delineate this feature as a separate unit during county-scale mapping. Faint fluting or subglacial lineations might be present in the southwestern corner of Clinton County (plate 1). However, it is still unclear whether fluvial systems entrenched between these ridges are the cause of their formation or whether they simply evolved within the low interfluves between parallel flutes. The orientation of these features might indicate a southwestern flow direction of Illinoian ice in Clinton County.

Chronologic control on the Illinoian Glaciation is sparse in Ohio but has been well dated to MIS 6 (125–165 ka) at the type section for Illinoian Loveland Loess in western Iowa (Forman and Pierson, 2002). It is widely believed that the Laurentide Ice Sheet advanced contemporaneously across the southern Great Lakes states during MIS 6. The southeastern corner of Clinton County is located about 20 mi from the maximum extent of the Illinoian ice sheet. Therefore, it is a fair assumption that glacial sediments from the Illinoian Glaciation in Clinton County were deposited near the end of MIS 6 when ice reached its maximum southern position and deglaciation began at the sharp MIS 5/MIS 6 transition.

Illinoian outwash is preserved in one terrace along the Todd Fork valley along the western border of Clinton County. This outwash terrace stands about 30 ft above an adjacent Wisconsinan-aged outwash terrace. The surface of the outwash exhibits more weathering than the other Wisconsinan-aged outwash terraces surrounding it. Currently, there is no chronologic control on the deposition of Clinton County Illinoian outwash, but deposition would have occurred when ice was still within the Todd Fork watershed. Getting chronologic control on this outwash feature could lead to a better understanding of the Illinoian deglaciation in the region.

Too little is currently known about the Illinoian Period in Clinton County to give a detailed account of advance and retreat. Larger-scale regional studies are needed to better characterize large scale glacial features such as flutes and potential Mega Scale Glacial Lineations. These subtle features might become more visible with future high-resolution LiDAR surveys.

Sangamonian Interglacial (MIS 5)

The Sangamonian Interglacial began immediately after the deglaciation of Illinoian ice during the sharp transition between MIS 6 and MIS 5 (Railsback and others, 2015). In Illinois, the Illinoian-Sangamonian transition was abrupt, with maximum interglacial conditions occurring around 123 ka (Curry and Follmer, 1992). Evidence from Pittsburg basin in Illinois suggests a gradual shift from deciduous trees, grasses, and *Ambrosia* (ragweed) from this climatic maximum to grasses and coniferous trees during the Wisconsinan Glaciation (Grüger, 1972). The Sangamonian Interglacial period in Ohio likely had similar conditions to what has been reported in Illinois, but to this point no continuous records to confirm these conditions have been discovered in Ohio.

Clinton County remained ice-free during the Sangamonian Interglacial from about 125–24 ka. During this time, the Rainsboro Till ground moraine was dissected by stream erosion primarily from tributaries to East Fork Little Miami River and Todd Fork. Sangamon soil development is best preserved in higher elevation hummocks and ridges that were not affected by stream dissection. Greater leaching depths and soil development (relative to Wisconsinan-aged sediments) occur on the Rainsboro Till ground moraine because of the nearly 100,000-year Sangamonian Interglacial. The Sangamonian Interglacial ended with the latest advance of ice into Ohio, the Wisconsinan Glaciation.

Wisconsinan Glaciation (MIS 2)

The most recent incursion of ice into Ohio occurred during the Wisconsinan Glaciation (MIS 2), when the Huron-Erie lobe advanced southward from the Labrador Ice Center. The Huron-Erie Lobe of the Laurentide Ice Sheet was further split into four sublobes in Ohio, two of which deposited sediments in Clinton County during the Wisconsinan Glaciation (fig. 1, inset map). The Scioto Sublobe is responsible for most of the deposition in the county; however, a small sliver of the Hartwell Moraine deposited by the Miami Sublobe is preserved in the northwestern corner of the county to the west of Caesar Creek (plate 1). The Scioto Sublobe reached its terminal position in Clinton County, making it an ideal place to begin developing a stratigraphic framework for the Scioto Sublobe based on the history of glacial advance and retreat.

Some of the first Wisconsinan sediments deposited in Clinton County during the Wisconsinan Glaciation were wind-blown silts. As the Scioto Sublobe advanced into Clinton County from the north it entered the Todd Fork watershed and began depositing outwash intermittently through this drainage network. Glacially derived silt was deposited on Todd Fork floodplains, deflated during dry periods, entrained by westerly winds, and deposited along the dissected Rainsboro Till ground moraine. This loess blanketed the landscape and preserved Sangamon soil profiles below a cumulative soil that developed as more silt was deposited throughout the Wisconsinan Glaciation.

The Scioto Sublobe continued to advance over Clinton County until it reached its terminal position during the LGM (24 ka) near the town of Cuba (fig. 13). The Scioto Sublobe did not stabilize at this margin for an extended period of time like other sublobes and lobes of the Laurentide Ice Sheet. Instead, the ice margin fluctuated over a five- to six-mile belt extending from around New Vienna in the southeast and looping past the I-71 and SR-380 intersection in the northwest (plate 1). This fluctuation led to the construction of 3 traceable ridges within the Cuba Morainal Complex. The sequences of retreat and subsequent readvance occurred three times based on radiocarbon dating of buried interstadial soils (Dubois, 1996). These retreats were likely minor because Caesar Till is deposited throughout the Cuba Morainal Complex, indicating a similar source area for the till, and no major weathering horizons or paleosols are observed in outcrops that exhibit multiple sequences (till/outwash packages) of glacial advance. This fluctuation of the ice margin ceased during the start of deglaciation associated with MIS 2 and the construction of the Wilmington Moraine.

The Cuba Moraine complex developed over a relative short

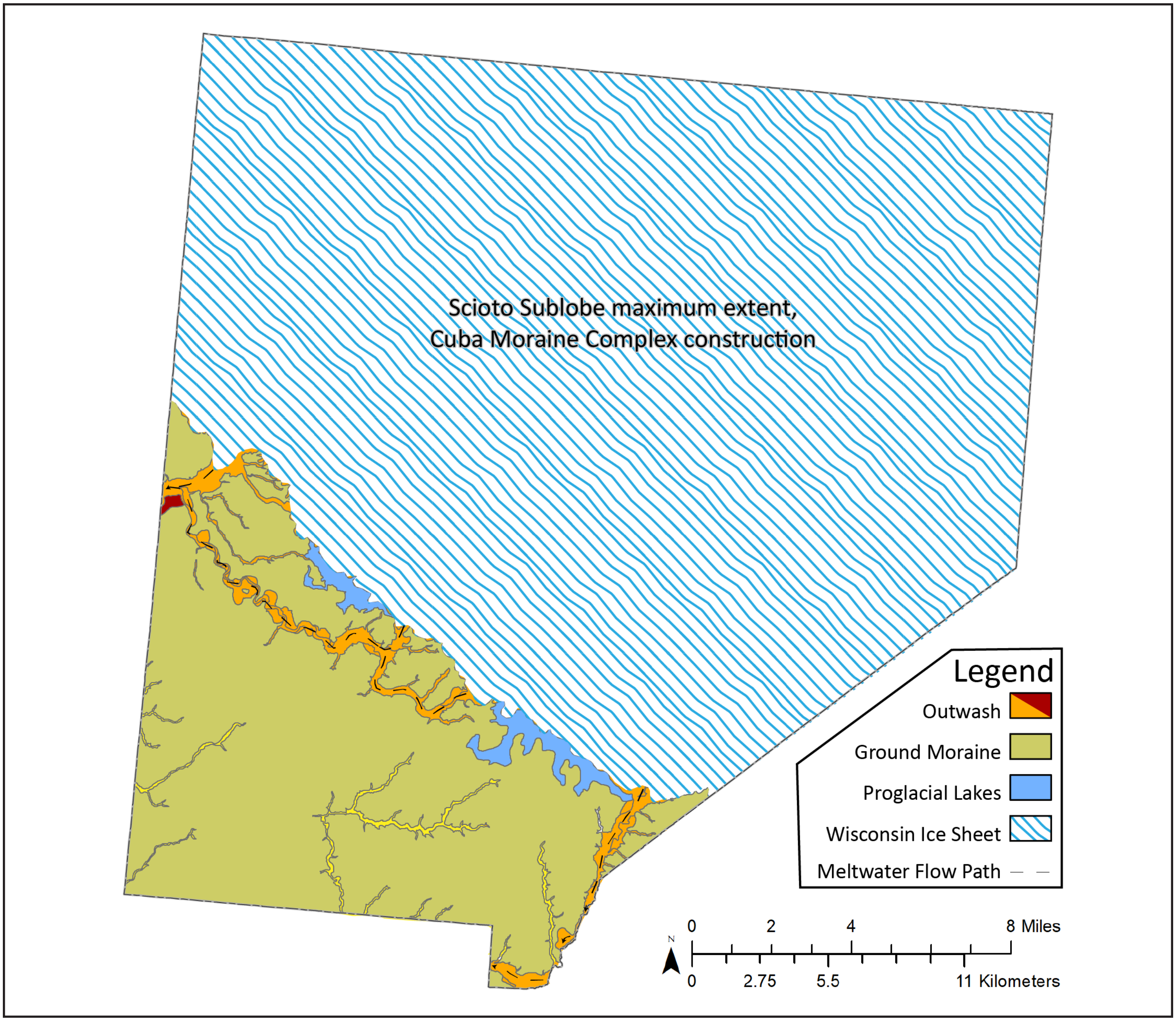

FIGURE 13: The maximum extent of the Scioto Sublobe into Clinton County, Ohio, during the LGM (~24 ka) and the construction of the Cuba Moraine Complex. The Scioto Sublobe oscillated along this margin burying short-lived interstadial organic beds. At its maximum extent, two proglacial lakes existed in contact with the Scioto Sublobe margin. During moraine construction proglacial lakes formed and valley train outwash was routed down the East Fork Little Miami, East Fork Todd Fork, and Todd Fork valleys.

time period. The initial formation of the outermost ridge occurred around 24.5 ka (Higley and Norris, 2020). New radiocarbon ages from this report indicate that portions of the innermost ridge were formed around 23.2 ± 675 ka, meaning the Cuba Morainal Complex formed during a period of about 1,300 years. The inconclusive age of Wilmington Moraine development of 27–29 ka (before the construction of the Cuba Moraine Complex) leads to doubts about the accuracy of the dates acquired from the Curry Road site. The presence of aquatic plant macrofossils ground into the microscopic matrix of plant material in the peat layer could have led to an unchecked reservoir effect. Ages of about 24 ka on the Hartwell Moraine suggest that it formed synchronously with the Cuba Moraine Complex in northwestern Clinton County (Ekberg and others, 1993; Higley and Norris, 2020).

Outwash was deposited along the East Fork Todd Fork and East Fork Little Miami concurrently with the development of the Cuba Moraine Complex. The valley train outwash deposits were fed by two outwash plains at the heads of each valley northeast of Martinsville (plate 1). Only outwash associated with the construction of the Cuba Moraine Complex was captured by these valleys. Outwash deposits associated with the Cuba Moraine Complex were also probably funneled down the Todd Fork valley but overriding outwash associated with the Wilmington Moraine aggraded over the Cuba Moraine Complex outwash with little to no hiatus, erasing any elevation profile associated with the earlier valley train deposits.

The construction of the Cuba Moraine Complex appears to have diverted the course of East Fork Todd Fork and Cowan Creek. These tributaries to Todd Fork flowed through an Illinoian-aged valley developed on top of a buried preglacial bedrock valley. The ice sheet terminated directly on top of this Illinoian-aged valley, building up a surficial drainage divide that diverted water and cut a sinuous gorge through Rainsboro Till and Ordovician bedrock on the Illinoian ground moraine. No glaciofluvial or glaciolacustrine deposits older than about 24.5 ka are found at depth in these valleys, which makes it unlikely that the valley would have formed before this.

After the construction of the Cuba Moraine Complex, diversion of East Fork Todd Fork and Cowan Creek, and deposition of Cuba Moraine Outwash, the Scioto Sublobe retreated to the Wilmington Moraine and stabilized at that position for an extended period (fig. 14). Because the Wilmington Moraine is composed of the same Caesar Till as the Cuba Moraine Complex, it is tempting to associate this moraine with the LGM fluctuations of the Scioto Sublobe. However, the Wilmington Moraine cannot be associated with the minor retreats of the Cuba Moraine Complex for two reasons. Firstly, radiocarbon dates obtained on plant macrofossils preserved in till on the Wilmington Moraine indicate that this moraine formed after the Cuba Moraine Complex (table 1). Organic materials are preserved within the upper 5 ft at the Curry Road site and are likely representative of final moraine deposition based on the melt-out interpretation of the moraine. Secondly, Wilmington Moraine Outwash was deposited above Cuba Moraine Outwash in Todd Fork Valley. There is no apparent break or hiatus between these outwash deposits in Todd Fork Valley indicating a continuous deposition of outwash through this valley during both moraine-building events.

Wilmington Moraine Outwash was also funneled down the Cowan Creek and Lytle Creek valleys, along with Todd Fork Valley. Buck Run and Turkey Run, tributaries to Caesar Creek, were likely minor valleys for Wilmington Moraine outwash as well. Unlike the Cuba Moraine Complex outwash, Wilmington Moraine outwash heads directly from the moraine and not an associated outwash plain. While outwash is being deposited in these valleys, loess deposits sourced from these outwash units are being deposited in front of the ice sheet, draping over the Rainsboro Till ground

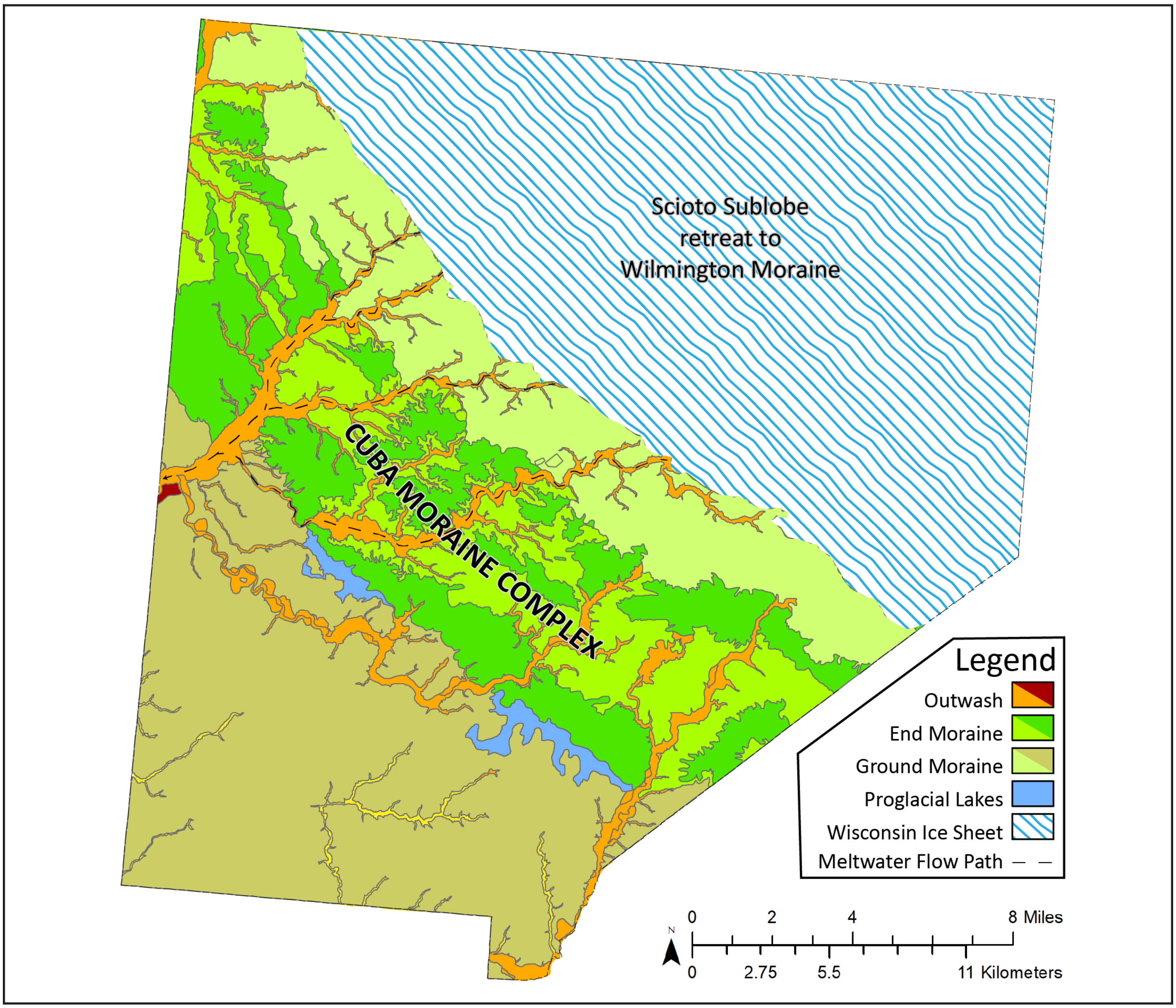

FIGURE 14: The Scioto Sublobe retreated to the Wilmington Moraine position after the construction of the Cuba Moraine Complex in Clinton County, Ohio. The Scioto Sublobe reached this position around 22 ka. Valley train outwash was mainly routed down the Todd Fork, Lytle Creek, and Cowan Creek Valleys.

moraine, Cuba Moraine Complex, Wilmington Moraine, and Caesar Till ground moraine. Wilmington Moraine Outwash marked the end of valley train outwash deposition in the Todd Fork, Lytle Creek, Cowan Creek, Buck Run, and Turkey Run valleys.

After the development of the Wilmington Moraine and deposition of Wilmington Moraine outwash, the Scioto Sublobe retreated out of Clinton County (fig. 15). The scale of the Scioto Sublobe retreat post-Wilmington Moraine development is unknown, likely due to the subsequent readvance of the Scioto Sublobe back into Clinton County. This readvance either buried and obscured the sedimentary record of the retreat or eroded this material and incorporated it into the deposition of a new till unit. The deposition of a new till unit implies that the recession of the Scioto Sublobe moved far enough away to incorporate a new bedrock/sediment source during the subsequent readvance. The source for the Scioto Sublobe till moved from primarily Ordovician and Silurian bedrock to a higher proportion of Devonian-age Columbus Limestone and Ohio Shale. The nearest source area for these lithologies (along the Scioto Sublobe flow path) is Pickaway and Franklin Counties. However, a retreat to either of these counties may not be necessary to explain higher proportions of Devonian-aged rocks because older tills in Fayette County could be further enriched in Devonian erratics relative to till in Clinton County because of the closer proximity to the bedrock source.

After this short interstadial, the Scioto Sublobe readvanced, depositing Darby Till and constructing the Reesville Moraine (fig. 16). There is currently no direct chronologic control on the construction of the Reesville Moraine, primarily due to the unavailability of outcrops along the ridge. The Reesville Moraine acts as the primary drainage divide between Anderson Fork to the

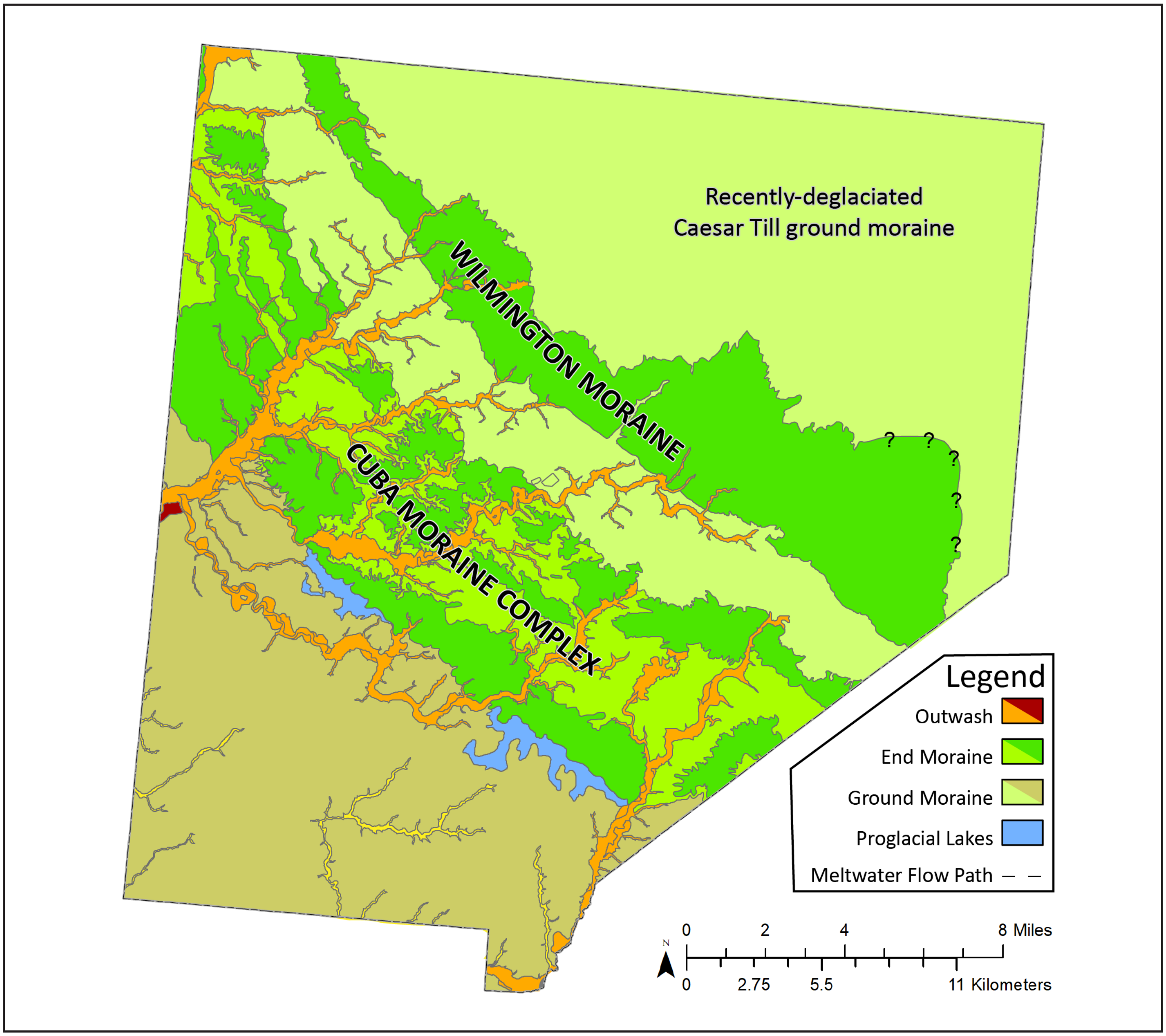

FIGURE 15: The Scioto Lobe retreated out of Clinton County, Ohio, after the construction of the Wilmington Moraine. Portions of the Wilmington Moraine margin are approximate (denoted with question marks) where obscured by subsequent glacial deposition events. The Scioto Sublobe retreated out of the county after 22 ka.

west and Rattlesnake Creek to the east, decreasing the probability of significant stream-cut exposures. The primary road through northeast Clinton County, SR-72, follows along the crest of the moraine making human-made cuts, usually for controlling grade, unnecessary. More subsurface investigations directly on the moraine are necessary to better resolve the age of the Reesville Moraine.

The closest bounding age on the Reesville Moraine is a minimum age from the ground moraine 5 miles northeast of the Reesville Moraine, between the Sabina and Glendon Moraines in Fayette County. This radiocarbon date (OWU-256) with a calendar age of about 21 ka was made on a total organic carbon sample collected during the construction of I-71 (Ogden and Hay, 1969). Samples were collected at a depth of 45.9 ft below the surface within the topsoil of a paleosol. This horizon could represent the land surface exposed during the post-Wilmington Moraine retreat; in radiocarbon age this represents a maximum age for the Reesville readvance. Future subsurface investigations focused on exploring this paleosol with detailed descriptions of till units could be compared to the surficial stratigraphic framework in this report to determine how this paleosol fits into the greater regional context.

A cross-cutting relationship exists between the Reesville Moraine and the Wilmington Moraine at SR-729 in Lees Creek (39.420404, -83.649267). This juxtaposition of the Reesville Moraine on top of the Wilmington Moraine has significant implications for the glacial history of the county. Firstly, this cross-cutting provides a relative age date indicating that the Wilmington Moraine must have formed before the Reesville Moraine. Secondly, this relationship is evidence that the Reesville Moraine formed during a readvance of the Scioto Sublobe and overran older Caesar Till deposits.

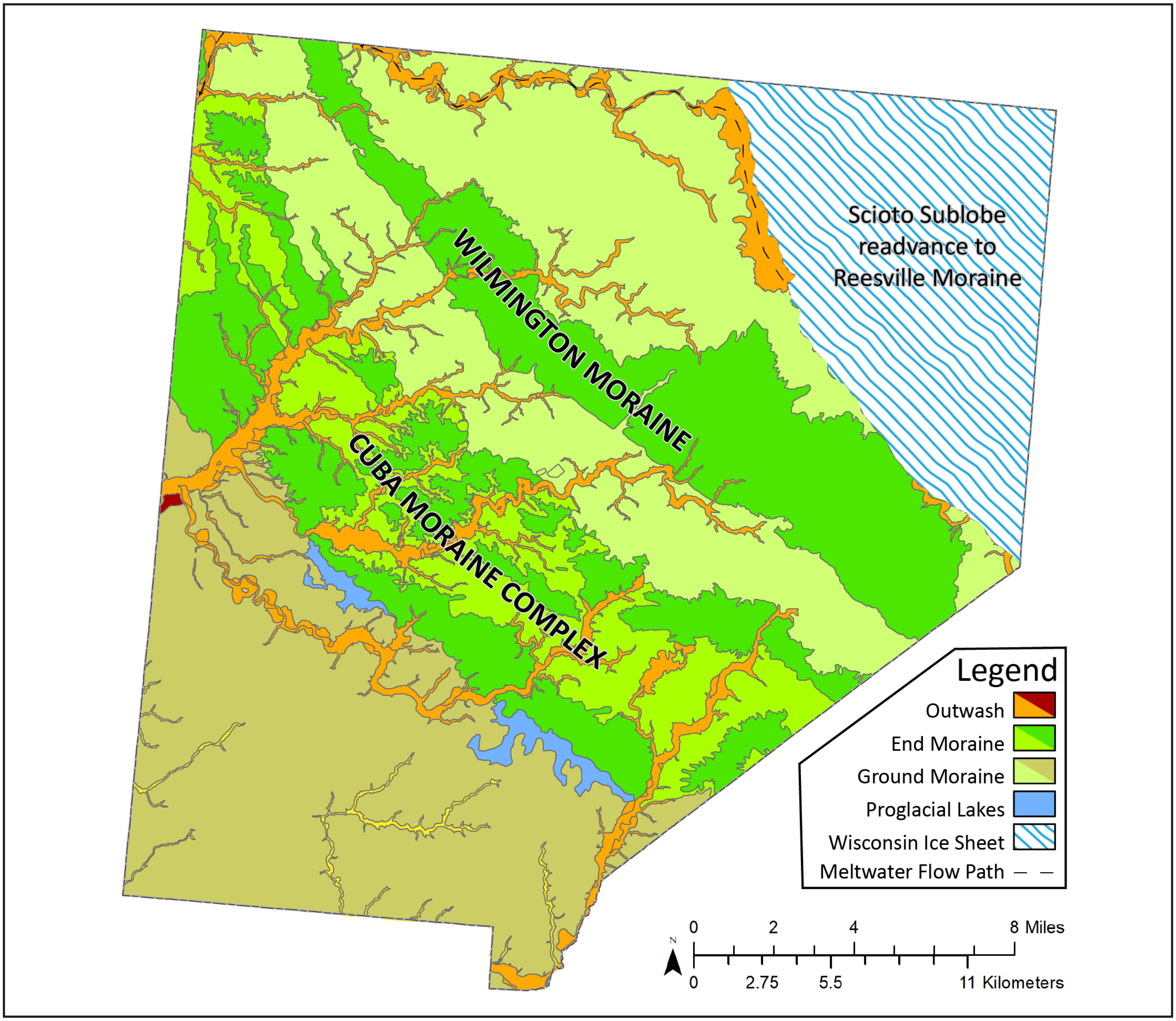

FIGURE 16: The Scioto Sublobe readvanced to the Reesville Moraine after the short interstadial period where Clinton County, Ohio, was ice free. The Scioto Sublobe readvanced to this position around ~21 ka. Valley train outwash was routed down the Anderson Fork valley (dashed black line) with an outwash plain source along the Scioto Sublobe margin. Silt associated with this outwash was the primary source of loess that capped the Caesar Till on the Cuba Moraine Complex, Wilmington Moraine, and associated ground moraines.

Reesville Moraine Outwash in Clinton County was primarily routed through valley train deposits in Anderson Fork valley with some minor outwash routes along Lee Creek valley (Highland County) and Caesar Creek valley (Greene County). This outwash was sourced from a large outwash plain at the headwaters of Anderson Fork. This 5-mi-long outwash plain is capped by a few feet of lacustrine silt, possibly resulting from a decrease in meltwater discharge or the formation of a natural dam in the headwaters of the Anderson Fork valley. Aggrading outwash could have led to slackwater conditions that persisted after the retreat of the Scioto Sublobe from the Reesville Moraine.

Loess deposition in Clinton County increased during the Reesville readvance. This loess was primarily sourced from the outwash routed through Anderson Fork valley and was deposited across the Cuba Moraine Complex, Wilmington Moraine, and their associated ground moraines up to the Reesville Moraine. A major difference in the soils developed on Caesar Till plains relatively to those soils developed on Darby Till plains is the thickness of loess cover. The greater thickness of loess on Caesar Till plains can be explained by this increase in silt source material during the readvance to the Reesville Moraine. As the Scioto Sublobe remained stationary at the Reesville Moraine front, deposition of loess occurred only on the Caesar Till plain while the Darby Till plain remained covered by ice.

After the development of the Reesville Moraine, the Scioto Sublobe retreated about 2.5 mi, forming the Sabina Moraine (fig. 17). Previous investigations on the glacial geology of Clinton County failed to recognize this ridge as a moraine due to its subtle relief (about 20 ft) and thin width (about half a mile). The subtle features of the moraine indicate that it was likely a short-lived pause or stagnation of the ice in the Scioto Sublobe deglaciation. The lack of any organized outwash routes also supports the hypothesis for

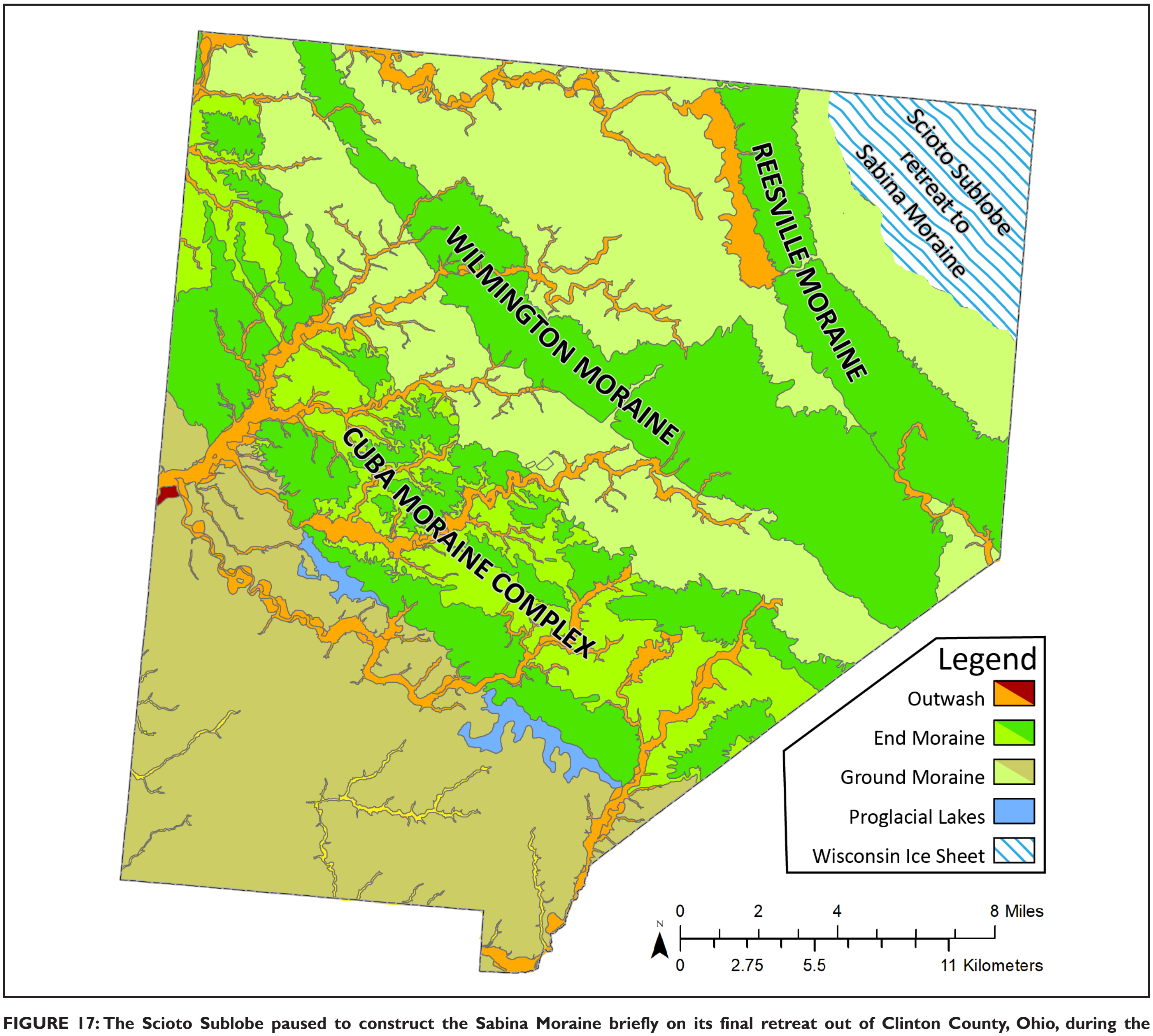

FIGURE 17: The Scioto Sublobe paused to construct the Sabina Moraine briefly on its final retreat out of Clinton County, Ohio, during the Wisconsinan. The Scioto Sublobe retreated to this position after the construction of the Reesville Moraine, but no absolute age control exists along the moraine. No outwash events are correlated to this recessional moraine within Clinton County.

a short stagnation at this margin. So far, no dateable material has been found along the Sabina Moraine. The Scioto Sublobe retreated out of Clinton County for the last time during the Wisconsinan Glaciation after the construction Sabina Moraine.

Holocene (MIS 1)

After the Scioto Sublobe retreated from Clinton County, environmental conditions shifted relatively quickly toward modern (pre-industrial) conditions. Environmental conditions stabilized to modern levels before the beginning of the Holocene recognized by a shift in more coniferous pollen to deciduous pollen in lake basins (Ogden, 1966). During this modern ice-free period, rivers became the primary mechanism for the erosion and deposition of unconsolidated materials. Modern rivers began eroding Wisconsinan-aged sediments, sorting previously massive till units, and depositing the grains in a variety of fluvial facies including floodplains, fans, bars, and channels.

Alluvial terraces preserved along Anderson Fork are indicative of a changing base level during the Holocene Period. Global sea level rise during deglaciation had a large control on the increasing base level and subsequent deposition of sediments in fluvial systems. At some point in the Holocene, base level decreased, and streams began to cut down through aggraded fluvial sediment, leaving sections of remnant floodplain surfaces stranded above the modern floodplain as terraces. Modern rivers continue to display erosive tendencies, including those that produce exposures which make it possible to study the Quaternary history of the county. Increased runoff and overland flow from industrialization and meander mitigation techniques could be responsible for increased channelization and erosion seen in streams.

CONCLUSIONS

The understanding of Clinton County's Quaternary geology has been built upon more than a century of previous research in the county, which provided a foundation for the origins of this study. The technological advances of the past half century and since the last published Quaternary map of Clinton County have greatly improved the ability to produce precise, high-resolution maps. This study applied these technological advances to create a detailed, high-resolution map of the Quaternary geology of Clinton County.

Results from this detailed mapping include a new interpolation of the bedrock topography, which provides a high-resolution image of the preglacial land surface and a more precise measurement of drift thickness. Improved bedrock topography mapping supports Teller's (1967) findings of a large central buried valley that transported water from a divide on the border of Clinton and Highland Counties to present day Caesar Creek Lake at the border of Warren and Clinton Counties. This resulting bedrock topography map of Clinton County has implications for the preglacial surficial drainage network of Ohio and could play a valuable role in future water resource demands. The thickness of Quaternary-aged sediments is now known to vary from 0–376 ft in Clinton County. The drift thickness derivative product provides data necessary for groundwater management and resource estimate calculations.

The creation of a chronostratigraphic framework for the county is useful for interpreting sediments such as the Rainsboro Till, Caesar Till, and Darby Till and for the future correlation of these units outside of the county boundaries. The Rainsboro Till is distinguished from other till units lithologically based on its higher compaction, deeper weathering profile, and higher abundance of near vertical, evenly spaced joints. The Caesar Till is distinguished from the younger Darby Till, lithologically, based on its loamier matrix texture, blue tint in fresh sample, and relatively large loess cap. The differences between these three till units preserved in the county are subtle but their properties are the critical for interpreting the regional history of glaciation. The units also have distinct engineering properties, providing useful information for engineers and regional planners who are interested in infrastructure development.

Glacial landforms such as moraines and outwash plains/valley trains were used to interpret the past events that defined the Quaternary Period of Clinton County. New radiocarbon ages collected on plant materials within Caesar Till have better defined the construction of the Cuba Moraine Complex and the Wilmington Moraine. Observations of crosscutting relationships between the Reesville and Wilmington Moraines bolster the Quaternary history with evidence of relative age differences and support the theory that ice readvanced to deposit the Darby Till and construct the Reesville Moraine. The delineation of a subtle new moraine, the Sabina Moraine, from historic boulder concentrations data and modern LiDAR-derived DEMs provides more evidence on deglaciation processes of the Scioto Sublobe. Overall, the detailed mapping of the Quaternary geology in Clinton County, Ohio, has led to a better understanding of the glacial history of the county and provides valuable data for citizens to continue the development of the county.

ACKNOWLEDGEMENTS

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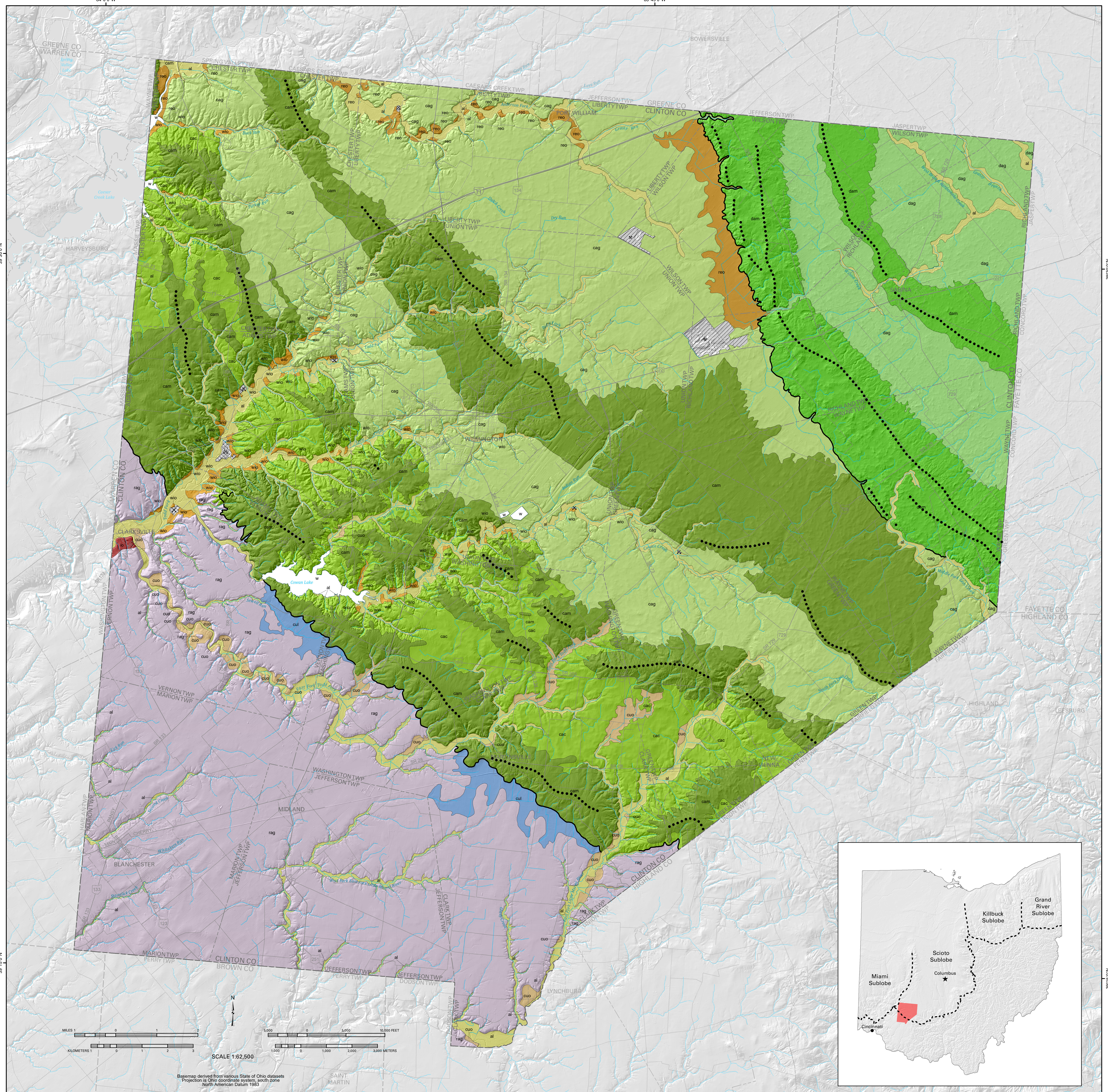

Quaternary Geology of of Clinton County

By T. Andrew Nash
with cartography by Dean Martin

Lithologic Units

Holocene

al — **Alluvium.** Varying facies of silt, sand, and gravel found along floodplains, channels, and bars associated with modern rivers systems developed after the Pleistocene.

Wisconsinan

cag — **Caesar Till Ground Moraine.** Silt loam, blue-gray, pebbly diamicton associated with the ground moraines between the Cuba and Reesville End Moraines. Typically capped with 40-60 inches of loess cover.

cam — **Caesar Till End Moraine.** Silt loam, blue-gray, pebbly diamicton associated with the Cuba and Wilmington End Moraines. Typically capped with 40–60 inches of loess cover.

cac — **Colluviated Caesar Till.** Silt loam, pebbly to stony diamicton found on hillslopes bordering Cuba Moraine ridges. Thicker packages of till could be deposited as gravity-fed flow till. Loess cap decreases in thickness in areas that experience more pronounced colluviation.

dag — **Darby Till Ground Moraine.** Silt loam, dark gray, pebbly diamicton associated with the ground moraines northeast of the Reesville End Moraine. Typically 0–12 inches of loess cover.

dam — **Darby Till End Moraine.** Silt loam, dark gray, pebbly diamicton associated with the Reesville and Sabina End Moraines. Typically 0–12 inches of loess cover.

cuo — **Cuba Moraine Outwash.** Sand and gravel deposits formed concurrently with the Cuba End Moraine. Deposits isolated above modern floodplains on terraces and on outwash plains adjacent to the Cuba End Moraine.

wio — **Wilmington Moraine Outwash.** Sand and gravel deposits formed concurrently with the Wilmington End Moraine. Deposits isolated above modern floodplains on terraces.

reo — **Reesville Moraine Outwash.** Sand and gravel deposits formed concurrently with the Reesville End Moraine. Deposits isolated above modern floodplains on terraces and on outwash plains adjacent to the Reesville End Moraine.

cul — **Cuba Moraine Proglacial Lake.** Glacial lacustrine silt and clays adjacent to the Cuba End Moraine.

Illinoian

rag — **Rainsboro Till Ground Moraine.** Loamy, compact diamicton with abundant pebbles associated with the ground moraine south of the Cuba End Moraine.

io — **Illinoian Outwash.** Sand and gravel deposits with an unspecified morainal origin.

Contact

Limits of major advances

Moraine crests

Pit. Pit bottom generally underlain by unconsolidated lithologic units of surrounding polygon(s). May contain reclaimed areas.

Quarry. Floored in bedrock; may contain reclaimed areas.

w — **Water.** Lakes generally larger than 20 acres.

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