Archaeological Prospection for Precontact Burial Mounds Using Light Detection and Ranging (LiDAR) in Scott and Crow Wing Counties, Minnesota

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Chapter 1: Introduction

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Between 1000 B.C. and AD 1200, Native Americans in eastern and central North America interred their dead in earthen mounds. Construction of these and other earthworks were part of major changes in the demographic, economic, political, and spiritual organization of human culture throughout the North American continent. The spatial organization of mounds and other earthworks on the landscape have informed scholars about territorial control and astronomical knowledge of ancient people. Archaeological excavations of mounds, although rarely conducted today, provide important insights into prehistoric demography, diet, and pathology, through the osteological analysis of the human interments. In addition to their significance to the humanities, burial mounds are venerated by Native Americans, whether or not they trace their ancestry to the mounds' builders.

Mounds are also among the nation's most threatened archaeological sites. Mounds tend to be concentrated along major rivers and lakes, where urban expansion and recreational development have profound effects on their survival.

Previous studies of Minnesota mounds have shown that about 12,000 mounds have been recorded in the state (Anfinson 1984; Arzigian and Stevenson 2003). These mounds are found in over 1,500 individual sites in numbers varying from over 200 mounds per site to single mound sites. Mounds are found in all regions of Minnesota with the highest numbers in the east-central and southeastern parts of the state and lowest numbers in the northeast.

Light Detection and Ranging (LiDAR) is an emerging technology with great promise for identifying, preserving, and studying ancient earthworks. LiDAR uses airborne lasers to measure ground surface elevations to submeter accuracy. The vertical and horizontal accuracy of LiDAR data is more than sufficient to resolve very subtle topographic features, including burial mounds (Riley 2009; 2010).

An increasing number of federal, state, and city governments are acquiring LiDAR data for use for a wide variety of purposes. The data are most often provided by commercial vendors.

OBJECTIVES

The present project examines the feasibility of using publicly-funded LiDAR as a tool for identifying precontact earthworks. Documentary records were obtained and reviewed for all recorded precontact mound sites in Crow Wing and Scott counties, Minnesota (Figure 1.1). The documented locations of these sites and mounds were recorded in a Geographic Information System (GIS). LiDAR data was obtained for the two counties, and examined for each site location to match documented mound positions to mound-like topographic shapes visible in the LiDAR data. A sample of the sites were then visited and mapped with GPS and total station to ground truth the LiDAR analysis.

A second objective was to critically evaluate the problems and pitfalls of using LiDAR as a tool for archaeological mound prospection. This objective goes beyond understanding LiDAR technology, to understanding the dimensions, spatial arrangement, and locational preferences of precontact earthworks. Government agencies do not have archaeological features in mind when they write specifications for acquiring LiDAR data for their jurisdictions. This study was therefore envisioned as a case study in applying county-funded, commercially-provided LiDAR to archaeological prospection.

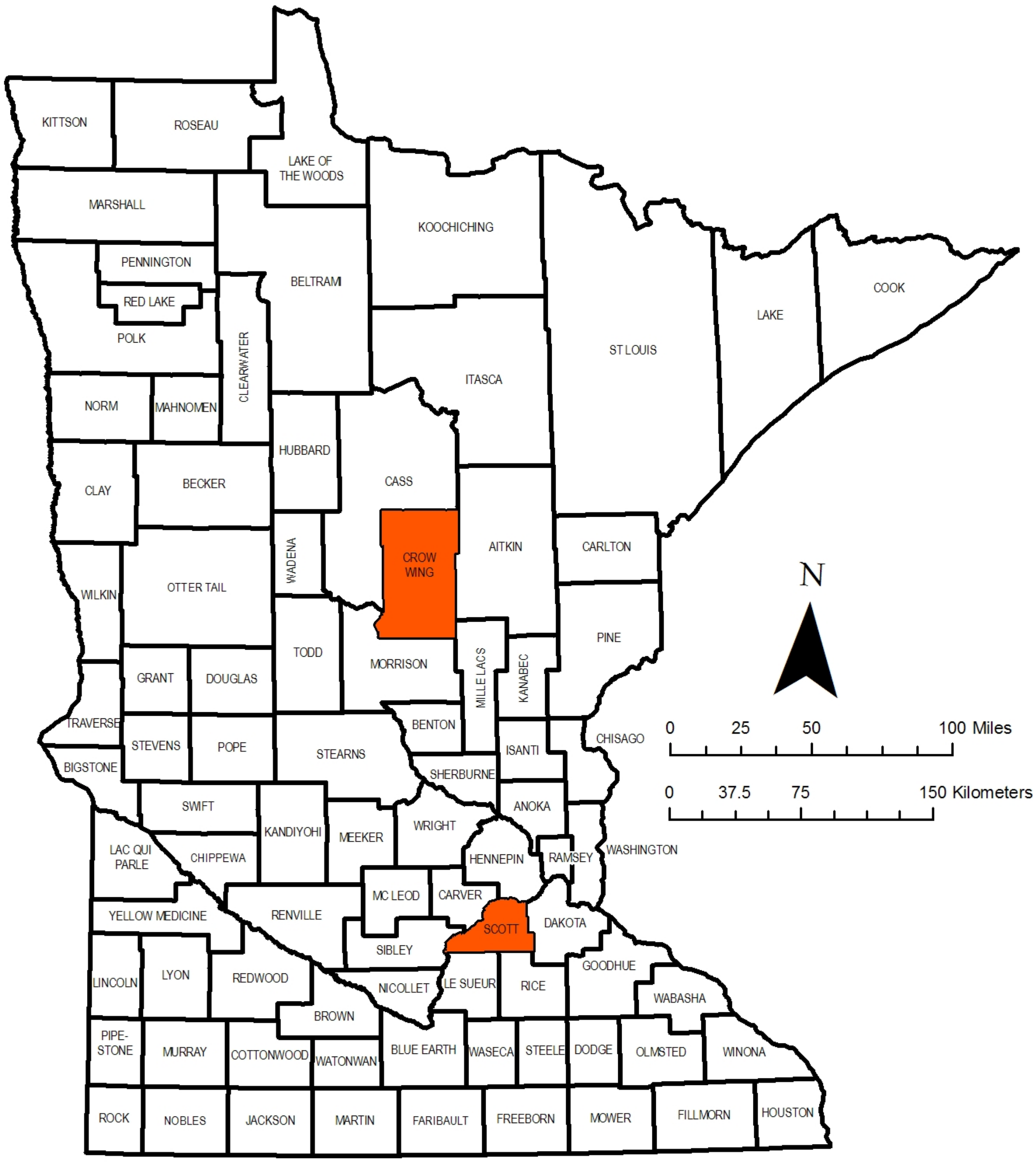

Figure 1.1. Location of Crow Wing and Scott counties, Minnesota.

The work reported herein was conducted by the University of Iowa Office of the State Archaeologist (UI-OSA) with funding from the Arts and Cultural Heritage Fund of the Minnesota Legacy Amendment. UI-OSA worked closely with Minnesota's Office of the State Archaeologist (hereinafter, Mn-OSA) in all aspects of the project. Nonetheless UI-OSA is solely responsible for the interpretations and recommendations contained in this report.

LIDAR IN ARCHAEOLOGY

In the 1970s, the U.S. military began developing laser profiling techniques that laid the groundwork for LiDAR. Early commercial use of LiDAR began in the early 1980s, but airborne, large-area scanner systems like those used today did not become available until the mid-1990s. Over the past 15 years, government agencies have begun to fund large scale LiDAR collection. This increase in LiDAR collection is driven by advances in the accuracy and speed of airborne scanners, and also by increases in the processing and data storage capabilities of desktop computers and servers.

LiDAR has not been extensively used in archaeology or other humanities, but in the past decade several published studies have emerged, primarily by European researchers (Barnes 2003; Bewley 2003; Challis 2006; Devereux et al. 2005; Humme et al. 2006; van Zijverden and Laan 2003). Most studies thus far focus on large-scale structures such as stone monuments, castles, hill forts, villages, and fields.

In the United States, archaeologists are just beginning to use LiDAR. Many applications use land-based lasers to map archaeological features. Fewer examples of the use of airborne LiDAR have appeared. The authors are aware of only three published applications of airborne LiDAR, none prior to 2006. In one study, LiDAR images were used to study historic landscaping of two 18th century plantations in Maryland, identifying low relief features such as abandoned garden terraces (Harmon et al. 2006). In another study, 32 potential archaeological sites were identified in LiDAR-based shaded relief images from Isle Royale National Park, Michigan. Field survey confirmed 25 of the 32 as archaeological sites, and identified heavy vegetation, analyst inexperience, and over-smoothing of the LiDAR elevation data during initial processing as factors that made site detection difficult (Gallagher and Josephs 2008). In Ohio, Romain and Burks (2008) used LiDAR to detect a 2,000 year old road, remnants of which were preserved in a wooded area as two parallel, 30-cm-high embankments rising above either side of the path.

HISTORICAL BACKGROUND

The present project employs 21st century technology to map mound sites, many of which were initially recorded by the late 19th century archaeologists T. H. Lewis and J. V. Brower. The field surveys of these two individuals laid the foundation for the study of prehistoric earthworks in Minnesota. The two surveys recorded hundreds of mound sites, with Lewis in particular demonstrating a technical competence that is commendable even by modern standards (Dobbs 1991; Haury 1993). In much the same way that present-day civil surveyors still refer to the original General Land Office surveys to establish benchmarks for modern surveys, modern archaeologists routinely turn to Lewis's notes and maps in conducting field surveys and analyses of mounds and mound sites.

In some ways, the present project brings the study of prehistoric mound sites in Minnesota full circle. We begin with the notes of the 19th century Lewis and Brower surveys, use GIS to bring their survey data into a digital environment, and then use LiDAR-derived imagery to search for and map in GIS, the mounds they and others have identified.

Because of the importance of these early archaeologists in this study, the following paragraphs summarize the life and work of those individuals who figure most prominently in the early records used in this study.

From the mid-nineteenth century through the first decades of the 1900s, a few intrepid individuals recorded and excavated archaeological sites, although sometimes for different reasons, and at times as rivals or adversaries. In sum their work provides the backbone of what is known about the extent of prehistoric mounds in Minnesota in the 19th century. Spurred by the disappearance of mounds under the plow or due to development, the early Minnesota archaeologists made contributions that are still relevant today. Antiquarian endeavors were most often carried out by individuals who worked independently and had no formal training in archaeology. Nevertheless, as this report shows, their paper records are often of such accuracy to allow transformation to modern digital technologies.

Mounds and other earthworks were noted by early explorers, settlers, military expeditions, and missionaries, and others. Random digging was often done but seldom recorded in this era. The first documentation of a mound excavation dates to 1856 (Arzigian and Stevenson 2003:5).

The work of early antiquarian researchers, while more sophisticated than uncontrolled digging, was primarily a search for objects of antiquity. The work was also driven by curiosity and, for some, a desire to explain the mounds' origin. One popular theory claimed that the mounds and earthworks had been built by an ancient and extinct race of people who preceded the Indians in North America. The Mound Builder theory was widely accepted, despite its ethnocentric and racist bias. The theory stemmed from a belief that Native Americans possessed neither the intelligence nor sophistication to construct the mounds. Therefore, these earthworks must have been built by an ancient race of people more closely related to the white Euroamericans. A driving force for some antiquarians was a belief that many if not all of the mounds and earthworks soon would disappear as large-scale land clearing and cultivation began in the 1860s and needed to be documented before they were lost forever (Benchley et al. 1997:50). This motive remains strong to the present day, and was indeed a major driver for the present project.

Alfred J. Hill and Theodore Hayes Lewis were responsible for the first attempt to conduct a systematic survey and record of the Minnesota mound sites. Hill (1833–1895) moved to St. Paul, Minnesota in 1855, where he spent much of his career working as a draftsman for the state land office. He was interested in both maps and archaeology, so his position in the land office gave him the opportunity to gather information through his contacts with surveyors, military personnel, and people living and working in the region. Although he never considered himself an archaeologist and had no formal training, he was intent on recording Minnesota's mounds. He was particularly concerned by the destruction of mounds by farming and development. He was a member of the Minnesota Historical Society (MHS) and served on the Committee on Archaeology. The Committee conducted excavations in mounds and gathered archaeological information by sending letters and distributing a circular throughout the state. Hill gathered this information into several large notebooks, and continued to gather archaeological information after the Committee disbanded. Hill's efforts to record and map sites are a source of much of what is known about Minnesota archaeology during the 1850s–1860s. In 1880, Hill met T.H. Lewis and they started a collaboration that would result in the mapping and recording of thousands of mounds in Minnesota and nearby regions of the upper Midwest.

Lewis (1856–1930) likely became interested in mounds during his youth in Ohio. He trained as a surveyor and began mapping mounds and earthworks in Ohio and the Mississippi River valley. In 1880, at age 23, he arrived in St. Paul and became acquainted with A. J. Hill. In 1881, the two men formed the Northwest Archaeological Survey (NAS). With Hill providing financial support, Lewis was to conduct fieldwork to survey and map mounds, earthworks, and other archaeological sites. The area traversed by Lewis would eventually extend throughout Minnesota and into surrounding regions, including the present-day states of North and South Dakota, Wisconsin, Iowa, Illinois, Indiana, Nebraska, Missouri, Kansas, and Michigan, and the Canadian province of Manitoba (Dobbs 1991:7). Information from Hill's notebooks provided guidance in selecting areas for survey (Dobbs 1991:9). As the survey progressed, Lewis noted that he could not locate some of the mounds previously reported to Hill, indicating they had been destroyed (Finney 2006:7, Haury 1993:84).

At the same time that Lewis was working in the field, the Smithsonian Institution's Bureau of American Ethnology was conducting a survey of mounds and earthworks in the upper Midwest, led by Cyrus Thomas (Thomas 1894). Lewis mapped over three times more mounds than the Bureau (Dobbs 1991), achieving this feat on his own and recording sites and mounds in greater detail (Benchley et al. 1997:52). He often tried to outrun the Bureau agents if they were working nearby. Lewis's independent, self-sufficient surveying technique put him at odds with Minnesota antiquarians, particularly Newton H. Winchell and Jacob V. Brower. He was unwilling to share his data with them or Smithsonian Institution surveyors (Finney 2006:1), all of whom he viewed as competitors (Arzigian and Stevenson 2003:15).

Hill and Lewis's agreement lasted for 15 years, during which time Lewis traveled over 54,000 miles, walking more than 10,000 miles. "In its regional extent and duration, the NAS constituted the largest privately funded archaeological project ever undertaken in this country" (Finney 2006:2). The NAS documented over 17,000 mounds and earthworks at over 2,000 mound and village sites (Dobbs 1991). In Minnesota, the NAS mapped over 7,700 mounds at 761 sites in 65 counties (Arzigian and Stevenson 2003, Dobbs 1991).

Lewis and Hill had always intended to publish the results of the survey as a comprehensive study of mounds and antiquities of the Northwest, but Hill's sudden death in 1895 put an end to the NAS. Unfortunately, despite Lewis's efforts to get them, the NAS notebooks, papers, and maps were divided between Hill's two nephews in England and Canada. Lewis continued to publish articles on archaeology until 1898. He left Minnesota in 1911 and died in poverty in St. Louis in 1930 (Finney 2006).

Although Lewis was never recognized for his achievements during his lifetime, his work continues to be of value. His detailed maps and drawings depict sites that have been damaged or completely destroyed (Benchley et al. 1997:52). Lewis recorded sites on a Minnesota landscape that in many places does not exist today.

Another early recorder of Minnesota archaeological sites was Jacob Vradenburg Brower (1844–1905). Brower served as a county auditor, attorney, and state legislator, and was an avid collector of archaeological materials, maps, and books for most of his life. He became involved with the Minnesota Historical Society in 1899 and collaborated with A J. Hill between 1889 and 1895.

Following Hill's death, Brower continued "expanding and testing theories and ideas about…the Indians who had peopled Minnesota" (Benchley et al. 1997:52). He conducted surveys of archaeological sites and performed excavations. This work was done independently of Lewis and without knowledge of where Lewis had worked. Despite losing his collected notes and artifacts, along with maps and other archeological information in a fire in 1896, he published an eight-volume series entitled *Memoirs of Explorations in the Valley of the Mississippi*. Four of the volumes are dedicated to Minnesota (Brower 1901, 1902, 1903; Brower and Bushnell 1900), incorporating a multidisciplinary approach including archaeology, geology, and historical perspectives (Dobbs 1991). Although Brower's maps are more schematic than Lewis', his contributions are nevertheless significant (Benchley et al. 1997:53, Birk 1986:27). Some of the sites he surveyed and excavated have since been disturbed or destroyed, and his maps are the only record of their existence. Brower's approach was problem oriented. In particular, he studied the relationship between Native American earthworks and the landscape, for example, recognizing the importance of portages in relationship to mound placement. His multidisciplinary perspective led to important contributions in natural history. For example, his extensive mapping and investigations of the Mille Lacs area helped identify the source of the Mississippi River. Perhaps most importantly, he came to believe that the mounds were built, not by an extinct ancient race, but by the American Indians, the conclusion also reached by Cyrus Thomas (1894).

One of Brower's most significant contributions to Minnesota archaeology occurred around 1903 when he purchased the NAS records from Hill's heirs. Brower died in 1905 before he could write and publish a compendium of his own archaeological studies with those of the NAS. He planned to refer to the combined works as the "Hill-Brower Explorations," with no intention of mentioning Lewis (Haury 1993:84). The antipathy apparently was mutual between Brower and Lewis.

The Minnesota Historical Society obtained the NAS records from Brower's estate. The records include 41 field notebooks, site maps drafted by Hill, and correspondence. A portion of the NAS was published by Winchell (1911).

Newton Winchell (1839–1914) became the archaeologist of the Minnesota Historical Society in 1906 after serving as the first director of the Minnesota Geological Survey from 1872 to 1900. Winchell's annual reports included archaeological information concerning areas such as chert quarries which had previously gone unnoted (Benchley et al. 1997:53). His greatest contribution to Minnesota archaeology was his 1911 *The Aborigines of Minnesota*, a detailed compilation of Minnesota archaeology and ethnography, published in 1911. The volume incorporated the NAS Minnesota records, along with brief notes on antiquarian investigations, and was presented in a county by county format (Arzigian and Stevenson 2003:17). This volume also published Winchell's belief, which he came to over his career that the mounds and earthworks had been built by Native Americans. *Aborigines* has proven to have lasting utility, containing information about both extant sites and those long destroyed. Winchell's *Aborigines* was a more comprehensive record of Minnesota's prehistoric earthworks than the volume published by the Bureau of American Ethnology (Thomas 1894) which surveyed mound sites mostly in the lower Minnesota River and Lake Minnetonka areas.

In the decades following the publication of Winchell (1911), Minnesota archaeology came to be "driven by an academic model of inquiry" (Benchley et al. 1997:53). In 1918, Professor Albert E. Jenks (b. 1869), an economist and self-taught ethnographer, founded the Department of Anthropology at the University of Minnesota. In the late 1920s, Jenks's interests changed to archaeology. In 1928, the year he became an associate Professor of Anthropology, he initiated a period of site excavation with assistance from his student Lloyd Wilford.

Since neither Jenks nor Wilford were trained in archaeological excavation, they sought instruction in New Mexico and continued excavations there and later in Algeria. In 1932, they began conducting the first scientific excavations in Minnesota (Benchley et al. 1997:54–55), taking their statewide program of field research beyond earthworks to a wider spectrum of site types.

Jenks's scientific approach to archaeology was continued over the next two decades under Wilford. Wilford began his doctoral studies at Harvard University in 1932, earning his degree in anthropology in 1937; his dissertation, based on information and materials from his years as Jenks' assistant. Jenks was one of the first archaeologists to apply the new Midwestern Taxonomic System (McKern 1939), marking a turning point in the study of Minnesota archaeology (Benchley et al. 1997:54).

Following Jenks' retirement in 1938, Wilford served as staff archaeologist in the University of Minnesota Department of Anthropology. He was appointed associate professor in 1948 and taught until his retirement in 1959. Throughout most of his career, Wilford was the only professional archeologist working in Minnesota. Each year he led field schools at several sites, keeping meticulous notes, analyzing the collected materials, and producing a typed report. According to Benchley et al. (1997:54), Wilford brought to Minnesota archaeology the fundamental premise, then current in North American archaeology, that content and the spatial and temporal relationships between sites and site complexes were the basis for sound interpretation of archaeological data (Willey and Phillips 1958). Wilford's cultural chronologies provide a basis for those that are in use today, the absence of absolute dating methods created some limitations to his approach (Birk 1986, Benchley et al. 1997).

ARCHAEOLOGICAL BACKGROUND

The exhaustive overview of prehistoric mounds in Minnesota by Arzigian and Stevenson (2003) reported 11,868 recorded mounds in Minnesota (Arzigian and Stevenson 2003: Table 4-1, pp. 63–64). The following summarizes the archaeology of mound sites in Crow Wing and Scott counties, primarily as reported by Arzigian and Stevenson (2003).

Crow Wing County

The natural vegetation of Crow Wing County was almost entirely coniferous forest, whereas upland landscapes in Scott County supported hardwood forests and savanna (Kuchler 1964, 1993). Crow Wing County is a glaciated terrain, with uplands covered by thick deposits of glacial till and supraglacial sediments, and the lowlands dominated by broad outwash channels and glacial lake plains (Figure 1.2; Minnesota Department of Natural Resources 1997a). The Mississippi River flows from northeast to southwest through the county. Lakes of glacial origin are common throughout most of the county (Figure 1.2).

Arzigian and Stevenson (2003) report 520 mounds in Crow Wing County, and five have been excavated. Lewis surveyed and mapped 49 mounds at two sites, 21CW4 and 21CW5. Brower mapped or noted mounds at 10 sites, excavated one mound at Upper Hay Lake Mounds/Fort Poulak (21CW7/14) in 1897. In 1898 he excavated one mound at Pine River/Warren Mounds (21CW1). Although he may have excavated at other sites in the area, no records remain. Winchell (1911) described Upper Hay Lake Mounds/Fort Poulak (21CW7/14). Wilford and Jenks excavated at Warren (21CW1) in 1932. Wilford tested a portion of a damaged mound at King Mound (21CW2) in 1957 and conducted excavations of two of the McAloon mounds (21CW3) in 1957. He tested only the habitation portion of Garrison Creek (21CW5) in 1949.

Mound sites in the county form four distinct clusters. The largest of these is in the northwest on the Pine River and its associated lakes. A second, smaller cluster, in the center of the county, is ca. 5 km southwest of the confluence of the Pine and Gull Lake. Mounds also cluster along the west shores of Lake Mille Lacs in the southeast part of the county. Other mound sites are distributed along the Nokasippi River in southwest and south central Crow Wing County (Figure 1.2).

Scott County

Most of Scott County is mantled by deposits of supraglacial drift, with numerous lakes, peat lands, and a complex, dendritic drainage pattern (Figure 1.3). In contrast to Crow Wing County, outwash deposits are not common, except on high terraces along the Minnesota River, which bounds the county on the north (Figure 1.3; Minnesota Department of Natural Resources 1997b).

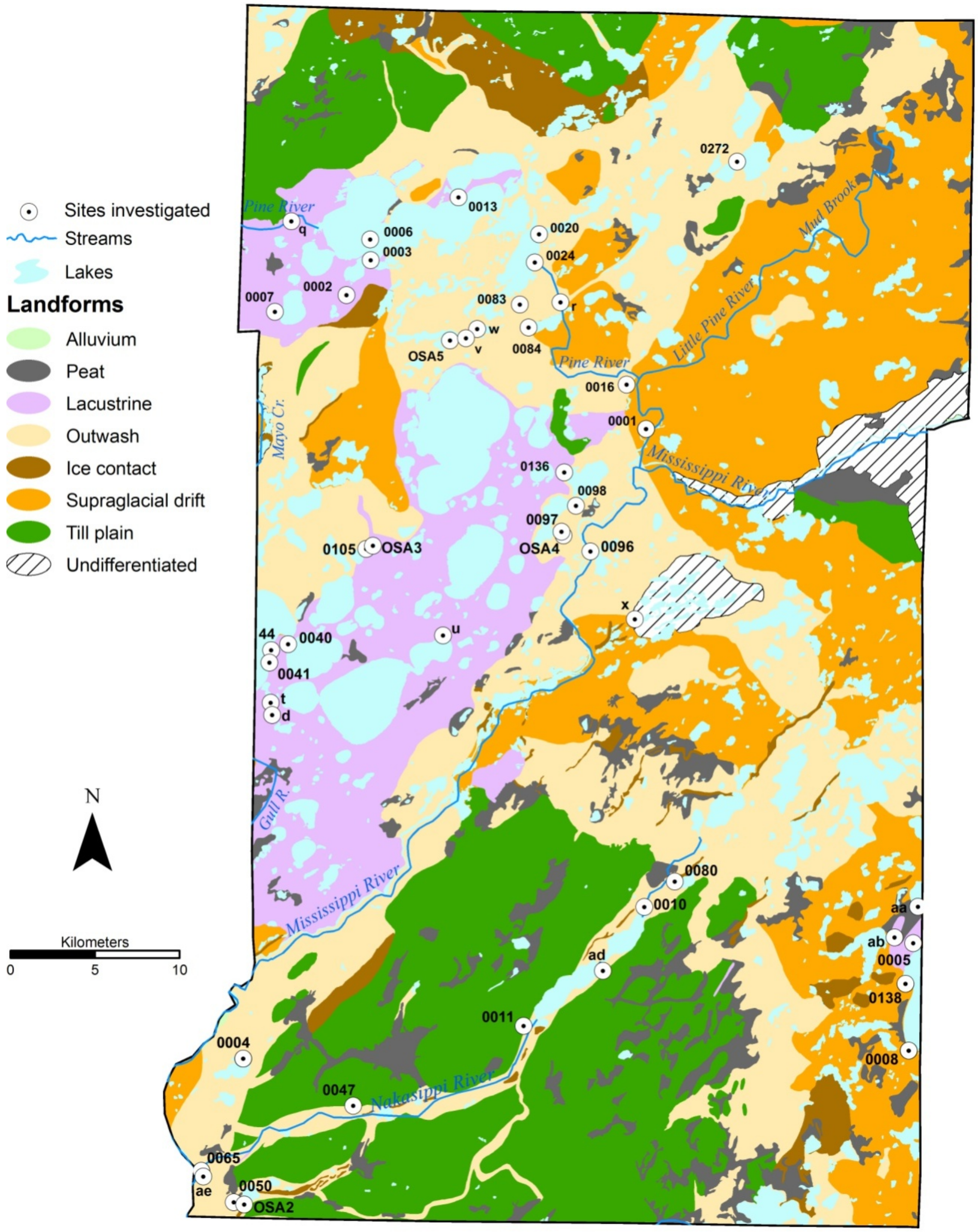

Figure 1.2. Geomorphological map of Crow Wing County, Minnesota, showing the location of sites investigated in this study. "21CW" omitted from site numbers. Base map: Minnesota Department of Natural Resources (1997a).

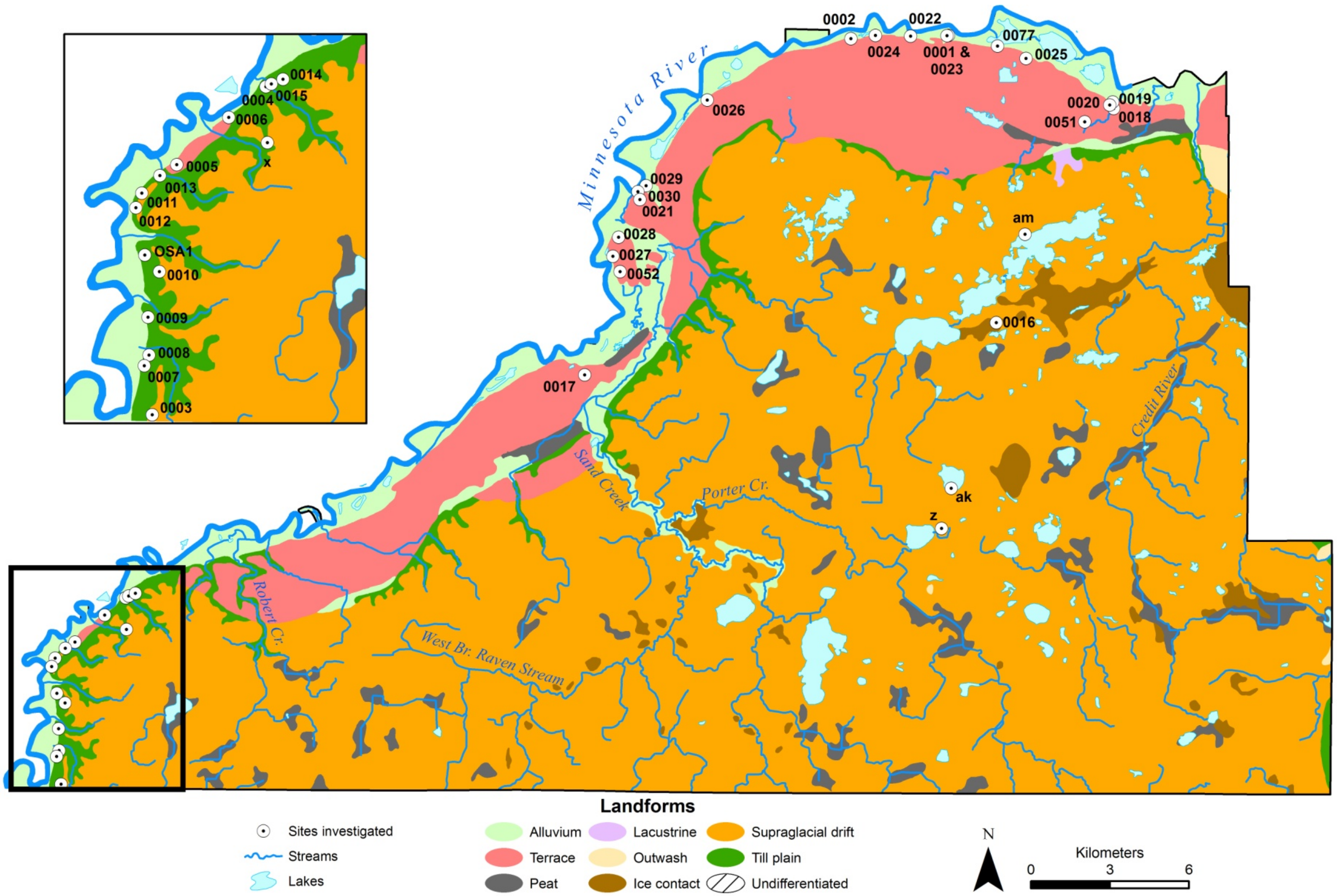

Figure 1.3. Geomorphological map of Scott County, Minnesota, showing the location of sites investigated in this study. "21SC" omitted from site numbers. Base map: Minnesota Department of Natural Resources (1997b).

Nearly all the county's mound sites are disturbed along the Minnesota River valley, clustering on uplands overlooking the valley in the southwest part of the county (Figure 1.3, inset), and distributed along its outwash terraces in the northern part. Perhaps because of its proximity to the Twin Cities headquarters of the Hill-Lewis surveys, T.H. Lewis surveyed and mapped 619 mounds at 29 sites in Scott County (Dobbs 1991:13). Arzigian and Stevenson (2003: 63–64, Table 4-1) report 636 recorded mounds in Scott County, indicating that nearly all known mounds in the county derive from Lewis's survey. One mound was excavated in 1940 by Wilford and 17 by Johnson in 1964.

ISSUES WITH EARLY MAPS

The early surveys, particularly those conducted by Lewis and Brower, are generally recognized for their importance as being the only record of sites now destroyed or damaged. The accuracy of site maps is essential to accurate site records and site relocation. The work of the early antiquarians was generally unsystematic, lacking uniformity, and with much of the mapping and excavation concentrated in select portions of Minnesota (Arzigian and Stevenson 2003:54). Errors from early surveys included errors in surveying, rounding errors, compounding errors, and defining mound centers (Arzigian and Stevenson 2003:62).

While Lewis's maps are detailed and accurate, particularly compared to Brower's, a number of problems have been noted (Dobbs 1991, Arzigian and Stevenson 2003). Lewis relied on whatever maps were available to him, generally original Public Land Survey which contained section and quarter section corners (Haury 1990) but few landmarks. Lewis's maps often incorporate little landscape detail. Lewis acknowledged that he selectively mapped mound groups that were undisturbed by farming or other activities that had degraded them. Inconsistencies in the number of reported mounds may have resulted from the presence of heavy vegetation, poor weather, plowing, and erosion. His mound numbers can sometimes be difficult to correlate when sites change over time (Arzigian and Stevenson 2003:55).

Lewis's survey method incorporated the use of a cloth tape, engineer's level, and a compass. Dobbs (1991) noted several errors resulted from this method, usually compounded in larger mound groups. The use of an open traverse method, linking each measurement to the one before it, lacked internal checks for accuracy. The surveyors compass was accurate to within plus or minus 1 degree, and Lewis often rounded to within a half degree. Both of these methods would allow for inaccuracies over a long series of bearings. Lewis recorded magnetic north which allows for an additional level of inaccuracy due to changes in magnetic declination over time. Legal descriptions could be in error as a result of using poor maps or later resurveying or remapping of areas Lewis had recorded (Haury 1990). He was never able to correct his maps since he could not access the records following Hill's death. He may have intentionally suppressed some information about sites so that only he could be the one to write an accurate report on them (Dobbs 1991:9).

The history of Minnesota archaeology reflects much of what occurred elsewhere in the Midwest. The independent antiquarian methods and theories were replaced by more methodical, scientific inquiries pursued in academia and CRM. The legacy of Hill and Lewis and the NAS, however, is unique, providing a record that continues to have significant research value today.

DATA COMPILATION

Site Records

UI-OSA traveled to Mn-OSA to research and obtain documents pertinent to mounds sites in Scott and Crow Wing counties. Mn-OSA archives a variety of records pertaining to burial sites in Minnesota. Three data sets are kept current as new information about sites is recorded. The Minnesota archaeological site files contain documents about all recorded sites in the state. A second set of documents, the burials files, contains records specific to human burial sites. The Cemetery Database, in Microsoft Access, contains tabular data on human burials in the state, and is kept current by the State Archaeologist in the performance of its statutory responsibilities regarding precontact burials.

Other primary source documents held at Mn-OSA include photocopies and microfilms of the notes of T.H. Lewis, photocopies of the field notes of J.V. Brower, and photocopies of L.A. Wilford’s typed notes. Individual site files contain correspondence and other materials from the papers of A. E. Jenks.

To start the documents acquisition part of the project, Mn-OSA provided a list of 44 mound sites in Crow Wing County and 37 sites in Scott County, printed from the Cemeteries database. Most sites are assigned Smithsonian Institution Trinomial System (SITS) numbers, but sites with poorly documented locations are identified by the county abbreviation (CW, SC) followed by lowercase alphabetic character. These are referred to herein as “alpha” or “letter” sites. Records for 13 letter sites in Crow Wing County and 4 in Scott County were obtained for this project (Table 1.1, Figures 1.2, 1.3).

Table 1.1 summarized the range of documentation obtained for each site. UI-OSA copied all the site files and burials files for the identified sites by either Xeroxing or scanning to pdf. Maps included in the site files were digitally photographed, a task especially important for large format maps too large for the photocopier and scanner.

Selected, pertinent portions of Wilford’s and Brower’s notes were copied or scanned. Mn-OSA provided photocopies of its copies of the T.H. Lewis notes. Mn-OSA lacked records for seven alpha sites in Crow Wing County, and these were obtained from the Minnesota State Historic Preservation Office in St. Paul.

With Mn-OSA concurrence, we decided not to research cultural resource management reports for information on mound sites. The project focuses on mound and site locations, which are extensively documented in the site file, burial file, and Brower and Lewis maps. Seeking additional information in reports was considered to provide a low return for time spent.

Mn-OSA provided photocopies of Lewis’ notes, but as they were not made from original documents, legibility was sometimes poor. As a backup, we digitally photographed a second set of copies from the microfilm reader.

Additional materials provided by Mn-OSA included their Cemeteries Access database that contains information about burial sites, an ESRI shapefile of recorded site locations, and PDFs of the published volumes of Brower’s notes. UI-OSA also acquired a copy of the Gustav’s Library reprint of Winchell (1911). At the conclusion of our Mn-OSA trip, we reviewed the list of materials we had obtained with Scott Anfinson and Bruce Koenig, and all agreed we had obtained sufficient materials to proceed. Dr. Connie Arzigian, University of Wisconsin-La Crosse, provided a copy of the Access database, Burials2000MVAC, created during her previous comprehensive review of Minnesota burial mounds.

Table 1.1. Types of Documents Contained in Mn-OSA Site Files for the Sites.

Site	UMAL Survey	Minn Arch Site File	Minn Ach Site Form	NR Form	Maps	Winchell photocopies	Lewis notes	Brower notes	Jenks notes	Wilford notes	Letters/Emails/Memos	Report excerpts	Newspaper clippings	Photos
CW1	X				X			X	X	X	X			X
CW2		X			X					X		X		
CW3	X	X	X		X					X	X	X		
CW4	X				X		X					X		
CW5	X	X	X		X	X	X				X			
CW6	X				X					X				X
CW7	X		X	X	X	X					X	X	X	
CW8	X	X	X		X			X			X	X		
CW10		X	X		X					X	X	X		
CW11	X	X			X					X				
CW13	X		X		X					X				X
CW14		X	X		X					X			X	
CW16	X			X	X						X			
CW20		X	X		X						X			
CW24	X	X			X									
CW40		X			X	X		X				X		
CW41		X			X									
CW44	X				X									
CW47	X				X									
CW50		X			X									
CW65		X	X		X						X	X		
CW80		X			X							X		
CW83		X			X									
CW84		X		X	X						X			X
CW96			X		X						X	X		
CW97		X	X		X			X			X	X		X
CW98		X			X						X	X		
CW105			X		X									
CW136			X		X			X						
CW138			X		X							X		
CW272			X		X									
SC1	X	X	X		X					X				X
SC2	X	X	X		X		X			X	X	X		
SC3	X		X		X	X	X				X			X
SC4	X				X		X					X		
SC5	X		X		X		X							
SC6	X				X		X					X		
SC7	X				X							X		
SC8	X				X							X		
SC9	X				X							X		
SC10	X				X							X		
SC11	X				X	X	X					X		X
SC12	X				X	X	X					X		X
SC13	X				X	X	X			X		X		
SC14	X				X							X		
SC15	X				X		X					X		
SC16	X				X	X	X				X	X		

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Site	UMAL Survey	Minn Arch Site File	Minn Ach Site Form	NR Form	Maps	Winchell photocopies	Lewis notes	Brower notes	Jenks notes	Wilford notes	Letters/Emails/Memos	Report excerpts	Newspaper clippings	Photos
SC17	X				X		X					X		
SC18	X				X		X				X	X		X
SC19	X	X	X		X	X	X					X		
SC20	X		X		X		X				X	X		
SC21	X				X		X					X		
SC22			X		X		X				X	X		X
SC23	X	X			X		X							X
SC24	X		X		X	X	X				X	X		X
SC25	X				X	X	X							
SC26	X		X		X	X	X				X	X		
SC27	X	X	X		X	X	X			X	X	X	X	
SC28	X				X	X	X							
SC29	X				X		X					X		
SC30	X				X		X					X		
SC51			X		X									
SC52			X		X									
SC77			X		X									
SCak					X						X			
SCam					X							X		
SCx					X							X		
SCz					X						X			
Total	42	23	28	3	68	14	26	5	1	12	24	39	3	13

GIS Data Compilation

Baseline GIS data, such as county boundaries, roads, USGS 7.5' topographic maps, 1930's aerial photography and Farm Services Administration color orthophotos, were obtained by downloading from the Minnesota Department of Natural Resource's GIS Data Deli (http://deli.dnr.state.mn.us/) or by direct link to the Deli's Web Map Service (WMS) (http://deli.dnr.state.mn.us/services.html).

Mn-OSA provided an external hard drive containing LiDAR data obtained from Crow Wing and Scott counties at the request of State Archaeologist Scott Anfinson. These data are discussed in detail in Chapter 2. Additional LiDAR data, as well as information and documents relating to LiDAR acquisition by the counties, were provided by Scott and Crow Wing counties on request from UI-OSA.

Chapter 2: LiDAR Analysis

Melanie A. Riley and Joe Alan Artz

Although airborne LiDAR offers tremendous potential for archaeological research, many steps intervene between the time an airplane soars aloft to acquire the data and the time the processed data appears on the archaeologist's computer monitor. As this chapter demonstrates, the LiDAR data an archaeologist receives is not necessarily ready for immediate use in detecting archaeological features, and in some cases may have been processed in ways that makes its use for archaeological purpose problematic.

The chapter therefore begins with an overview of LiDAR, from data collection, through post-processing, to the production of an end-user product. Although hopefully of interest to archaeologists in and of itself, this background material is also important to understanding the methods and results of the archaeological analysis that comprised the remainder of the chapter.

Because technical terminology cannot always be avoided, a glossary of terms and acronyms is provided as Appendix A. Maune (2007) is an excellent resource for understanding and using digital elevation data. Much of the following is summarized from Fowler et al.'s (2007) chapter in that book.

BACKGROUND

A Brief History of LiDAR

The first application of lasers for measuring distance from one point to another (ranging) was to study the moon with the sensors installed on satellites. In 1964 the National Aeronautics and Space Administration (NASA) launched the Beacon B satellite followed by the Lunar laser ranging program. Since the 1960s a global network of ground stations has been developed to measure ranges to satellite-borne reflectors. Satellite laser ranging is still an important part of NASA's geodesy program to study the shape of the earth and determine the exact position of geographical points.

Suborbital airborne LiDAR was first implemented in 1975 as part of a multi-agency, worldwide project to test new applications in remote sensing. Laser sensors were used to measure the levels of biological and chemical substances such as chlorophyll in the oceans. The wavelength of the laser also allowed for the collection of underwater topographic information. In 1994, the Airborne Topographic Mapper (ATM), an airborne LiDAR system dedicated to overland topographic mapping was developed. The 1990s saw rapid improvements in laser scanning technology and commercial systems began to emerge.

Over the last decade, as LiDAR data acquisition became more affordable, the use of the technology has grown exponentially. LiDAR has proven to be a rapid and cost-effective way to conduct 3D elevation surveys over large areas. Active systems including LiDAR generate their own light sources to survey the area, unlike aerial photography and other multispectral sensors which need sunlight to collect the electromagnetic radiation data of different wavelengths. The LiDAR mission can therefore be carried out day and night given certain weather conditions and conditions on the ground such as flooding, snow, and tree leaf-out that inhibit the collection of accurate bare-ground elevation data. All airborne laser systems are equipped with positioning and orientation capabilities for obtaining highly-accurate X, Y, and Z coordinates of the laser footprint, typically 0.15 m vertically and 0.3–5 m horizontally, depending on the system. LiDAR technology also provides a means of high-speed acquisition of data in heavily vegetated and rugged areas which were previously difficult or impossible to access.

Airborne LiDAR

There are three operational categories of LiDAR systems: continuous wave, light striping-video profiling, and pulse. The LiDAR data used in this study was acquired with the pulse system, which is the system commonly used for large-area data collection efforts currently taking place in Minnesota and many other states. This LiDAR system transmits laser pulses, and then amplifies the light that is scattered back through an optical telescope receiver and photomultiplier tube. The distance to the object is calculated using the time the transmitted pulse travels to the target and back, given the speed of light as a constant. Lasers used for collecting topographic information on land are in the near-infrared portion of the light spectrum, typically 1,064 nanometers, so we cannot see the light that is emitted for a LiDAR mission. The output power of the laser pulse is far too weak to cause blindness in people and animals, a common concern among people when first told about the technology. The pulse may intersect several objects on the way down, bouncing back multiple returns to the sensor or may only have one return such as a building roof or the ground (Figure 2.1).

Not only are there different ways of emitting the laser, but also various ways of “steering” the laser beam depending on the system. The laser beam is directed by mirrors or fibers creating different scan patterns over the landscape including zigzags, straight lines, overlapping loops, or ellipses. In theory there are no reasons why one scanning technique is preferable to another. Each method has its advantages and disadvantages and most of the disadvantages can be overcome during post-processing of the data (Fowler *et al.* 2007).

Airborne systems can be operated at 80–6,100 m altitude, the choice of altitude depending on the strength of the laser, weather conditions and specifications for final deliverables. Time-of-Flight scanners, which are used for large-area data collection, can capture data at a rate between hundreds and thousands of points per second. Phase-based scanners can collect hundreds of thousands of points per second - but have very limited applications (Fowler *et al.* 2007).

Processes That Effect Data Outcome During Flight Mission

Many processes are involved before the end-user lays eyes on a bare-earth digital elevation model (BE DEM) (Figure 2.2). Some processes introduce error, and others potentially omit data that would facilitate the detection of an archaeological feature. Positioning, the first process, requires high-precision equipment because the airborne laser source is constantly and rapidly moving. The collection hardware includes an inertial measurement unit (IMU) and a Global Positioning System (GPS). The IMU incorporates 3 gyroscopes which aid the unit in recording the aircraft’s velocity, orientation (roll, pitch and yaw), and gravitational forces at the instant the laser pulse is sent and received. Over the course of a flight mission, the gyroscopes become less accurate in determining the orientation of the pulse in 3-dimensional space.

All LiDAR systems use Differential GPS (DGPS) positioning technology. At least 4 satellites with precisely known orbits are needed to determine the position of the GPS receiver. For the very precise locations required for accurate positioning in LiDAR, a lock on at least six GPS satellites is desirable. Two GPS receivers are used during flight, one aboard the aircraft, and the other a well-surveyed location. The ground receiver should preferably be located at a survey monument that has been precisely measured in coordinates of the horizontal and vertical projection the end-user wants. Complications with GPS come from irregularities in the earth’s gravity, shape of the earth, the map projection to be used, as well as inconsistencies in atmospheric conditions and other phenomena such as sun spots. Data from both GPS units are

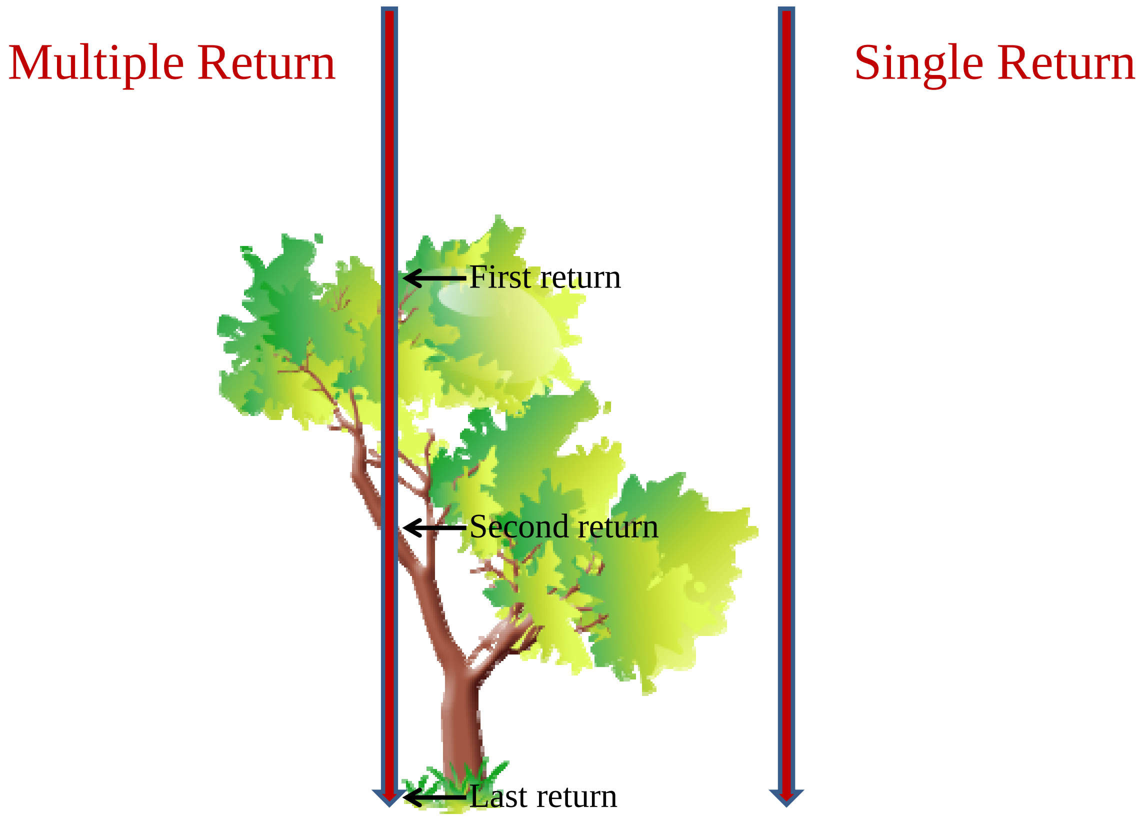

Figure 2.1. Illustration demonstrating how a laser pulse can have a single or multiple returns.

post-processed to get the exact location of the aircraft's antenna for the whole flight. Data from the IMU is post-processed along with GPS data to get a file indicating the trajectory of the aircraft and laser antenna at all times during the LiDAR mission.

As mentioned above, the laser beam can be directed. Not only does the steering of the beam control the pattern of scanning on the ground, it can also change the angle of the beam. Scan angles are the angle the pulse was off-nadir when sent. The wider the scan angle, the more area is collected at one time which shortens flight time, increasing cost effectiveness. However, over forests, as the scan angle widens, pulses at the outer limits of the scan will pass through the canopy at increasingly oblique angles, and likelihood of their being blocked by a limb or leaf increases. In contrast, a narrow scan angle results in nearly-vertical pulses that pass through less canopy and therefore have a greater chance of reaching the ground. Narrow scan angles provide the best, cleanest bare-earth data.

Most LiDAR operators test their equipment over a calibration site for which they have a large amount of data acquired by using another survey technology with high accuracy. Calibration allows the operator to know if the subsystems have been set up properly and if there are any inherent biases in the instrumentation. For acceptable data acquisition, the many interworking parts of the LiDAR system must be set up correctly to function together. For example, differences of a thousandth of an inch in the alignment of the IMU center and the laser head are magnified greatly when the beam is extended from 3,000 ft in the air (Fowler *et al.* 2007).

Post-Flight Processing

The DGPS, IMU and laser point ranges are the true "raw data" acquired by LiDAR. The term has been used interchangeably by end-users for the mass point data but this is technically not correct.

The raw data first needs to be processed by the vendor that collected the data before it is delivered to the end user. This processing is usually done by the same vendor that collects data, because the initial processing software has been developed specifically for the LiDAR system or model series used by the vendor. Initial processing creates mass point files in XYZ WGS 84 coordinates, or in polar coordinates of latitude, longitude, and height (lat, long, H WGS 84; Figure 2.2). These data are then reprojected to the coordinate system requested by the customer (e.g., Universal Transverse Mercator, or UTM).

The laser system records every echo (return) it receives which can be from rooftops, branches, leaves, towers, and vehicles, as well as ground. The points need to be sorted (Figure 2.2) so usable data can be created specific to the project. Sorting and classification is done using software within the LiDAR system, proprietary software developed by the consultant, or commercial off-the-shelf (COTS) software. The software automates the classification of points as ground or non-ground, but the process, in reality is semi-automated, since some human intervention is necessary for quality assessment and controlling systematic errors. In addition to sorting and classification algorithms have also been developed to filter out superfluous returns caused by birds, electric transmission lines, atmospheric effects such as dust and moisture, systematic range errors caused by different reflectivity of the surface elements, and erroneous points caused by very bright objects. Manual sorting may also be implemented, but this added feature is time consuming and expensive; for large projects it is not financially feasible. Additional filter techniques can be used for further classification of non-ground points such as vegetation and buildings.

The laser points recorded by LiDAR are not evenly spaced in a straight line but rather are randomly located (Figure 2.3). To create the rasterized or gridded products, not every point is needed. A nearest neighbor algorithm is implemented that compares nearby points to identify points that contribute new information versus those that basically “repeat” a neighboring point. Thinning (Figure 2.2) is used to remove points that do not add to the definition of the required object. Thinning laser points in this matter helps speed up post-processing. The thinned points are then converted into gridded Digital Elevation Models (DEMs). The most common interpolation method is Inverse Distance Weighted (IDW). Interpolation results in the assignment of a single elevation value to each cell in the grid. IDW is referred to as “a non-exact interpolation method” in the sense that the cell value in the DEM is not necessarily equal to the value of a mass point that resides in that grid cell’s extent. As shown in Figure 2.3, some grid cells may not have a corresponding point at all and are assigned values interpolated from nearby points. If contour line files are part of the deliverables, the ground points are thinned further before the lines are processed. This is necessary because the difference in vertical accuracy to horizontal accuracy of the point data can cause jagged, crossed, or looped contour lines which are improved by a filter targeted for creating contour files.

LIDAR DATA

Crow Wing County LiDAR Data

Crow Wing data collection began May 5, 2007 in the western portion of the county and progressed in an easterly direction. Two weeks later the collection efforts were approximately 80–90% complete when the flights were delayed due to weather conditions. The extreme easterly portion of the county was flown on June 10th. Flight lines from a final, June 24th mission overlapped flight lines flown previously (Doug Hansen, personal communication November 2009). According to Mr. Hansen the specifications of the project was leaf off-bud on with a collection target date of May 1–May 30, 2007. The May 5th through June 10th flights were early

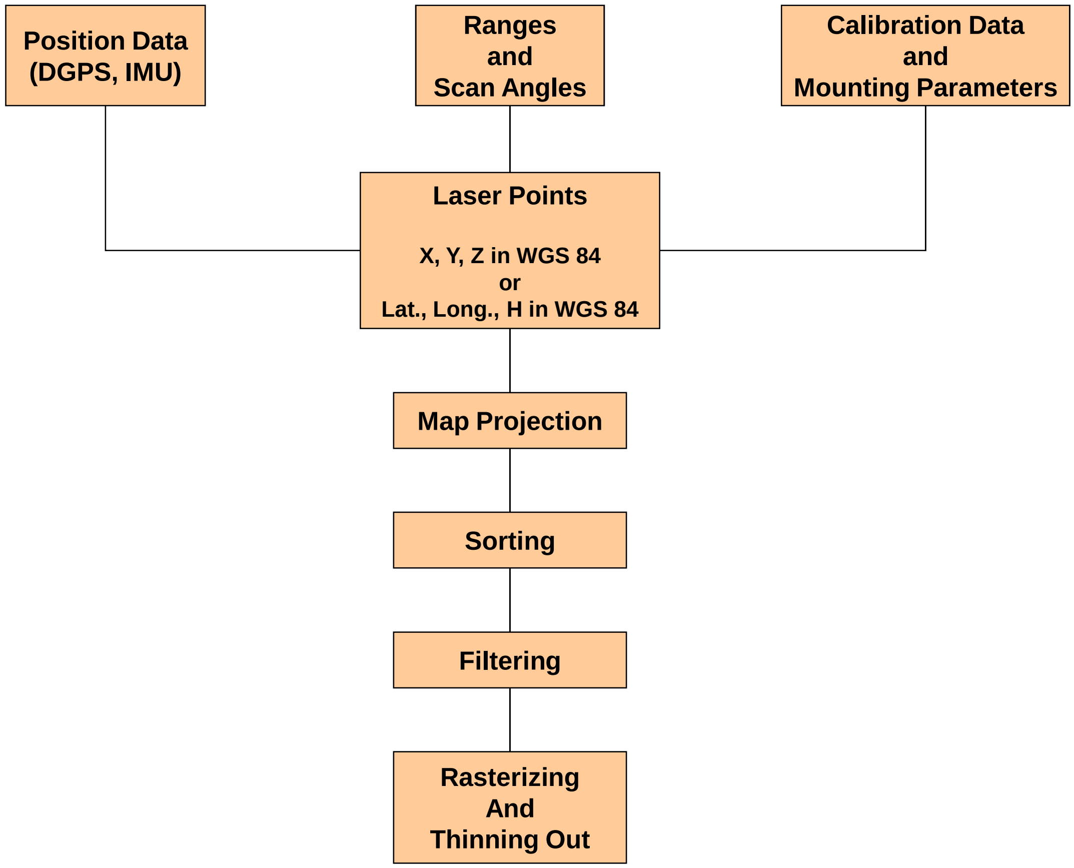

Figure 2.2. Simplified diagram of the processes LiDAR data pass through before reaching the end user (Fowler et al. *2007).*

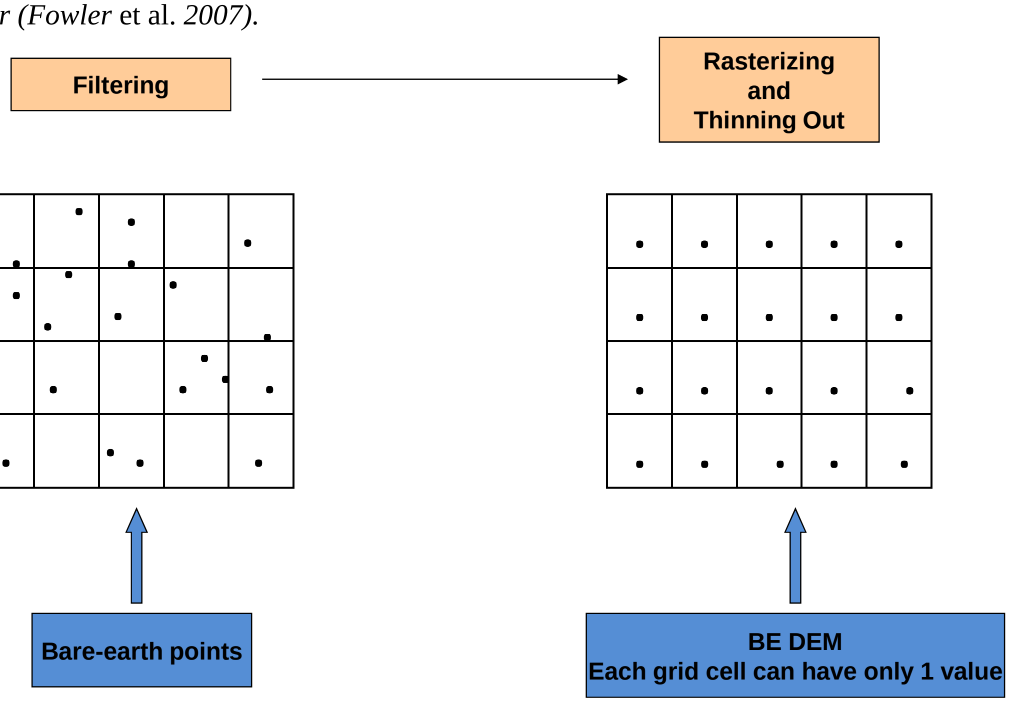

Figure 2.3. Illustration demonstrating data thinning and interpolation necessary to provide one elevation value per grid cell of BE DEM raster (Fowler et al. *2007).*

enough to obtain bare-earth data suitable to producing Bare-Earth Digital Elevation Models (BE DEM) to the contract's required accuracy and resolution specifications. These specifications were as follows (St. Cloud State University 2007):

- Horizontal absolute accuracy of 30 cm RMSE
- Vertical absolute accuracy of 15 cm RMSE
- Maximum nominal point spacing of 2 m.

The June 24th flight may have been intended to meet the specification of Section 4.1.3.3 of the project's Request for Proposal (RFP) that required gathering data "when deciduous forests have low canopy cover but sufficient leaf-on conditions to capture above ground biomass" (St. Cloud State University 2007).

No explicit requirements were listed for maximum scan angle or maximum percentage of land area leaf-off during collection. Data used for this project that were acquired from Crow Wing County included BE DEMs, tile boundaries, classified mass points with a return intensity attribute in LAS format, and an Obscured Area feature class delimiting areas where there were not enough elevation data (points) to meet specifications for accuracy. The Obscured Area map (Figure 2.4) shows the density of obscured areas increasing from west to east. By the June 10th collection mission, understory vegetation may have had time to rebound and grow and the canopy may have been in bud-out or early onset of leaf-on.

Shaded relief images needed for the project were created by UI-OSA in ArcGIS 9.3.1 utilizing tools available with the Spatial Analyst and 3D Analyst extensions.

Scott County LiDAR Data

Scott County data provides an interesting contrast to Crow Wing County in that Crow Wing intentionally sought LiDAR data with many related deliverables such as BE DEMs, Digital Surface Models (DSM), contour lines, tile boundaries and data for biomass studies. Scott County did not intentionally seek collection of LiDAR data but rather sent out an RFP for acquiring 2-ft contours (Jim Hentges, personal communication November 2009). Scott County did not specify that the data be acquired by LiDAR, as opposed to alternatives such as traditional aerial photogrammetry. The method of acquisition was left up to the vendor. The project Scope of Work (SOW) specifies vertical accuracy for the 2-ft contours to be less than 0.3 m (1 ft) of true ground elevation at the 95% confidence interval and less than 0.6 m (2 ft) at the 100% confidence interval (Scott County, Minnesota, 2003). Data provided to UI-OSA for the present project from Scott County consisted of ASCII text files of bare-earth X, Y and Z coordinates and 2-ft contours in .dwg file format.

The ASCII text files, in addition to columns of x, y, and z coordinates, had an additional column of superfluous data left by the vendor. To create BE DEMs, the UI-OSA parsed out the extra column of data, then converted the xyz data to LAS format. Nearly 400 hundred ASCII text files were provided by the county, each containing points for a Public Land Survey System section (typically 1 x 1 mi). The nearly 400 files were combined into blocks by township and range. UI-OSA created thirty-one blocks of LAS data using LibLAS open source txt2las command-line utility plus an additional line of code to parse out the extra column. UI-OSA then processed the LAS files further in ArcGIS 9.3.1 utilizing tools available with the 3D Analyst extension to create the 1-meter raster grid BE DEMs. Only the townships that have recorded mound sites were processed into BE DEMs and shaded relief images. Processing additional townships is considered beyond the scope of this project.

A preliminary review of the bare-earth points over aerial photography and the shaded relief image revealed that not all of the original mass point data were provided, but had been thinned by the vendor in order to produce smooth contour lines (Figure 2.5). In areas where the landscape

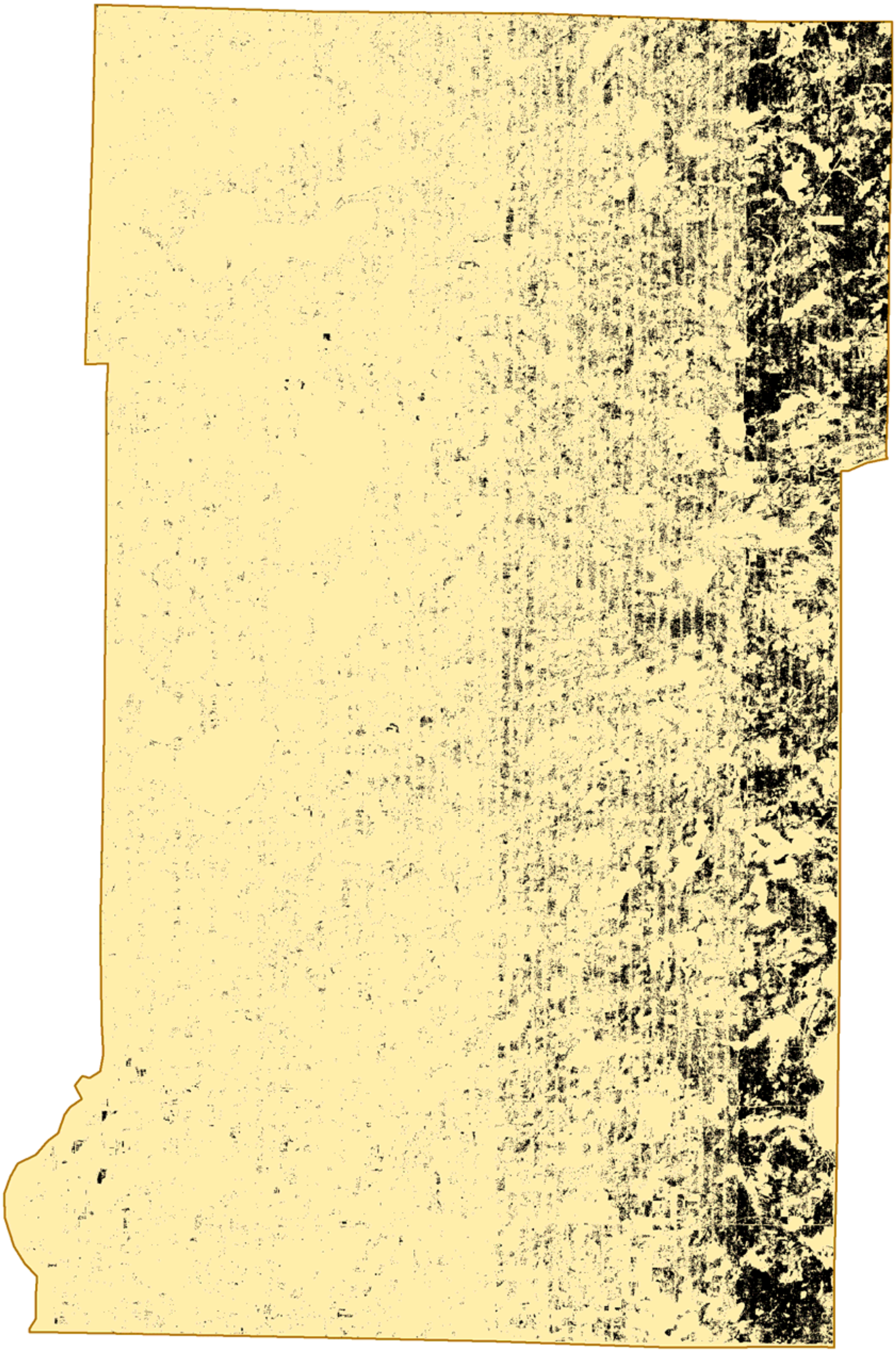

Figure 2.4. Map of Crow Wing County showing the systematic increase in obscured areas (in black) from east to west.

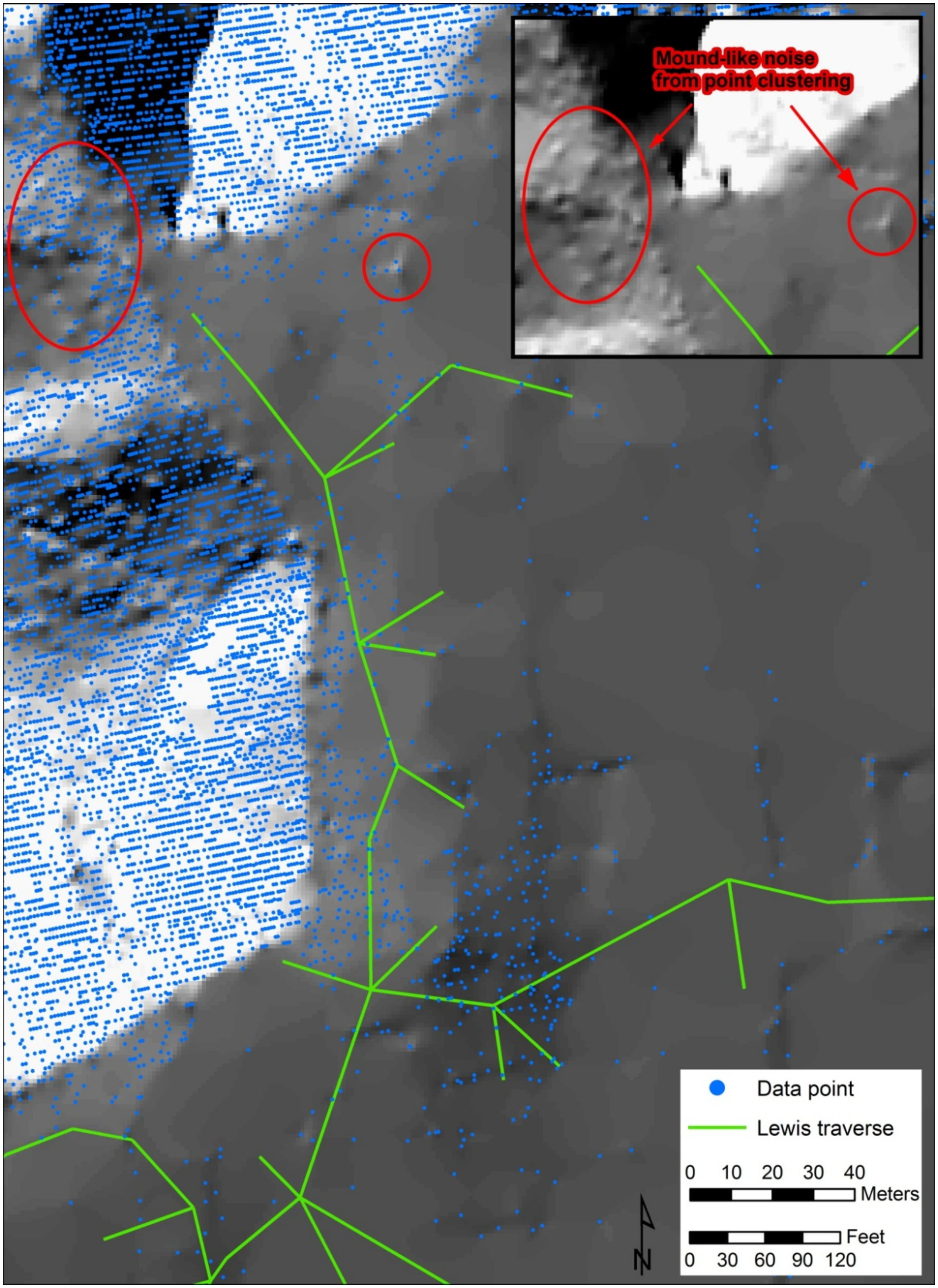

Figure 2.5. Bare-earth point dataset from 21SC3, with Lewis traverses in green. Points from the level area, including the site, appear to have been over-thinned to produce contour lines (note conical features in upper left of image and inset).

had been plowed level or is naturally flat, a semi-automated algorithm used by the vendor apparently determined points that did not contribute additional information to the topography and removed them from the dataset. Information on what software was used for thinning the points or the criteria for sorting elevation points that do not "contribute" to the surrounding topography is not available. In addition, ASCII text files of each tile with the suffix "f" (assumed to stand for "filtered") contain very few additional points, or are empty, and do not fill the large gaps left by thinning. The presence of these two files suggest the data passed through two thinning processes, once when the raw data from the flight were processed into ASCII files and again during the creation of the 2-ft contour line data, which was the primary objective of the project. Nevertheless, in areas where the terrain is rugged and therefore less likely cultivated, we believed the bare-earth point density was sufficient to produce BE DEMs that could express mound features.

TASK A: DELIMIT SITES FROM DOCUMENTARY RECORDS

GIS shapefile of site boundaries was digitized for 80 of the 81 mound sites in Scott and Crow Wing counties using locational information contained in site file records obtained from the Minnesota OSA (see Chapter 1). When only a point coordinate for a site was available, the site's point was used as a centroid for a 50 m- radius circle representing that site.

One lettered site, 21CWs, could not be digitized because pieces of available site location information greatly conflicted with each other. The coordinates from the MHS archaeological site database places the site between Markee and Lougee Lake in T136R28 Sec. 36 but copies of the paper site files show a topographic map of this location and a handwritten message that this was the wrong location. A photocopy of Brower's notes from notebook 1, page 16, has "CWs?" noted in the margins next to Brower's entry about a mound site in the woods north of Wilson's farm in Section 1 at the outlet at Long Lake. Brower's location in earlier entries elude that the Long Lake he was referring to is in T136R28 and is now called Ossawinnamakee Lake. An 1899 map depicts this lake as Long Lake as well as another lake in the southern part of the county which is now named North Long Lake. More paper files under 21CWs also show a 1913 plat of Laura Wilson's property near Ossawinnamakee Lake in T136R28 Section 2. However, the legal description for this location is attributed to 21CWv in the archaeological site database.

All available Theodore Lewis traverses for Scott and Crow Wing Counties were digitized as a polyline feature class using the Coordinate Geometry (COGO) Traverse window in ArcGIS. Each record in the traverse polyline file represents a segment in the traverse with attributes of: distance, bearing, site number, point from, point to, mound diameter (ft), mound height (ft), mound type, and whether the mound was excavated (Appendix B, Table B1). The mound type attribute is coded as follows:

C – conical
L – linear
E – effigy
O – oval
W – earthwork

Traverses were digitized for 26 sites, 2 in Crow Wing County and 24 in Scott. A companion point shapefile of 791 features was created from the traverses, with each point representing every mound, measurement point on an earthwork or stake Lewis noted in each traverse (Appendix B, Table B2). This point shapefile file contains the same attributes as the polyline file minus distance and bearing and the addition of coordinates in NAD83 UTM 15N meters.

The traverse origins were found to be general, usually to the QQ section or even half quarter section. Initially, the traverse was placed in the vicinity by matching topographic features sketched in Lewis' notes to those visible on a 7.5-minute topographic base map within the given legal location. The topography that Lewis sketched is remarkably close to the actual topography present at the sites and a few sketches included distances from mounds to bluff edges or terrace scarps. Comparison to modern topography also facilitated the placement of traverses.

The traverse locations were refined in Task B, during the analysis of LiDAR-derived images. Where possible, the traverses were shifted and rotated to align mounds recorded by Lewis with those visible in LiDAR. On occasion, a few remaining mounds in forest that were detectable on LiDAR-derived imagery aided in the placement of traverses for large mound groups where most of the mounds may have been plowed level. The clear depiction of topography provided on LiDAR shaded relief images also facilitated traverse placement in close proximity to the actual location with a high level of confidence

TASK B: INTERPRET LIDAR DATA FROM BE DEMS

Methods

Each site's Area of Interest (AOI) was interpreted first from a shaded relief image derived from the BE DEM. In an ideal situation, most of the mounds that are at least 30 cm high and 5 m diameter should be detectable on this type of imagery (Riley 2010). In a shaded relief image, mounds may not be visible because they are overshadowed by a prominent landscape feature, such as a bluff overshadowing an adjacent high terrace below. This is easily remedied by changing the brightness of the image or clipping the BE DEM to the area in question, taking out the high relief feature causing the large shadow, and then viewing the new shaded relief image.

In areas where mounds were not readily apparent on the shaded relief image, additional methods were employed. First, an area around the mound site was clipped from the BE DEM. This limits the range of elevation values and visually creates more contrast for distinguishing minute elevation trends. The trends can be further highlighted by manipulating the stretch rendering between the grid's minimum and maximum values (Figure 2.6). Some mound signatures are so subtle, it was necessary to view the clipped BE DEM in a 3D rendering environment where vertical exaggeration can be applied in addition to stretch rendering and dynamic lighting (Figure 2.7).

Many shaded-relief images from both counties were less-than-ideal for locating mounds. The problems were largely inherent in data provided by the counties. Scott County shaded relief images were derived from BE DEMs created from thinned bare-earth points intended for contour line creation. This produced shaded relief images with smoothed features. Landscape features such as ridge spurs, streams and terraces were discernable on these images but the microtopographic features, including low-relief mounds, lacked definition.

A second consequence of using thinned Scott County data for BE DEMs is that the points kept by the thinning process are not uniformly distributed, but are clustered to emphasize sharp relief, and sparsely scattered over local or broad, low-relief areas. Clustered points surrounded by data voids were often interpolated as mound-like features that can be misinterpreted as mounds. For example in Figure 2.5, small clusters of points in the open field and along the forested slopes and ridges show up on the shaded relief image as exaggerated conical features. The retention of a few points in a small area could have been triggered by tree bolls, colluvium, clumps of dead vegetation on the ground, or unfiltered vegetation above the ground surface. Burrowing activities by animals such as gophers may even create enough topographic relief to allow the filtering

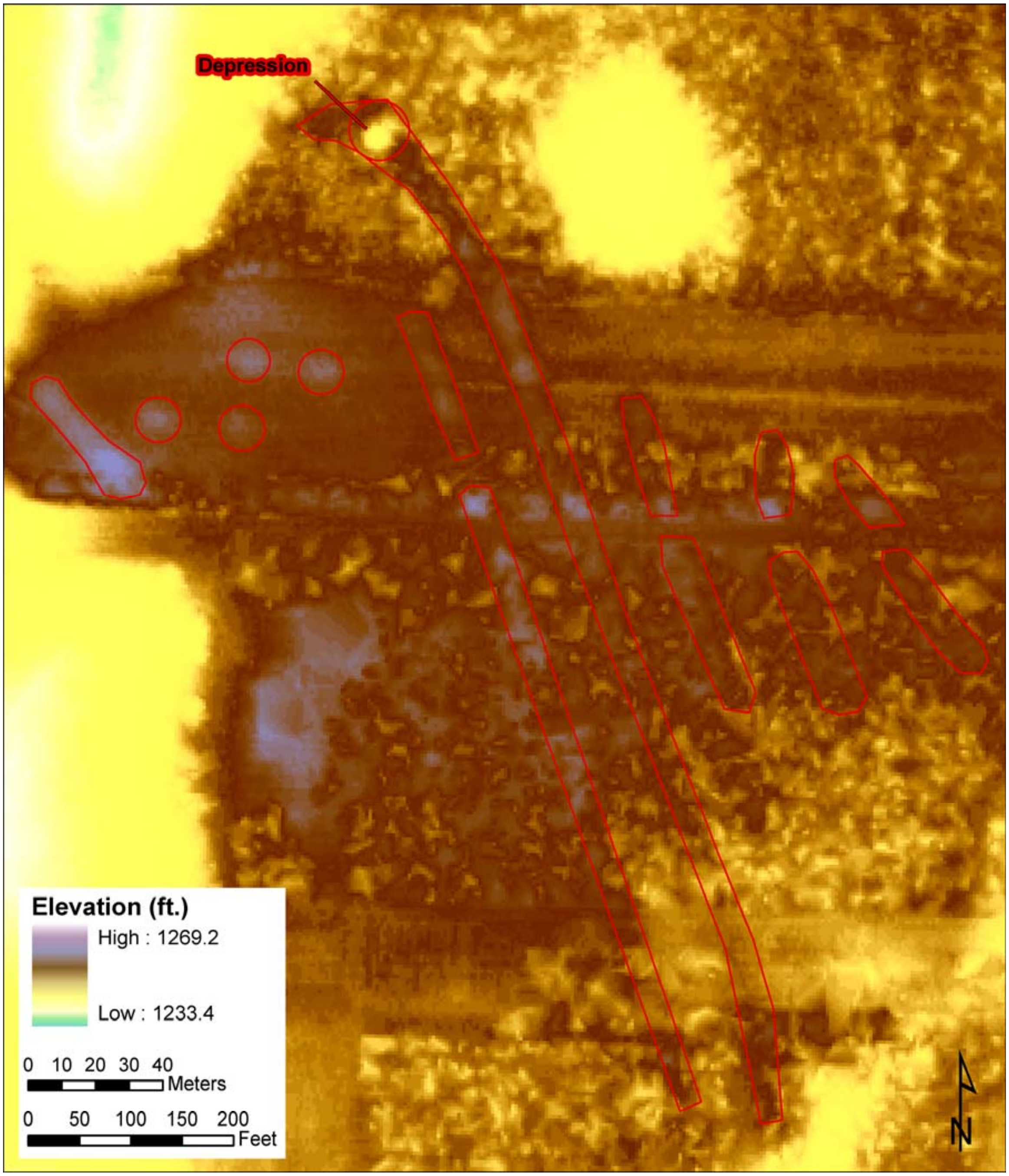

Figure 2.6. Portion of 21CW7/14 that required a customized stretch rendering of the BE DEM in order to interpret extent of the long earthworks in wooded areas.

algorithm to retain points over those features. Similar interpolation artifacts are ubiquitous on the Scott County shaded relief images so mound-like features detected outside a known site were treated with a high degree of skepticism by heavily scrutinizing position on the landscape, symmetry, size and spatial context in relation to other mound sites.

Shaded relief images from Crow Wing County data vary in quality depending on ground cover. In cultivated areas, the images are clear and highly detailed showing, for example, mounds that have been plowed over for decades and were barely discernable in this project's field survey.

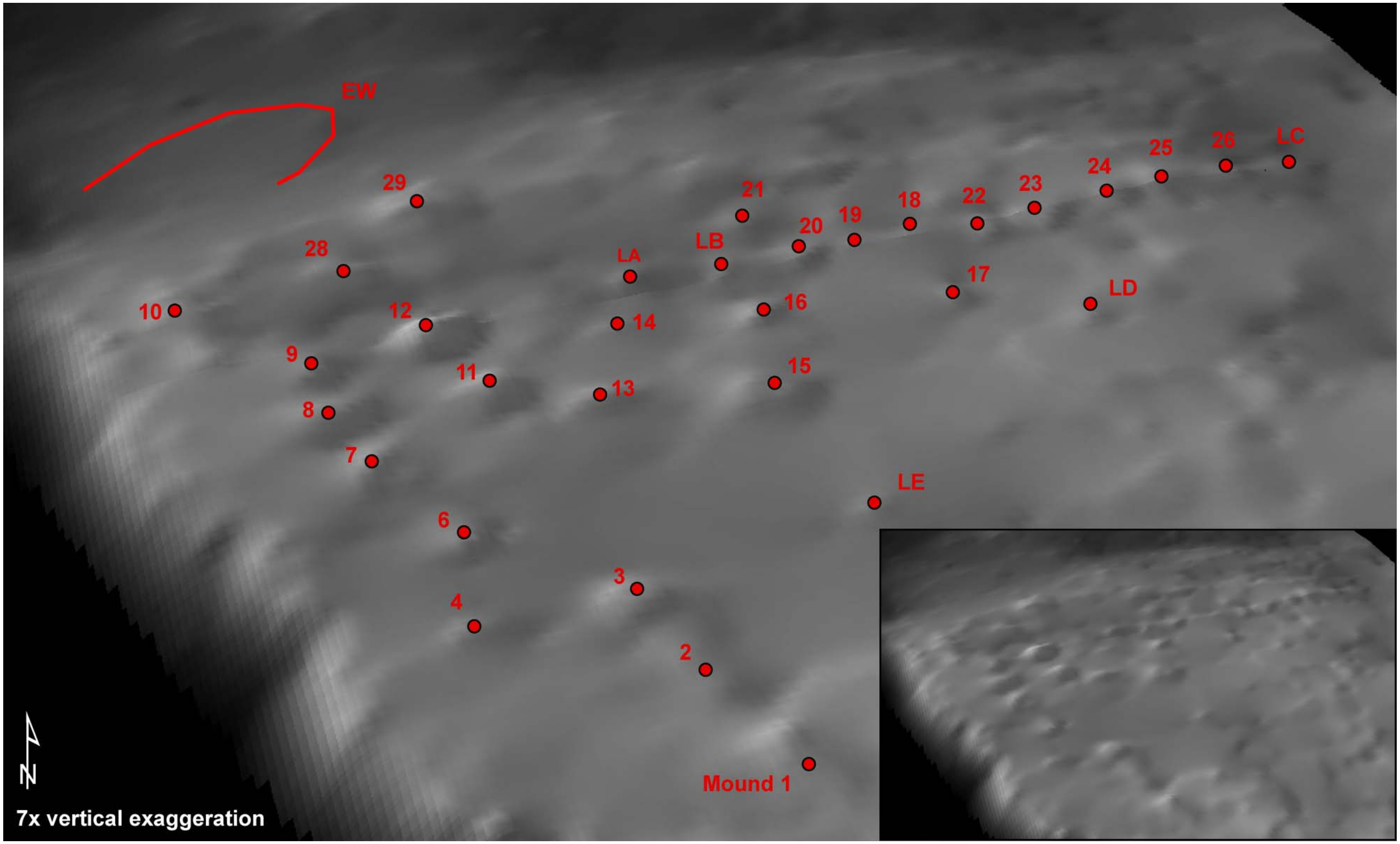

Figure 2.7. Three dimensional rendering of 21SC27 with 7x vertical exaggeration applied, earthwork and mounds marked in red.

In other areas, particularly under forest, the images exhibit many pocks and small, sharp peaks with faceted sides, regardless of whether the forest is deciduous or deciduous/evergreen mix (Figure 2.8).

The rough ground texture in these vegetated areas could be attributed to actual ground morphology, for example clumps of dead vegetation accumulating over the years, but the phenomenon are widespread and present wherever there is vegetation. Instead, the sudden flat spots, peaks and facets are a tell-tale sign that not enough ground points were available to create a clear, 1 m BE DEM. Some of the worst areas were those identified by the LiDAR vendor as "obscure areas," where the elevations could not be guaranteed to meet contract accuracy standards (Figure 2.9).

Other vegetated areas in the county, however, were supposedly flown to contract specifications, with leaf-off conditions, but still yielded rough ground textures and did not produce a shaded relief image conducive for detecting mounds. This would be understandable if every rough area were heavily vegetated by evergreens, which are never 'leaf-off," and therefore very effective at blocking the laser from the ground. However, parkland and deciduous forest in early May should not have had such sparse ground data.

Even after extensive visualization and processing, many Crow Wing County mounds that were known to exist, based on relatively recent field surveys, were undetectable due to the lack of ground information. The areas where these mounds existed were neither solely in evergreen forests nor limited to the eastern portion of the county where data collection occurred late in the season.

Another possibility for the dearth of ground data is that the ground points were misclassified as non-ground points and were filtered out from the dataset that creates the BE DEM. To determine if the points were misclassified or whether not enough elevation data were captured from the ground, LAS mass point data for 23 sites were requested from Crow Wing County. Among these sites was 21CW1, where round, smooth, flattened, areas in the otherwise rough-textured shaded relief were coincident with the mapped locations of mounds up to 20 m in diameter and 1–3 m high (Figure 2.10).

The LAS mass points for the 23 sites received from the county had been classified into two groups – ground and non-ground. Viewing the mass points by classification in a 3D rendering revealed that the mound points, and many other true ground points, were misclassified as non-ground (Figure 2.11). The misclassification of mounds over 2 m high is somewhat understandable because the semi-automated algorithm may have been triggered to classify an object that tall as non-ground, as a small structure would have been; but two low-relief mounds with maximum relief of 30–45 cm in a cultivated field were also misclassified (Figure 2.12).

Some of the mass point data was initially viewed with Merrick Advanced Remote Sensing (MARS) software but when it became apparent the misclassification problem was pervasive, QCoherent LP360 was obtained because of its greater system stability, easy interoperability with ArcGIS and quicker rendering of the mass point data in 2D, 3D, and transect profiles.

Results

Mound Detection. In essence, the analysis involved "visiting" each of the 81 previously recorded sites, searching for mounds in LiDAR data. If the site had been reported destroyed, or if the location was recorded as uncertain, LiDAR images for the locality and its surrounding areas were nonetheless examined for evidence of mounds.

Maps for 80 sites are provided as appendices. Maps in Appendix C shows site locations at a scale of 1:10,000 on a base map of USGS. 7.5-minute topographic quadrangles. Appendix D

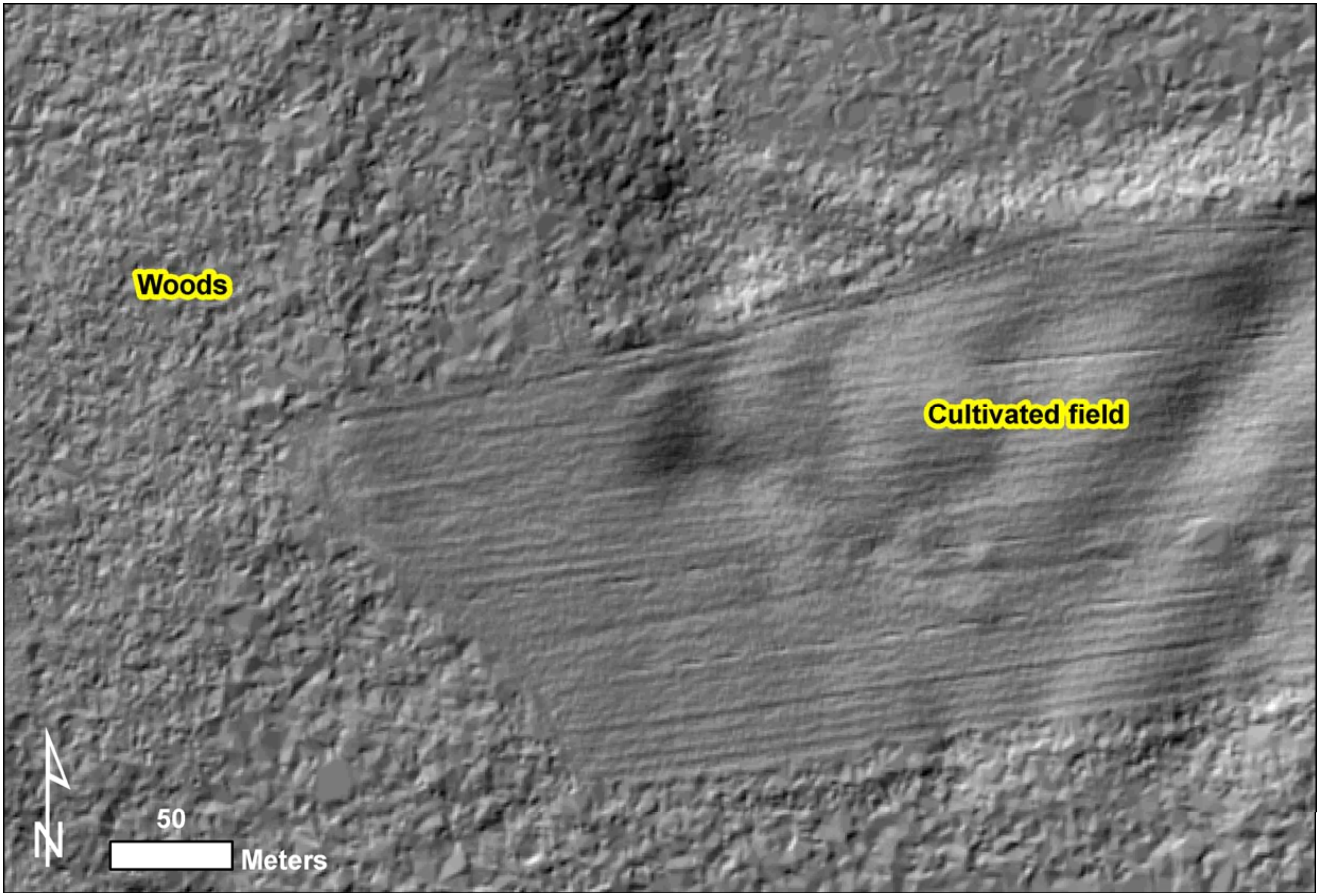

Figure 2.8. Typical shaded relief image from Crow Wing County at 21CW1 showing the textural differences between wooded areas and cultivated fields.

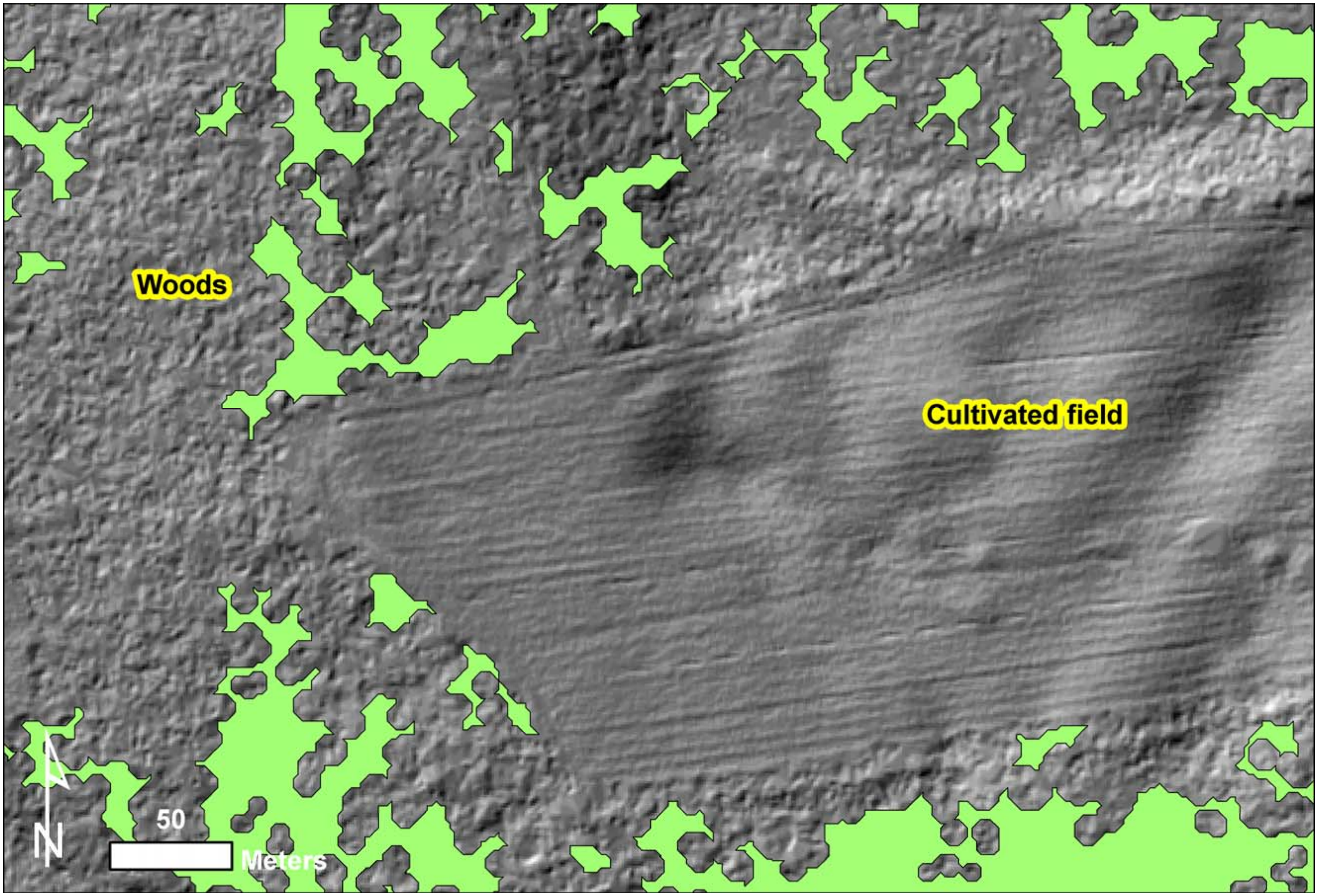

Figure 2.9. Same shaded relief image shown in Figure 2.8 with vendor-designated obscured areas in green.

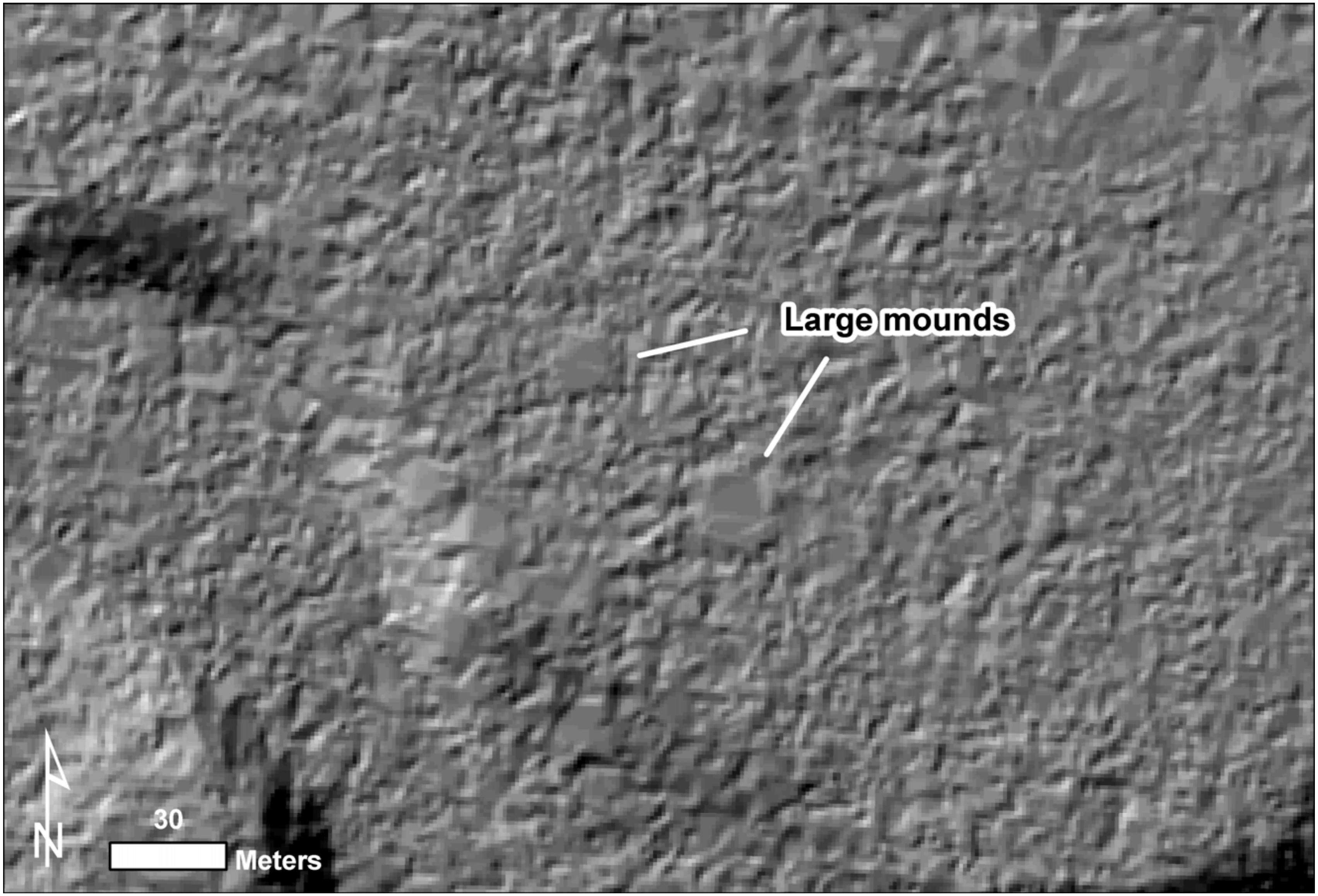

Figure 2.10. Location of large mounds at 21CW1 marked by abrupt, flat surfaces on shaded relief image.

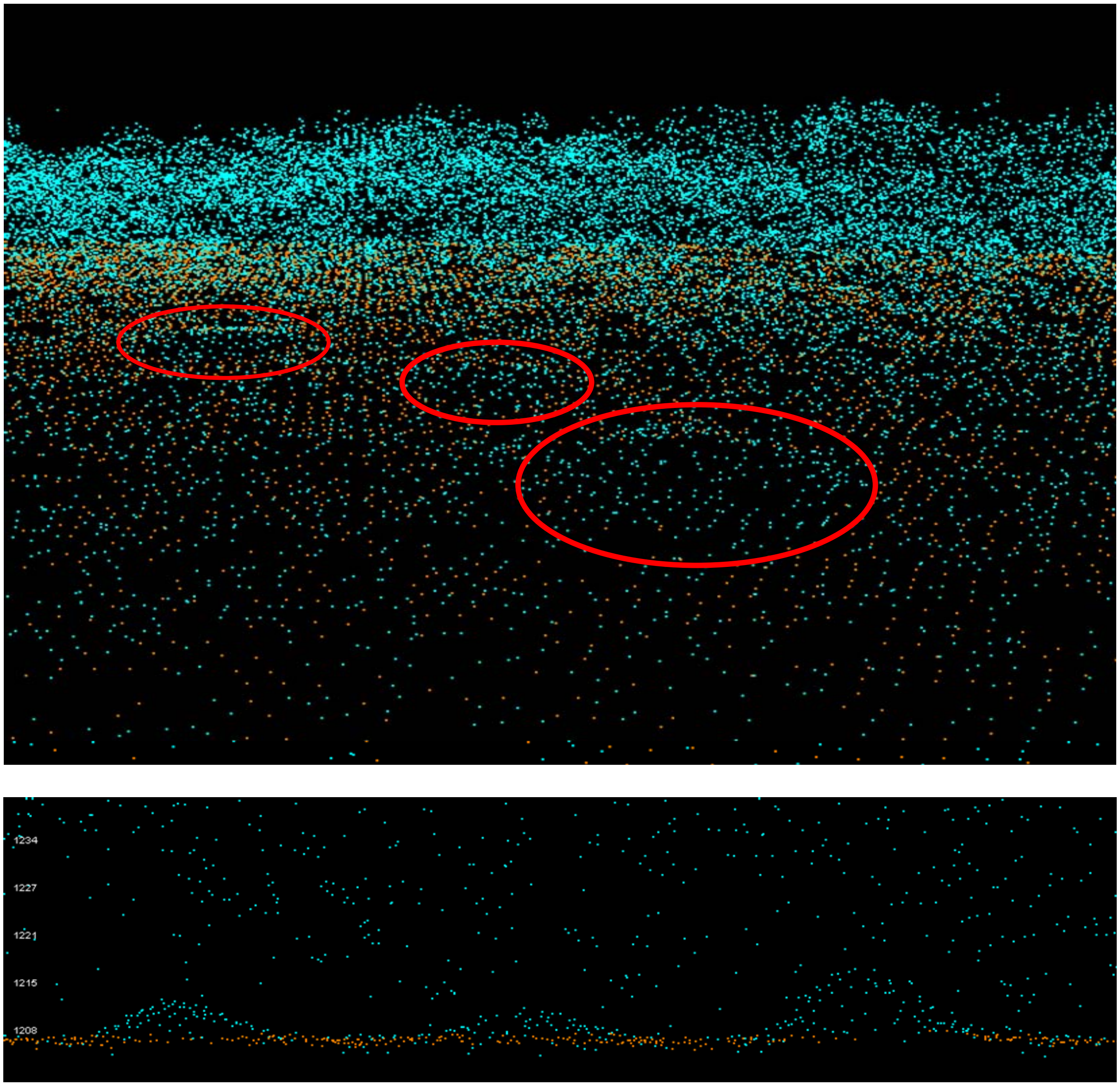

Figure 2.11. Mass point image of same mound group as shown in Figure 2.10. Top: Oblique view of point cloud with blue points classified as non-ground and orange points classified as ground; mounds are delineated in red. Below: Profile of mounds showing their surfaces misclassified as non-ground (blue points).

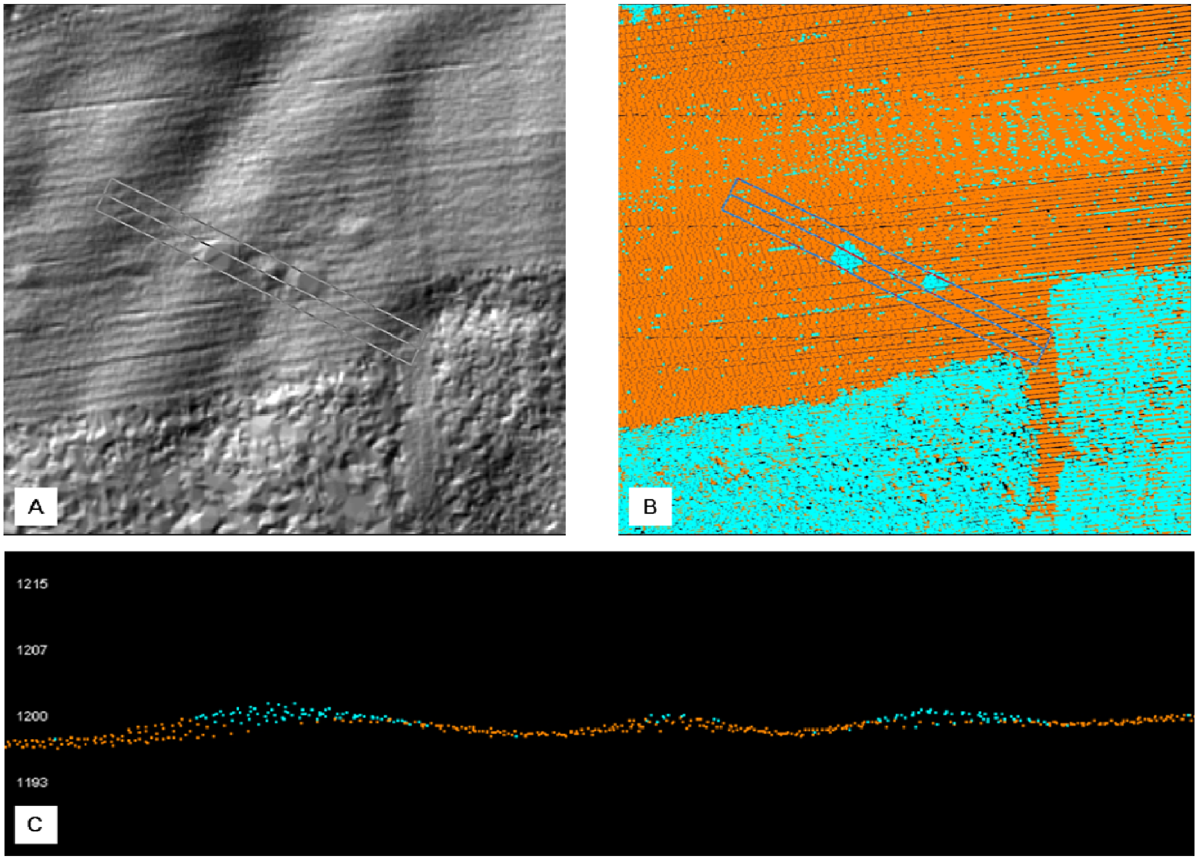

Figure 2.12. Misclassified ground points belonging to site 21CW1 mounds in cultivated field. A) Shaded relief image showing flat, smooth tops of two mounds; B) Mass points image showing mounds classified as non-ground (in blue); C) Profile image of the transect shown in A and B showing tops of low-relief mounds classified as non-ground.

presents LiDAR-generated images documenting the appearance of mounds on shaded relief, 2D BE DEMs or 3D renderings of shaded BE DEMs.

LiDAR analysis detected mounds on 46% (n=37) of the sites, including three letter-sites (21CWt, w, and x) where mounds had not previously been confirmed (Table 2.1). Another 18 sites (23%) were confirmed as having likely been completely destroyed by construction and quarrying, or altered to the extent that only subsurface features are expected to remain. Areas where mounds may have been prone to cultivation were not considered as having a destroyed surface. That designation was reserved for more intrusive disturbances such as construction and quarrying.

Mounds were either not observed or could not be confirmed at the remaining 25 sites (Table 2.1). At 15 sites, the reason involved LiDAR point densities too low to detect mounds if present. The other ten sites had sufficient LiDAR ground data in the sites' vicinities but some of the sites had other circumstances that hindered mound detection. Sites 21CW6 and 21SCak were reported by informants, but archaeologists have not been able to locate 21CW6 in field survey and 21SCak has a discrepancy between the informant's description and map. 21CWae has vague locational information that covers a large area with many developed portions, and the general location of 21CWs could not be identified from available records. Two sites, 21CWad and 21CWr, were reported by Brower as being cultivated, noting that 21CWad was nearly plowed level. The field

Table 2.1. Summary of LiDAR Investigation of 81 Mounds Sites in Crow Wing and Scott Counties.

Site Number	Mounds Detected with LiDAR	Site Destruction Confirmed by LiDAR	No Mounds Observed in LiDAR	No Mounds Detected (Thin Ground Points)
21CW0001	X			
21CW0002	X			
21CW0003				X
21CW0004		X		
21CW0005	X			
21CW0006			X	
21CW7/CW14	X			
21CW0008				X
21CW0010	X			
21CW0011	X			
21CW0013		X		
21CW0016	X			
21CW0020		X		
21CW0024				X
21CW0040		X		
21CW0041	X			
21CW0044	X			
21CW0047	X			
21CW0050	X			
21CW0065	X			
21CW0080		X		
21CW0083	X			
21CW0084	X			
21CW0096	X			
21CW0097	X			
21CW0098	X			
21CW0105	X			
21CW0136	X			
21CW0138		X		
21CW0272	X			
21CWaa				X
21CWab				X
21CWad			X	
21CWae			X	
21CWd			X	
21CWq			X	
21CWr			X	
21CWs			Site Location Unknown	
21CWt	X			
21CWu		X		
21CWv			X	
21CWw	X			
21CWx	X			
21SC0001		X		
21SC0002		X		
21SC0003				X
21SC0004	X			

Table 2.1. Summary of LiDAR Investigation of 81 Mounds Sites in Crow Wing and Scott Counties.

Site Number	Mounds Detected with LiDAR	Site Destruction Confirmed by LiDAR	No Mounds Observed in LiDAR	No Mounds Detected (Thin Ground Points)
21SC0005	X			
21SC0006	X			
21SC0007				X
21SC0008				X
21SC0009	X			
21SC0010				X
21SC0011	X			
21SC0012	X			
21SC0013	X			
21SC0014	X			
21SC0015		X		
21SC0016		X		
21SC0017		X		
21SC0018		X		
21SC0019		X		
21SC0020		X		
21SC0021		X		
21SC0022	X			
21SC0023		X		
21SC0024	X			
21SC0025		X		
21SC0026				X
21SC0027	X			
21SC0028	X			
21SC0029				X
21SC0030				X
21SC0051	X			
21SC0052	X			
21SC0077				X
21SCak			X	
21SCam			X	
21SCx				X
21SCz				X
Total Count	37	18	10	15
Percent	46%	22.5%	12.5%	19%

where 21CWr is recorded was in cultivation in the 1930s and at the present-day so the mounds associated with the site may have also have been plowed level.

In spite of past site destruction and interpretation challenges presented by the datasets, LiDAR analysis detected 285 precontact earthworks at 37 sites, including 279 mounds, 4 nonmound earthworks (at 21CW19, 21SC6, 21SC13, and 21SC27) , and 2 house depressions (at 21CW7 and 21CW105). In a few instances, compound mound features were counted as individual mounds in the MHS archaeological database but were difficult to discern as individual features on LiDAR and were digitized and counted as one feature.

Detection Methods and Confidence. Out of the 285 features detected in the analysis, 122 were designated as archaeological features using shaded relief images alone, 62 with the aid of clipped BE DEMs, 73 with vertical exaggeration and dynamic lighting in a 3D visualization environment, and 28 by visualizing classified mass points in profile and 3D when all other methods were insufficient. The methods used to identify earthen features at each site are tabulated in Table 2.2. Rarely was the shaded relief image alone sufficient to detect all mounds on a site. In examining the data in Table 2.2, keep in mind that the methods become increasingly complex from left to right across the table.

For each mound, the analyst (Riley) recorded her confidence that the LiDAR-identified feature was an actual mound. The level of confidence is a subjective assessment that considers factors such as the clarity of the image in LiDAR, previous maps or descriptions of position and dimensions of the mounds, and the location of the mound on the landscape. As shown in Table 2.2, about three-quarters of the 285 features were identified with a high level of confidence.

Table 2.3 cross tabulates detection method against confidence level. As each site was visited, mounds were first search for in the shaded relief images. Nearly half of the mounds (122 of 285) were identified in this initial stage, and nearly all (n=107) were identified with a high level of confidence. If mounds could not be identified in this first step, the BE DEM was clipped to the area of interest, and examined within a more tightly restrained range of elevation, increasing the contrast of the resultant image. Sixty-two mounds were identified during this second step, 53 with a high level of confidence. Seventy-three mounds (26% of the total) were not identified until the BE DEM had been rendered into a 3-D visualization. The analyst was not as confident in these identifications, because 40% were identified with high, 40% with moderate, and about 20% with low confidence. When identified using mass points (28 mounds), about 19 (70%) were identified with high confidence.

These data, on the surface, indicate that the analyst placed nearly equal confidence in identifications made from shaded-relief images, clipped BE DEMs, or from 3D visualization of mass points and tepid confidence in identification from BE DEM 3D rendering. Of the 29 mounds identified with low confidence, half were identified from 3D visualization of vertically exaggerate terrains. The low confidence of these identifications is somewhat counter-intuitive, because 3D renderings of LiDAR data can produce exceptionally clear visualizations of mounds (e.g., Figure 2.7). However, the level of confidence assigned to each identified mound was more a function of the condition of the LiDAR data, condition of the site, or completeness and clarity of site field maps, rather than the methodology used. If the sites had to be interpreted using 3D rendering and vertical exaggeration, then the shaded relief and clipped BE DEMs were not clear enough to locate or verify all the mounds. The clarity of the images is directly related to the amount of LiDAR ground point data available which can be limited by heavy vegetation, post-flight filtering and the classification methods used in assigning points as ground or not ground. The difficulty in determining features as mounds from noisy images is further compounded when the maps of the mound groups are vague. Some of the sites have been prone to decades of cultivation, leaving very little relief. The 3D rendering and vertical exaggeration of these areas aided in the geovisualization of low mounds that were not readily apparent on a shaded relief image or BE DEM.

It is important to note, however, that 3D visualization was necessary for only about 35% of the mounds. The majority (184 of 285, or 65%) was identified from 2D shaded relief images or clipped BE DEMs, and 87% of these (160 of 184) were identified with high confidence. Hillshading and clipping are relatively simple raster GIS procedures that can be completed using open-source software such as GRASS, whereas 3D rendering requires additional processing capabilities and may require proprietary software, especially when the entire cloud of mass points

Table 2.2. Tabulation of Methods Used to Detect Mounds.

	Number of Mounds Detected by Each Method					Confidence of Detection			
Site Number	**Shaded Relief BE DEM**	**Clipped BE DEM**	**3-D Rendering with Vertical Exag-geration**	**3D Visuali-zation of Mass Points**	**Total Count**	**High**	**Mod-erate**	**Low**	**Total Count**
21CW1	7	3	12	6	28	25	3		28
21CW2			1		1		1		1
21CW5				4	4	4			4
21CW7	18	22	10		50	41	7	2	50
21CW10	4	4	3		11	11			11
21CW11	2	1	1		4	2	1	1	4
21CW16		1		6	7	5	1	1	7
21CW41				1	1			1	1
21CW44			1		1	1			1
21CW47	1				1	1			1
21CW50			4		4			4	4
21CW65	3	1	2		6	6			6
21CW83	4	10	2		16	16			16
21CW84			1		1		1		1
21CW96		1			1		1		1
21CW97	1	3	1	5	10	5	3	2	10
21CW98	2	3	4		9	5	4		9
21CW105	2	5	2	2	11	9	2		11
21CW136	3	1	6	1	11	5	6		11
21CW272	3				3	3			3
21CWt		1			1	1			1
21CWw		1			1		1		1
21CWx	1				1			1	1
21SC4	2		1		3			3	3
21SC5	6	3			9	3	5	1	9
21SC6	3		2		5	2	1	2	5
21SC9	1				1	1			1
21SC11	3	2			5	5			5
21SC12	2				2	2			2
21SC13	7				7	7			7
21SC14	1				1	1			1
21SC22	7		10		17	7	3	7	17
21SC24	6		3		9	5	1	3	9

Table 2.2. Tabulation of Methods Used to Detect Mounds.

	Number of Mounds Detected by Each Method					Confidence of Detection			
Site Number	**Shaded Relief BE DEM**	**Clipped BE DEM**	**3-D Rendering with Vertical Exag-geration**	**3D Visuali-zation of Mass Points**	**Total Count**	**High**	**Mod-erate**	**Low**	**Total Count**
21SC27	25		5	3	33	28	4	1	33
21SC28	6				6	4	2		6
21SC51			2		2		2		2
21SC52	2				2	2			2
Total	122	62	73	28	285	207	49	29	
Percent	42.8%	21.8%	25.6%	9.8%		72.6%	17.2%	10.2%	

Table 2.3. Cross Tabulation of Detection Methods and Confidence.

	High	**Moderate**	**Low**	**Total**
Count				
Shaded Relief BE DEM	107	6	9	122
Clipped BE DEM	53	6	3	62
3-D Rendering with Vertical Exaggeration	28	30	15	73
3D Visualization of Mass Points	19	7	2	28
Total	207	49	29	285
Percentage				
Shaded Relief BE DEM	37.5%	2.1%	3.2%	42.8%
Clipped BE DEM	18.6%	2.1%	1.1%	21.8%
3-D Rendering with Vertical Exaggeration	9.8%	10.5%	5.3%	25.6%
3D Visualization of Mass Points	6.7%	2.5%	0.7%	9.8%
Total	72.6%	17.2%	10.2%	100.0%

is being examined. The success of hillshading and clipping in revealing mounds lends support to the idea that LiDAR can provide a cost-effective and relatively simple means of initially scanning a landscape for mounds.

Comparison with Field Results. Table 2.4 lists sites in the two counties that have been revisited in the last 35 years, and compares the number of mounds identified in the most recent field survey with those detected by LiDAR. This comparison is a test of LiDAR’s ability to replicate data acquired by field survey. Nearly 54% (176 of 324) of the mounds visible in the field at the time of the most recent survey were found with LiDAR data (Table 2.4). LiDAR did not relocate 46% of the previously known earthworks.

Table 2.4. Comparison of Mound Counts from Most Recent and LiDAR Surveys. Shading depicts sites where LiDAR data quality inhibited accurate prospection.

	Most Recent Survey		LiDAR Survey			
Site Number	**Date**	**No. of Mounds**	**No. of Mounds**	**Additional Earthworks Detected by LiDAR**	**Current Land Use**	**Notes on LiDAR Analysis**
21CW1	4/2010*	44	28		cultivation, forest	Much of the area is forested with heavy undergrowth - very few ground points. Other, larger mounds were misclassified as 'non-ground'. Cultivated area expressed very plowed-down mounds not visible in 1972 survey.
21CW3	8/1988	5	0		forest, residential, eroding lake shoreline	Most of area where mounds should be is designated by LiDAR vendor as "obscured area" where heavy vegetation created very few bare earth points - creating questionable integrity of the elevations.
21CW8	7/1999	22	0		residential lots with trees	Mound location is in "obscured area". There are not enough bare earth data points to create a BE DEM that can express the mound group or the general surface geomorphology.
21CW10	4//2010*	20	9		residential with trees and lawn	Much of site area is designated "obscured" by LiDAR vendor, but was also able to detect earthwork between 9 and 10 and modern push pile(?) by Mound 11.
21CW11	6/1978	7	4		residential lots with trees, parkland, cultivation	Mound count includes Jack Smart site and 2 other mounds recorded by Wilford. Smart site was heavily damaged or portions destroyed in 1978. The 1978 survey did not try to relocate one of Wilford's mounds.
21CW16	1/1975	9	7		forest, tree farm	Most of site is in vendor's "obscured area" but a look at the classified mass points show that most of the mounds' points were misclassified as non-ground.
21CW24	4/1978	5	0		residential	Area is close residences and 2 mounds probably too small to interpret from LiDAR. Urbanized areas are not good for mound prospection from BE DEMs. Could not see anything moundlike.
21CW41	11/1978	1	1		residential, forest	Heavily wooded residential area. BE DEM surface very noisy. Mass points suggest linear mound may have trees or shrubs growing out of the mound or just adjacent to it.
21CW44	11/1978	1	1		residential, forest	Found conical moundlike feature near described location; although 133 m, not 100 m, from bluff and not right at drop into marsh as described on site form. Mound is large, ca. 15 m diameter and 1 m high.

Table 2.4. Comparison of Mound Counts from Most Recent and LiDAR Surveys. Shading depicts sites where LiDAR data quality inhibited accurate prospection.

	Most Recent Survey		LiDAR Survey			
Site Number	**Date**	**No. of Mounds**	**No. of Mounds**	**Additional Earthworks Detected by LiDAR**	**Current Land Use**	**Notes on LiDAR Analysis**
21CW47	5/1978	1	1	0	cultivation	Subtle depression north and almost adjacent to mound. Could be noise from isolated tree.
21CW50	5/1978	3	3	1	forest	No mound site map was available - checked all of knoll west of boat launch and found 4 possible mounds (only 3 were recorded) - all small and low relief. Larger depression just west of potential mounds.
21CW65	10//2002	6	6		forest, cultivation	LiDAR was very good, but still difficult in the wooded areas. Located 9-m diameter mounds in the woods though. Mound in cultivated area has field-measured height of less than 1 ft.
21CW80	3/1979	4	0		cultivation, building site	A large structure has been built over the 3-mound area mapped by Birk (1979) and the 4th mound location description falls near a new driveway. Surface is heavily disturbed surrounding the reported mounds areas.
21CW83	5/1986	22	16		cultivation, forest, residential	Area has been disturbed by highway construction and cultivation. Far east group of the Gordon mounds were not detectable, only 2.5 mounds were visible there in 2001, which may be located in the dense stand of trees.
21CW84	11/1974	1	1		forest	Dense wooded area which made finding reported mound almost impossible - needed to rely on site maps.
21CW96	4//2010*	1	1		forest, recreation	Heavily wooded with conifers. Could only see elevation trend on clipped BE DEM in vicinity of reported mound that matched size description of mound.
21CW97	4/2010*	26	10		forest	Many extant mounds are in vendor designated "obscured area". Tree cover over the obscured area seems no denser than the southern side of the site where mounds were detected, heavy underbrush though.
21CW98	11/1985	25	9		forest, residential	25 mounds are still visible in latest field report. Combination of heavy vegetation and misclassified mass points inhibited interpretation, this area was very hard to see anything.
21CW105	5/1991	12	9	2	forest, cultivation, road	Nine out of twelve mounds reported for the site could be detected, plus one south of the site and one possibly within site not previously reported. Mature oaks and heavily vegetated understory, some trees growing in the mounds. Mass points show some mound points were misclassified.

Table 2.4. Comparison of Mound Counts from Most Recent and LiDAR Surveys. Shading depicts sites where LiDAR data quality inhibited accurate prospection.

	Most Recent Survey		LiDAR Survey			
Site Number	Date	No. of Mounds	No. of Mounds	Additional Earthworks Detected by LiDAR	Current Land Use	Notes on LiDAR Analysis
21CW272	5/2008	3	3		forest, residential	Mounds are a little disturbed, but large.
21SC3	10/2001	7	0		cultivation, forest, road	Area has been heavily cultivated and is flat therefore many points were filtered out; could not determine mounds even with 3D visualization - not enough point data and/or all mounds are cultivated to ground level.
21SC4	5/2010*	5	3		forest; past cultivation	Rugged terrain, so vendor retained enough ground points to allow possible mound detection.
21SC5	5/2010*	11	6	3	cultivation, pasture, forest	Three of the detected mounds are not from original Lewis group. They were identified in a later field visit but have not been confirmed by subsurface probing.
21SC6	1/1975	3	4		pasture, forest	Possible earthwork remnant (Lewis' approach to mound 1) was also visible; very few data points in area of mound 2 so it was barely detectable.
21SC7	6/1975	1	0		forest	Could not locate.
21SC10	6/1975	1	0		forest, pasture	Could not find mound around farm described in site file; found moundlike feature northwest of farm in SW1/4 SW1/4 Section 19 but is much larger than Lewis' mound. Assigned as 21SCOSA1.
21SC11	11/2006	4	5	1	cultivation, forest	One of the mounds is not from original Lewis group and has not been field verified; not enough data points in cultivated area for low-relief mound detection; all detected mounds in forest.
21SC12	5/2010*	2	2		cultivation, forest	Mound site is in NE1/4 NE1/4 section 24. Site form and Lewis notes stated NW1/4 NW1/4 section 19.
21SC13	11/2006	6	6		forest, pasture	One of the two earthworks reported by Lewis was also visible.
21SC14	5/2010*	1	1		forest	This mound was presumed destroyed by road in a 1975 site record. The topography in the Lewis map, however, indicates that the mound should be on the other side of the ravine from the road mentioned in the 1975 site record.
21SC24	5/2010*	12	9		residential, commercial, highway, pasture, forest	Dense data points around highway, but area over mounds is very thin.

Table 2.4. Comparison of Mound Counts from Most Recent and LiDAR Surveys. Shading depicts sites where LiDAR data quality inhibited accurate prospection.

	Most Recent Survey		LiDAR Survey			
Site Number	**Date**	**No. of Mounds**	**No. of Mounds**	**Additional Earthworks Detected by LiDAR**	**Current Land Use**	**Notes on LiDAR Analysis**
21SC27	5/2000	33	27	5	parkland	Did not locate mound 5 or 27, but additional 5 not mapped by Lewis may be mounds. Earthwork also located (not included in the count).
21SC29	10/1975	5	0		trail, forest, railroad	Point density is too thin (average spacing about 4.0 m) to pick up the 5 mound remnants noted in a 1975 visit.
21SC30	10/1975	9	0		sand and gravel mining; forest; parkland; road	Point density too thin for interpretation of possible remaining mounds.
21SC51	4/1995	2	2		residential, pasture	Site is in residential area; very sparse point density due to heavy thinning of urban setting; would not have identified mounds without the aid of the site file map.
21SC52	8/1997	3	2		oak savannah restoration	Many moundlike but natural features are showing up on the LiDAR.
21SC77	12/2001	1	0		forest, Metro Sewer Board property	Point density too thin to create a DEM depicting a mound. Could see linear spoil pile mentioned in site form and plotted plausible mound location based on measurements given from spoil pile.
Total		324	176			

* see Chapter 3, this volume.

As documented in the table's "Notes" column, LiDAR indicates that mounds at some sites had been destroyed since the last survey (e.g., 21CW11, 21CW80), but the major factor in the failure of LiDAR to detect mounds appears to be due to low point density in the available LiDAR data. At the 21 sites where LiDAR data quality was an issue (shaded gray in Table 2.4), LiDAR detected only 46% of the mounds (111 of 236). In contrast, at the 16 sites where LiDAR data quality was not an issue, LiDAR prospection identified 74% of the features (65 of 88).

Poor data quality was due to a number of factors. Some sites (e.g., CW8) are located in the far-eastern part of Crow Wing County that the LiDAR vendor identified as Obscured Areas (Figure 2.4) where ground point density was acknowledged to be below specifications. At other sites, such as 21CW1, post-processing algorithms had misclassified large mounds as non-ground points (Figure 2.11). At 21CW24, a combination of the recorded mounds being small and low, and modern buildings being close together, made it difficult to interpret topography in the intervening ground surfaces. Although the close spacing of buildings increases the likelihood that the mounds have been destroyed, this could not be conclusively confirmed from LiDAR alone.

New Mounds and Possible Mounds. Despite problems in detecting known mounds, the LiDAR survey resulted in the location of 12, previously unnoticed mound-like features at 21CW50, 21CW105, 21SC5, 21SC11, and 21SC27. In addition, at several sites including 21CW44 and 21CW50 (Table 2.4), LiDAR made it possible to expand the search radius and locate mounds at distances away from their previously recorded locations.

Five previously unrecorded, prospective mound sites were detected by UI-OSA in the course of the LiDAR analysis. These are designated 21SCOSA1 and 21CWOSA2–5. One of these, 21CWOSA4, was field checked and determined to be semi-submerged natural features, not an archaeological site (see Chapter 3), although this was not confirmed by subsurface probing. Deep water rendered the features inaccessible. Another (21CWOSA2) is a possible lodge depression (Appendix D, Figure D41 and D42).

Automated LiDAR Survey. As part of Task B, UI-OSA (2009) proposed scanning the LiDAR data from both counties using a prototype mound detection model developed by Riley (2009). The model was developed to be used with BE DEMs produced from the classed bare-earth point data returned by the LiDAR surveys. The model automatically scans BE DEMs looking for surface features having the diameter, height, and hemispherical cross section of burial mounds. The extensive thinning of points from the LiDAR datasets obtained from both counties had the effect of eliminating or altering low-relief features such as mounds. Automatic detection of mounds with such data sets is problematic and the model was not employed in this project.

TASK C: CREATE GIS DATASETS AND MAPS

Task C was completed in conjunction with portions of Tasks A and B. Its purpose was to create GIS and cartographic products documenting the results of the project. As each site was visited, several GIS files were populated or edited. Figure 2.13 depicts the files created and their interrelationships. Tables in Appendix B present the data stored in each file.

During Tasks A and B, the files were stored in an ArcGIS 9.3.1 geodatabase (see Glossary) that allowed UI-OSA to strictly define and enforce the relationships among files. At the conclusion of the project, aware that the Mn-OSA currently uses an earlier version of ArcGIS, the geodatabase feature classes were exported to stand alone shapefiles, and the stand alone tables were exported to table into a format that can be imported into ArcGIS as well as Microsoft Access, which the Mn-OSA also uses for data management.

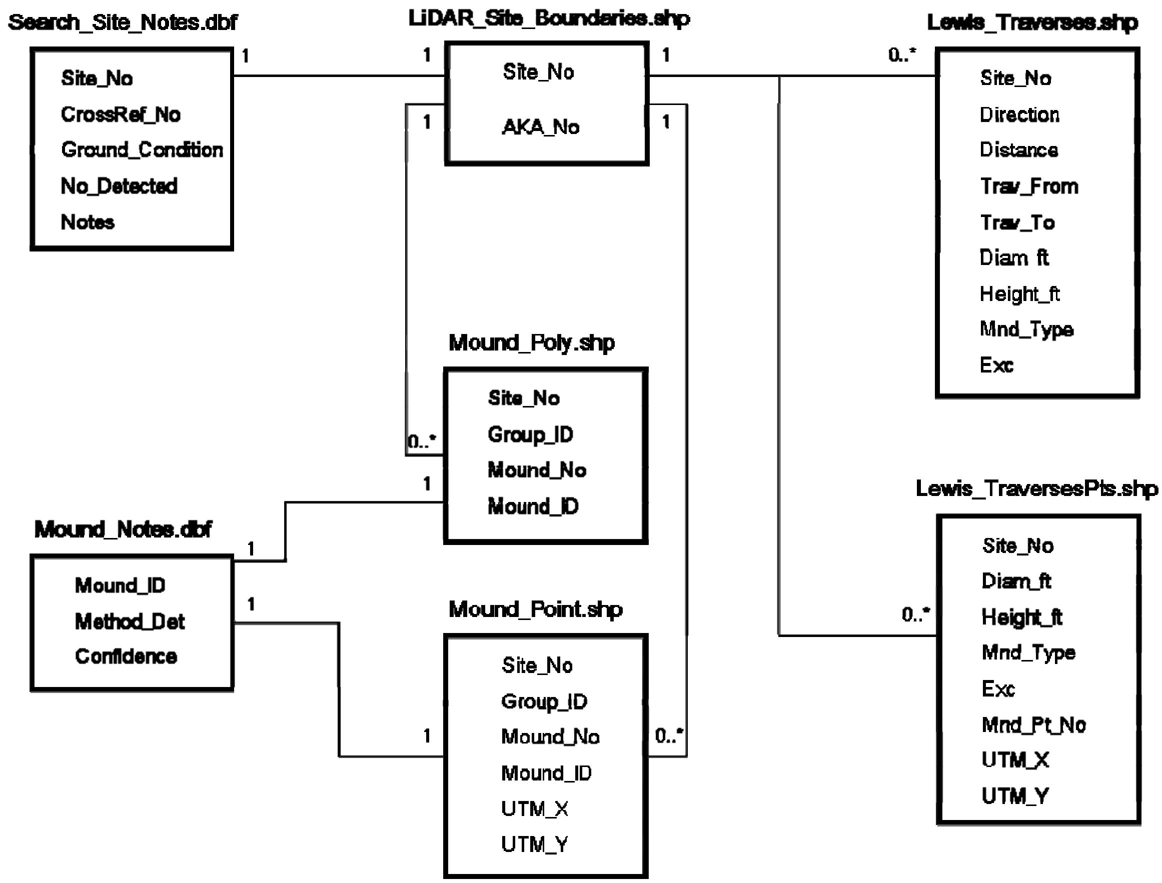

Figure 2.13. Entity-Relationship diagram of GIS datasets created for this project.

A polyline and a point shapefile store the T.H. Lewis survey traverses and mound locations, respectively (Figure 2.13; Appendix B, Tables B1–B2). The structure of the shapefile data tables were discussed under Task A, above.

Site boundaries were digitized in a polygon feature class, LiDAR_Site_Boundaries. The boundaries were determined by cross-referencing LiDAR-detected mounds with scaled field maps, or by using maps depicting surrounding topography and features such as roads to determine boundaries that would be inclusive of mounds not detectable with LiDAR data. Site boundaries determined entirely from LiDAR-based mound locations were drawn to encompass only areas occupied by mounds and other earthworks. They do not include artifact scatters identified in site records as part of the site if specific locational information or a good field map of the scatters was not available.

For sites where no mounds were found on LiDAR, field sketches from Lewis, Brower and more-recent surveys still aided in delimiting site boundaries, because topographic features depicted on the earlier site maps could be found on LiDAR imagery. A few letter sites where no mounds were found were not modified from the generalized boundaries depicted on topographic maps in the site file.

The attribute table of the LiDAR_Site_Boundaries shapefile, not included in Appendix B, has only two fields, one for site number and one for cross-reference, or “also known as” (AKA), site numbers. The latter field is used for mound sites that are spatially intertwined and have two site numbers. Five site numbers with the prefix ‘OSA’ are potential new sites that were detected by UI-OSA on LiDAR.

The LIDAR_Site_Boundaries file is linked by Site Number to a stand-alone table, Search_Site_Notes.dbf (Figure 2.13). The table contains the attributes cross-reference number, ground condition, number of mounds detected, and site search notes (Table B3). The ground condition attribute is coded as follows:

C – cultivated
F – forest
PK – parkland
P – pasture/lawn
Res – residential
U – urbanized
SD – surface destroyed as seen in LiDAR
RD – recorded destroyed by previous survey.

A more-comprehensive description of current land use is available in the Mound Field Survey Assessment table (Table 2.4) which also includes the following attributes: original survey date, original surveyor, number of mounds originally recorded, number of mounds currently visible, date of recent survey, reason for recent survey, name of recent surveyor, recent detailed map (Y, N), burial authenticated (Y, N) and need for resurvey (Y, N). This table can also be linked to the LiDAR Site Boundaries shapefile and Search Site Notes table by site number.

The Mound_Poly polygon shapefile stores the 299 earthworks detected from the LiDAR analysis (Figure 2.13). Attributes of this file are site number, mound number, group ID and mound ID (Table B4). Mound number, when possible, corresponds to field surveys where the mounds were numbered on a map. Most such surveys were either by Lewis or surveys conducted since the 1980s. Group number was used for sites where clusters of mounds within one site where assigned a group designation for each cluster. The only instance of group designation for this project was 21CW1. Mound ID is a concatenation of site number, group ID, and mound ID, with an alpha modifier of M for mound, EW for earthwork, DP for depression and PP for a single instance at 21CW10, where a mound-like feature found during a field survey was inconclusive of whether it was a construction-related push pile or mound. The concatenated ID is intended to give each mound a unique alphanumeric identification that also encapsulates the most pertinent information about its site, intrasite number, and feature type.

Where no numbering system from a previous field survey was available, Mound_No numbers were assigned. If a site had an established numbering system, but more mounds were detected on LiDAR than in the field survey, the new mounds were given an upper case alphabetic character as a designator. This worked well until site 21SC27 was encountered where a recent field survey used Lewis’ numbering system and assigned their own alpha designators to mounds they found and Lewis did not. More potential mounds were found on LiDAR in addition to the mounds that the latest field investigation found, so the alpha designators LA, LB, LC, and so forth, were assigned, where “L” stands for “LiDAR,” to indicate the originator of their identifier.

Mound_Points is a point shapefile of the centroid of each mound polygon. It contains the same attributes as Mound_Poly.shp, as well as the x and y coordinates of the centroid in NAD 83 UTM 15N meters (Table B5).

Mound_Notes.dbf (Table B6) is a stand-alone table that is can be linked to Mound_Poly and Mound_Points by the Mound ID field. Attributes stored in the Mound_Notes table include the method used for identifying the mound. The Method_Det attribute is coded as follows:

HLSHD – hillshade or shaded relief image
BE DEM – clipped BE DEM

VE – vertical exaggeration, 3D rendering
MP – mass points

The Confidence attribute, coded Low, Moderate, and High, denotes the level of confidence that the feature detected is an archaeological feature. The confidence and method of detection attributes are discussed at length under Task B, above, and tabulated in Table 2.2. Initially an attribute field was set for mound damage visible on LiDAR but neither county's dataset was suitable for consistently detecting damage, such as potholes, so it was omitted.

Topographic maps delimiting site boundaries at 1:10,000 were created on base maps of USGS 7.5 min. quadrangles (Appendix C). A 2D shaded relief map of the BE DEM was created for each site where mound features were located, with a color aerial photo inset at a smaller scale (Appendix D). If the 2D shaded relief did not adequately bring out the mounds, a 3D site map or BE DEM map was created to better display the mounds.

TASK D: INTERPRET RETURN INTENSITY DATA

Return intensity is the strength of the return pulse of the near-infrared laser beam. When displayed as a grayscale raster, with shades getting darker with decreasing return intensity, the resultant image resembles a black and white aerial photo (Figure 2.14). In the near-infrared spectrum, landforms or features that differ from the surrounding terrain in terms of soil properties such as moisture-retention or organic carbon content are sometimes detectable as tonal differences in the return intensity images. Riley (2010) used return intensity images to detect Late Prehistoric earthlodges in southwestern Iowa, which were visible because of the moister and more organic soils formed in the house depressions.

Scott County did not obtain return intensity data. Return intensity was stored in Crow Wing County's LAS files but neither the county nor the vendor had created return intensity images. UI-OSA used these data to create return intensity rasters using the LP360 software. The images have a minimum nominal resolution of 1.5 m, determined from the spacing of points used to create the images.

We were able to apply this method to only a small area of Crow Wing County, because most of the county's sites are located in woods. At nine sites, however, mounds are known to have formerly existed in areas that are now cultivated or pastured. At these sites, remnants of mounds were visible on the shaded relief images, and therefore not completely plowed down. The intensity signature for these features was no different than the surrounding surface, and therefore return intensity failed to detect them. The return intensity analysis was also applied to letter site 21CWr. The site was considered a good candidate for this task because it was in cultivation during Jacob Brower's visit and continues to be in cultivation to this day. Shaded relief images showed no indication of the mound group, either by vertical exaggeration of the BE DEM or by viewing the mass points in vertically-exaggerated 3D or in profile.

A 1.5 m return intensity image was created for the area and it too did not show any stains where the mounds once were. The sample size and the image resolution for this task was not sufficient to conclude either way on the usefulness of return intensity data for detecting mound features that had been cultivated level with the surrounding surface. Since mounds are often built with soils from the surrounding area, the soils of plowed down or leveled mounds may not differ from adjacent areas in terms of properties such as soil moisture to which near-infrared images are sensitive. Although the sample size is too small to be conclusive, the present study indicates that return intensity may not be of great utility in mound prospection.

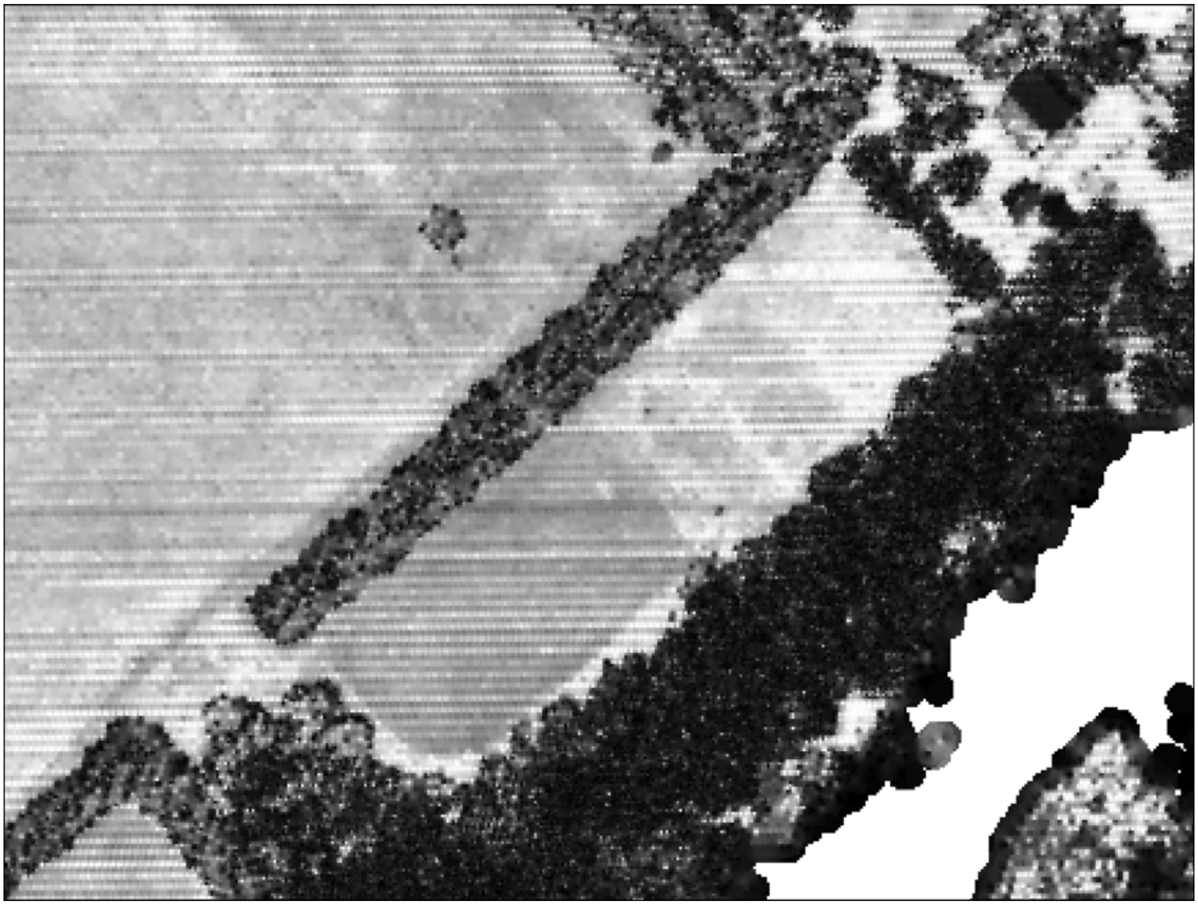

Figure 2.14. Return intensity image of 21CWr reported by Brower to have had a mound group.

DISCUSSION

Utility of Early Maps in the GIS Environment

The early maps by Lewis and Brower, as well as Winchell's reproduction of Lewis' maps, are important historical references for the study of mounds in Minnesota. Lewis' and Brower's records are the first and sometimes only reference to hundreds of sites. However, these data sources are limited in their usefulness in a GIS-based study such as this one. Brower's and Winchell's maps were not included in this project's georeferencing tasks. Although essential context for mound sites, these maps cannot be brought into a GIS by techniques truly compatible with the technology. Lewis' detailed traverse notes can be used directly in GIS via COGO methods. If tied to a known, still-extant benchmark, such as a section corner, or in one case in this study, a railroad culvert, Lewis' mounds can be located independently of his cartographic representations. Reference points to orient and scale Brower's and Winchell's maps must be selected from the cartography, and there is no reliable way to estimate the accuracy of the location. Lewis traverses, on the other land, can often be more successfully overlain on maps that also plot LiDAR, GPS, and total station data, and can be used to visualize and quantify differences between Lewis' survey results and those of modern technology, as maps in this report that plot Lewis' traverses show.

However, there are a few caveats associated with accuracy assessment of Lewis' surveys. The first challenge in this project to using Lewis's surveys was to place the traverse origin in a more-precise location than what is given in Lewis' notes. If none of the site's traverse data points were extant, or the notes and sketches did not contain distances from landscape features, then it was up to the discretion of the LiDAR interpreter where to place and rotate the traverse.

When Lewis data point features were visible on LiDAR, the traverses could be oriented to those features. However, the longer the traverse, the more difficult it was to line up the courses exactly with their respective mounds and some averaging was necessary. This was somewhat anticipated as Lewis' distances were reported only to 15-30 cm (0.5–1 ft) precision and bearings generally to 0.5°. As recognized by Dobbs (1991), over long traverses within a site, an accumulation of error can occur due to this level of precision. Unfortunately, only a cluster of a few mounds survived for some of these long mound groups, so no LiDAR assessment could be made on how much this error can accumulate from one end of a site traverse to the other. For small mound sites or sites where mounds were clustered and required many, shorter traverses, the relative error between mounds was minimal because there was less opportunity for accumulation of error over the shorter distances.

Assessing the accuracy of Lewis' traverses for this project is difficult due to the lack of origin information, the subjectivity of placement by the interpreter, the variable accuracy and precision of the GPS device, and a small site sample (n=4) that did not contain a large site with extant mounds on each end of the traverse length. At site 21SC12, the distances between the Lewis points and the field survey GPS points at the two extant mounds were 1.5 m (5 ft) and 3 m (10 ft). At a larger site, 21SC5, the distance between field points and Lewis points varied from 2.3–4.6 m (7.5–15 ft) at mounds 23, 25 and 26 to 5.2–6.7 m (17–22 ft) at mounds 15, 16 and 18. At site 21SC24, distances for 8 of the 9 mounds were 3–5.2 m (10–17 ft) with one outlier at 10 m (30 ft). Site 21SC4 is difficult to assess because the field survey was inconclusive on whether small rises were mounds or natural features.

LiDAR Data Quality and Mound Prospection

As previously discussed under "Comparison with Field Results," above, LiDAR data quality adversely affected the results of the LiDAR analysis. The present section continues that discussion by identifying the specific problems with the available Crow Wing and Scott county LiDAR data. Of relevance to mound detection is the density of ground points used to construct the BE DEM. For a given AOI (e.g., a site, or an area within a site), the LiDAR LAS files can be examined to determine the total number of points obtained for that area, and calculate the total return point density in points per m^2. A subset of the total return points reach the ground surface and these can be used to calculate a ground point density in points per m^2. Alternatively, area in m^2 can be divided by the number of points, deriving a density expressed as m^2 per point. This method of expressing point density is used in this analysis.

For this analysis, we selected a sample of 13 sites in Crow Wing County that we felt were the best candidates for examining the effect of ground point density on mound detection. Sites were selected based on following criteria: high locational confidence for mounds at the site as a whole, multiple mounds observed on the ground in the last 40 years, and sites where large mounds are known to be present but could not be delimited through interpretation of shaded relief images alone. Total point and ground point densities for these sites are presented in Table 2.5.

Table 2.5. Variability in LiDAR Point Density with Ground Cover on a Sample of 13 Sites.

Site Number and AOI	Ground Cover	AOI (m2)	Total AOI Point Count	% Ground Points	Total Points (m2 per point)	Ground Points (m2 per point)	Location in County	Data Quality Issue	Notes
Field Ground Cover									
21CW1	Field	75668	59483	ca. 100%	1.27		Central	None	Can see mounds with relief as minimal as 24 cm on hillshade image; mounds classed as non-ground 30 - 45 cm (1 – 1.5 ft) high outside analysis AOI.
21CW7	Field	12138	5788	ca. 100%	2.10		West	None	Some plowed-down mounds in field are faint on hillshade, but distinguishable on BE DEM and 3D rendering with vertical exaggeration.
21CW105	Field	1765	1235	ca. 100%	1.43		West	None	Unconfirmed mound is very clear in field just south of official CW105 location.
21CW65 (field portion)	Field	3709	2403	ca. 100%	1.54		West	None	Only mound in open area was very clear; forested AOI (see below) had many misclassed ground/mound points.
Summary Statistics				**Mean**	**1.59**				
				Minimum	**1.27**				
				Maximum	**2.10**				
Forest and Parkland Ground Cover									
21CW1	Forest	113699	147953	17%	0.77	4.55	Central	Misclassification	The cause of most mounds not located by BE DEM clipping, 3D rendering or hillshade was due to misclassed ground points on the mounds; two mounds misclassed in open field.
21CW3	Forest	4858	4397	12%	1.1	8.85	West	Tree Cover	The few ground points are clustered primarily in residential driveways and some lawn area; zero out of five mounds detected.
21CW5 (forest)	Forest	33542	38997	5%	0.86	16.03	East	Tree Cover	No mounds detected in forested AOI.
21CW5 (parkland)	Parkland	7403	6350	51%	1.17	2.27	East	Misclassification	Shaded relief image very noisy even in open forest area, needed other methods for detection including mass points.

Table 2.5. Variability in LiDAR Point Density with Ground Cover on a Sample of 13 Sites.

Site Number and AOI	Ground Cover	AOI (m2)	Total AOI Point Count	% Ground Points	Total Points (m2 per point)	Ground Points (m2 per point)	Location in County	Data Quality Issue	Notes
21CW7	Forest	18181	14758	26%	1.23	4.72	West	Misclassification	Could see on hillshade some linear trend with long embankments in the treed area but was not consistent.
21CW8	Forest	15599	16179	7%	0.96	14.75	East	Tree Cover	No mounds detected in forested AOI.
21CW16	Forest	22875	42664	11%	0.54	4.92	Central	Tree Cover, Misclassification	Point density is misleading - ground points are very clustered with large gaps in between. Hillshade was very poor for mound prospection.
21CW41	Forest	22408	26434	28%	0.85	3.06	West	Tree Cover, Misclassification	Detected a mound-like feature with mass points (low confidence) in the area; most of this feature does not have ground points due to shrubs and trees growing on or along the feature.
21CW65 (heavily forested)	Forest	7067	7159	10%	0.99	9.68	West	Tree Cover, Misclassification	This area shows significant increase in tree cover - same total point density as mound area to east, but much less point density at ground level.
21CW65 (lightly forested)	Forest	2802	2874	20%	0.97	4.94	West	Misclassification	OK ground coverage over most mounds in trees - quickly declines west of the main group; half of mounds identified by BE DEM or vertical exaggeration.
21CW83 (Mound 6)	Forest	2555	3252	31%	0.79	2.56	Central	Misclassification	Needed BE DEM clipped and 3D rendering of bare-earth to make determination of some mounds and mound boundaries. Can slightly see linear pattern of long embankments on hillshade.
21CW83 (Mounds 11-16)	Forest	8033	11507	26%	0.7	2.68	Central	Misclassification	Needed BE DEM clipped and 3D rendering of bare-earth to make determination of some mounds and mound boundaries. Can slightly see linear pattern of long embankments on hillshade.

Table 2.5. Variability in LiDAR Point Density with Ground Cover on a Sample of 13 Sites.

Site Number and AOI	Ground Cover	AOI (m2)	Total AOI Point Count	% Ground Points	Total Points (m2 per point)	Ground Points (m2 per point)	Location in County	Data Quality Issue	Notes
21CW83 (Mounds 1-5)	Forest	6002	8812	29%	0.68	2.35	Central	Misclassification	Needed BE DEM clipped and 3D rendering of bare-earth to make determination of some mounds and mound boundaries. Can see linear pattern of most long embankments on hillshade.
21CW97	Forest	15913	17534	24%	0.91	3.72	Central	Misclassification	Only one decipherable on hillshade. Half of mounds found by LiDAR was thru mass points.
21CW98	Forest	11697	17090	16%	0.68	4.17	Central	Tree Cover, Misclassification	Two mounds decipherable on hillshade with help of site map, the rest delimited with BE DEM and 3D rendering.
21CW105	Forest	6334	8722	28%	0.73	2.55	West	Misclassification	Could not detect most mounds by hillshade but could locate on BE DEM and with vertical exaggeration; some with mass points.
21CW136	Forest	9420	13919	21%	0.68	3.27	Central	Tree Cover, Misclassification	Detection of large mounds nearly impossible using hillshade.
Summary Statistics			**Mean**	**21%**	**0.86**	**5.59**			
			Minimum	**5%**	**0.54**	**2.27**			
			Maximum	**51%**	**1.23**	**16.03**			

Ground cover is noted, as is the general location of the site in the west, central, and eastern thirds of the county, the eastern part of the county having the lowest point densities due to late season survey (Figure 2.4). Notes are presented on point classification and dense vegetation problems.

For sites 21CW5, 21CW65, and 21CW83, calculations were made for more than one intrasite AOI, allowing comparison of different ground cover conditions within the same site and to check if there was significant variability of ground points over a large mound site area with homogenous vegetation. Forest, open field, and parkland land cover were considered in the analysis. Open field AOIs are presented separately from forest and open field covers. In open fields, because few above ground obstructions are available, total point and ground point densities are considered the same for purposes of this analysis.

As shown by summary statistics in Table 2.5, point density differs markedly with ground cover, from average ground point density of 1 point per 1.6 m^2 in open fields to 1 point per 5.6 m^2 in forested terrains. Frequency distributions of ground point densities under forest and open field ground cover are almost non-overlapping (Figure 2.15), and the range of ground point density is much greater in forest than open terrain. If points were evenly spaced on a 5.6 m grid, a 10 m diameter mound with an area of 78.5 m^2 would collect elevations from 1–4 points (Figure 2.16). Points spaced 1.6 m apart, would collect 30–32 elevation measurements, giving a much better image in a shaded relief or 3D rendering. Ground point densities of 9–16 m, at the extremes of the frequency distribution (Figure 2.15) would have produced a BE DEM with little utility for detecting mounds.

Two examples illustrate the problems caused by low ground point density. On a shaded relief image, the Gordon-Schaust embankments (21CW83) are difficult to discern, even though the linear features are 20–144 m long and 7–9 m wide (Figure 2.17, top). The features required the use of clipped BE DEMs at 3x vertical exaggeration to delimit them (Figure 2.17, bottom). The ground point density of the embankment areas, all in trees, is relatively consistent with one point per 2.35–2.68 m^2 or 0.4263–0.3735 points per m^2. Other forested sites in the analysis with ground point densities as sparse as one point per 4.94 m^2 could be interpreted by clipped BE DEMs or 3D rendering/vertical exaggeration methods. At this density, however, the identification of mounds also relies on the luck of some ground points being clustered in the location of a mound.

At 21CW65, the presence of three different ground covers provides insights into the effect of intrasite variation in ground point density on mound prospection. One mound is located in the densely forested portion of the AOI, one is entirely in the field, three are in less–dense tree cover, and one is on the field edge (Figure 2.18).

The south part of the site is a cultivated field, the north part is forested with canopy densities increasing from east to west. Within a site area of only 8,900 m^2, ground point density decreases from 1 point per 1.27 m^2 in the field, to 1 per 4.94 m^2 in the east part of the forest, to 1 per 9.68 m^2 in the west portion of the forest (Figure 2.18). While some of the mound ground points in the forest AOI were misclassified as nonground, the sudden ground point density decrease immediately to the west is largely attributed to thicker vegetation. The mound at the west end of the site was detected by a fortuitous group of ground points clustered over the mound, many misclassified.

Overall, in order to identify possible mounds on a shaded relief image without the aid of a field map, ground point densities of 1 point per 1.25–2 m^2, similar to the open areas, would be desirable; however this density may be difficult to maintain given that vegetation type (i.e., coniferous vs. deciduous) and density can change significantly in just a small area.

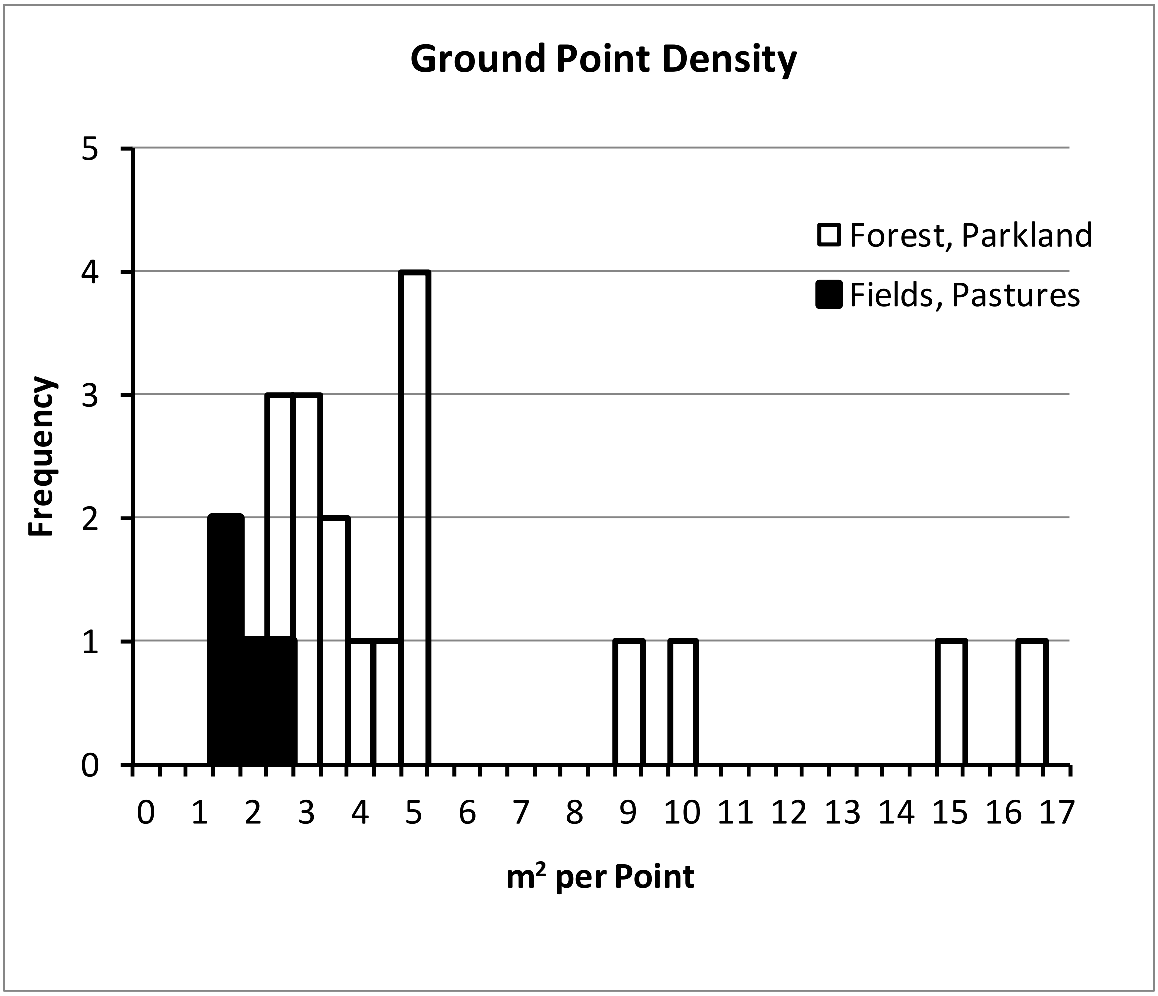

Figure 2.15. Histogram of the frequency distribution of ground point density between forested and open areas.

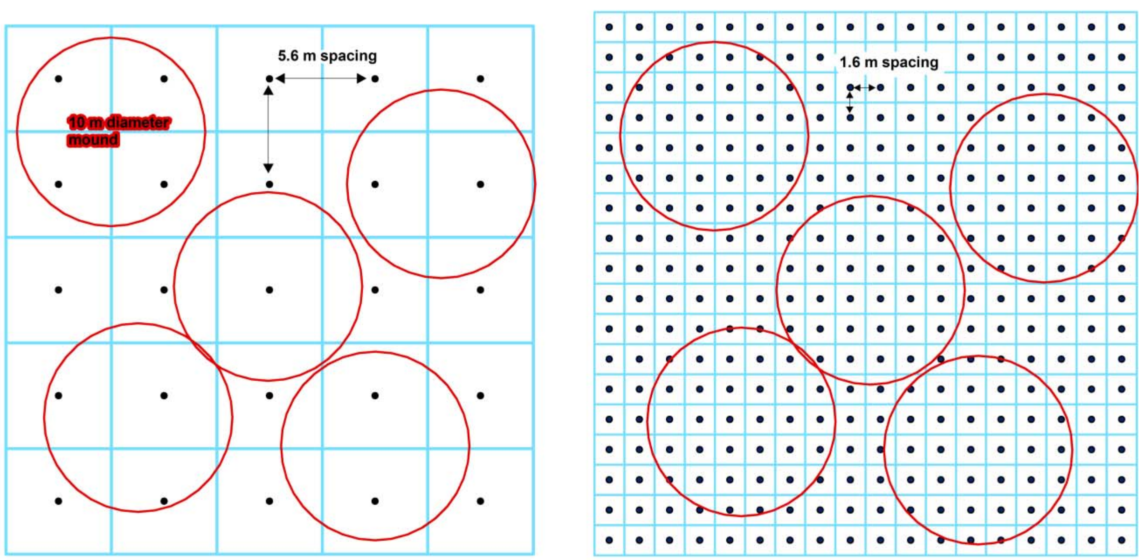

Figure 2.16. Illustration of the impact different point densities have with elevation data coverage over the area of a 10m-diameter mound.

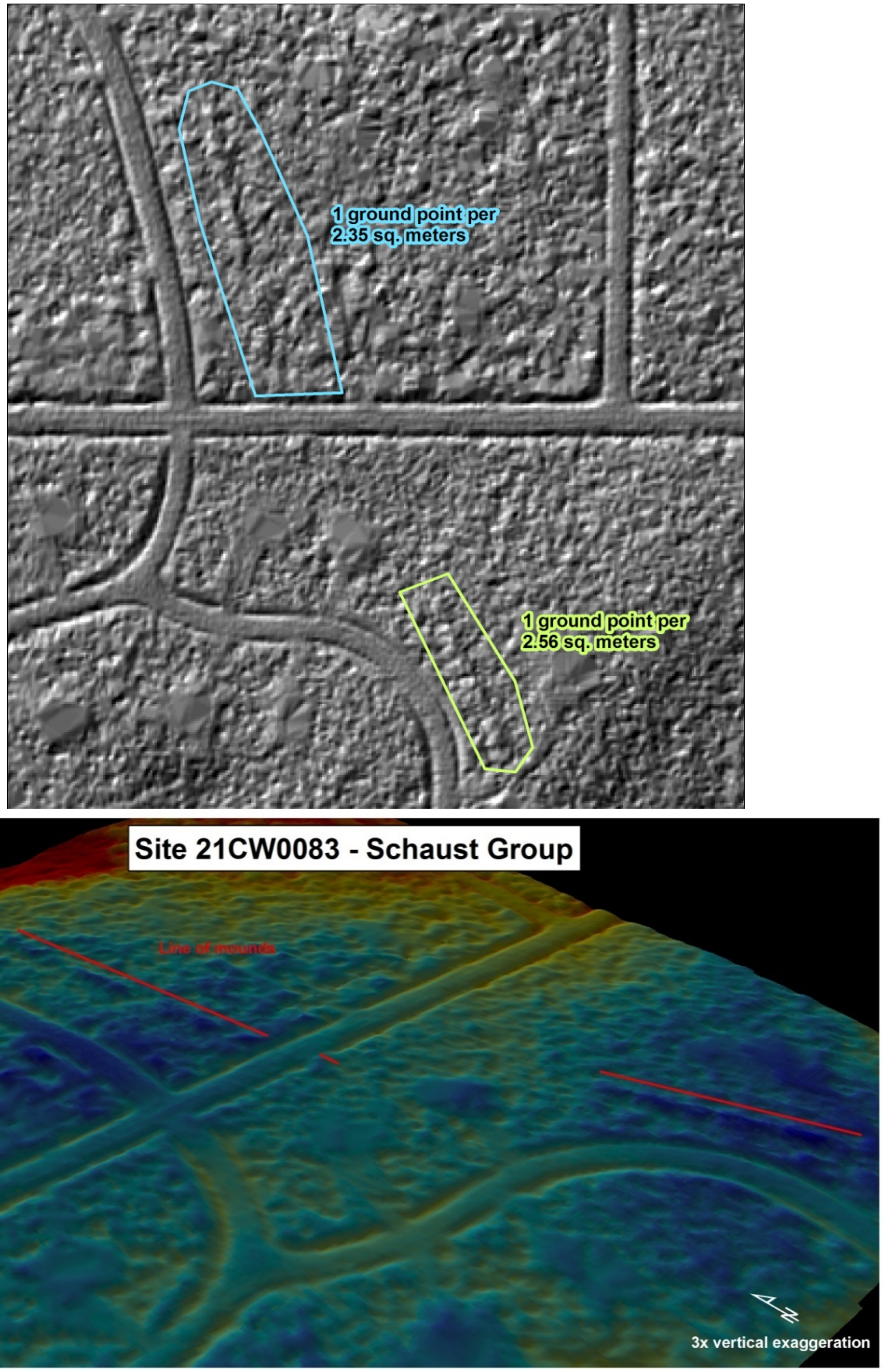

Figure 2.17. Portion of the Gordon-Schaust embankment. Top: shaded relief image. Bottom: 3D rendering.

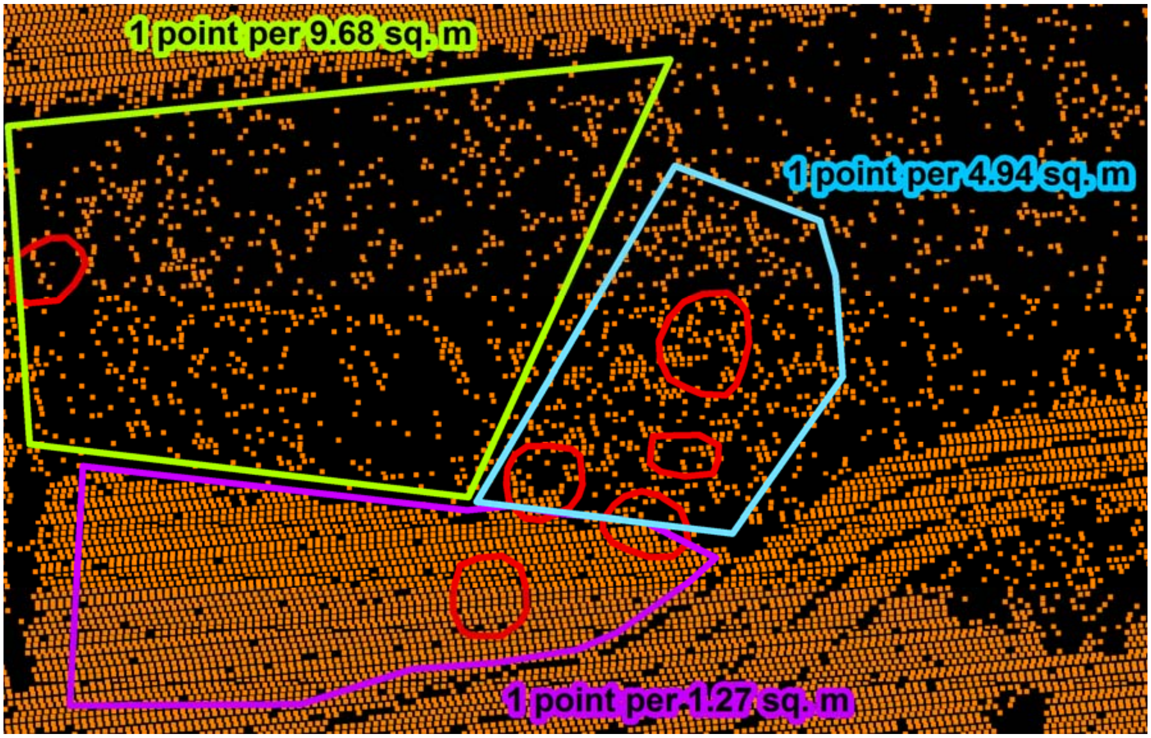

Figure 2.18. Ground point densities over site 21CW6; mounds delimited in red.

Chapter 4: Summary and Recommendations

This project examined the feasibility of using publicly-funded LiDAR as a tool for identifying Precontact earthworks. Documentary records were obtained and reviewed for all recorded precontact mound sites in Crow Wing and Scott counties. These counties had contracted with private-sector vendors to acquire LiDAR data. These data were obtained and examined at 80 archaeological sites in an attempt to match documented mound positions to mound-like topographic shapes visible in the LiDAR data. A sample of the sites were then visited and mapped with GPS and total station surveys to ground truth the LiDAR analysis.

This chapter summarizes the results of the LiDAR and field surveys, and presents recommendations for future applications of LiDAR in archaeological prospection for Precontact mounds and other earthworks.

SUMMARY

The project began by obtaining copies of documents and pertinent electronic datasets for all known mound sites in the two counties. The data were secured primarily from Minnesota's state archaeological site file at the Mn-OSA offices in St. Paul. The records included notes and maps from the surveys of T.H. Lewis and J.V. Brower, which remain the most detailed primary sources of locational data for many mound sites in Minnesota.

An initial step in the LiDAR analysis was to create a GIS of the T. H. Lewis survey notes. Traverses for 26 sites were digitized, along with point features for the 791 mounds, earthworks and other data points recorded on the traverses. These GIS layers provided a means of delimiting Areas of Interest (AOIs) within sites that were used as starting points for the LiDAR survey. Other map data, particularly Brower's maps, were also used to guide the LiDAR survey. However, as discussed in Chapter 2, Brower's and Winchell's maps cannot be brought into a GIS by techniques truly compatible with the technology. Lewis' traverse data were brought into GIS using COGO methods, but, as recognized by Dobbs (1991), the accuracy of these maps is limited by Lewis' survey methods, the accuracy of his instruments, and the precision of the linear and angle measurements he recorded. In the final analysis, his measurements, while precise, are accurate only over short distances, which limit their utility in the GIS environment. Chapters 2 and 3, and in particular Appendix B, Table B3, provide site-by-site information comparing LiDAR and field survey results to the early maps.

The LiDAR analysis detected mounds on 46% (n=37) of the sites, including three letter-sites where mounds had not previously been confirmed. Eighteen sites, 23% of the 80 examined sites, were either confirmed in past field surveys as having likely been completely destroyed by Postcontact land use, or LiDAR indicated that only subsurface features may remain. LiDAR analysis detected 285 precontact earthworks at 37 sites, including 279 mounds, 4 nonmound earthworks (at 21CW19, 21SC6, 21SC13, and 21SC27), and 2 house depressions (at 21CW7 and 21CW105). In addition, examination of areas surrounding the known sites resulted in the detection of mound-like features and a possible house depression at five previously unrecorded sites.

Mounds were either not observed or could not be confirmed at the remaining 25 sites (Table 2.1). At 15 sites, the reason involved LiDAR point densities too low to detect mounds if present. The other ten sites had sufficient LiDAR ground data in the sites' vicinities but some of the sites had other circumstances that hindered mound detection. Of the earthworks detected in LiDAR, 122 were identified from hillshaded BE DEMs alone. Sixty-two required clipping the BE DEMs to the AOI for enhanced contrast in the visualization of microtopography. Seventy-three features were detected by vertical exaggeration of 3D surfaces created from the BE DEMs. Twenty eight features could not be identified from the BE DEMs, and required visualization of the classified mass point data files in software specifically designed for this purpose. Rarely was the initial, shaded-relief image sufficient to detect all mounds on a site.

This multiple method approached resulted in nearly 75% of the 285 features being identified with what the analyst (Riley) considered a high level of confidence. From the perspective of future LiDAR applications, an important finding of the analysis was that nearly half the identified earthworks were detected in the shaded relief images, and nearly all of these were identified with a high level of confidence. Hillshading a BE DEM is perhaps one of the simplest operations that can be conducted with topographic raster data sets in widely-used proprietary software packages such as ArcGIS or open-source software such as GRASS. This lends support to the use of LiDAR as cost-effective means of initially scanning a landscape for mounds.

The major factor in the failure of LiDAR to detect mounds was low ground point density in the available LiDAR data. At sites with thin ground point data, 28% fewer mounds could be identified than at sites with greater ground point density (46% versus 74%, respectively). Low ground point density was due to a combination of factors, including late-spring flights that resulted in data acquisition after vegetation began to leaf out or conifers effectively blocking the laser pulse year-round. Another major source of error was over-thinning of the mass point data during post-processing, creating BE DEMs from ground point data that were of insufficient to show mounds.

As a consequence, a field survey of a sample of the LiDAR-surveyed sites resulted in more mounds being identified and mapped on the ground than had been seen in the LiDAR. A total of 132 mounds and possible mounds were identified at 10 sites.

RECOMMENDATIONS

A major objective of this project was to critically evaluate the problems and pitfalls of using LiDAR as a tool for archaeological mound prospection. Although disappointing in terms of archaeological results, the data quality issues encountered in the Scott and Crow Wing County LiDAR were extremely instructive. The amount of discussion devoted in this report to data quality is a good warning to archaeologists that, despite its outstanding potential, LiDAR cannot be used without a critical eye. Government agencies do not have archaeological features in mind when they write specifications for acquiring LiDAR data for their jurisdictions. The technology itself is still in its relative infancy, and strict standards have not yet been implemented. For the present project, what began as a project to conduct a field-verified test of LiDAR as a tool for mound prospection, rapidly evolved into a case study in the pitfalls of using public-funded, commercially-created LiDAR for archaeological applications.

Recommendations to Archaeologists Using LiDAR

The Minnesota DNR has begun the Minnesota Elevation Mapping Project. Funded in part by the Clean Water Legacy Act, the initial phase of the project will acquire LiDAR for 25 counties in the Minnesota River drainage basin of the southwestern part of the state. The remainder of the state will eventually be flown. The data for the first phase will be collected to Federal Emergency Management Agency (FEMA) specifications with vertical and horizontal accuracy standards as follows:

Vertical: 15 cm RMSE; 27 cm RMSE in vegetation.

Horizontal: 1.0 m RMSE.

These specifications require a nominal point spacing that Riley (2009) found adequate for detecting mounds as small as 5 m diameter by 30 cm high. Thus, Minnesota's statewide LiDAR project should provide data sufficiently accurate to detecting Precontact earthworks. The USGS has recently issued more stringent standards for adoption nationwide.

Even if collected to contract specifications, the usability of LiDAR BE DEMs for mound detection can be reduced by post processing steps that are undertaken to classify and thin the mass point data. Thinning is a necessary step to eliminate all but the true ground points for use in creating the BE DEM. Buildings and vegetation are the principal features eliminated in post processing, but as demonstrated in Chapter 2, over-filtering ground points results in loss of microtopographic information on the bare earth surface including burial mounds.

Archaeologists should never expect a BE DEM produced by nonarchaeologists to provide the information they need "out of the box." They should anticipate, and be ready to undertake, quality assessment of the LiDAR data they obtain from a vendor, agency, or website.

First, the shaded relief image itself can suggest data quality. Late season flights done over Crow Wing County produced shaded relief images in which open areas had good resolution, but forested areas were deeply pitted and facetted because of low ground point density. In Crow Wing County, ground-nonground misclassification resulted in anomalous, flat, circular areas on the shaded relief image that were found to represent the bases of conical mounds that been digitally lopped off just above the surface. As Scott County data demonstrated, an overly smooth or fuzzy shaded relief rendering of the BE DEM may also indicate low ground point density.

Second, the ground points used to create the BE DEM should be overlain on the area being searched, to examine the density and spacing of the original data used to create the BE DEMs. In most cases, including mound detection, archaeologists will most likely use their knowledge of the known or expected sizes and heights of the microtopographic features they are searching for. They need to ascertain whether the distribution of ground points is sufficient to detect features within those ranges. A number statistical procedures exist for determining the density/spacing requirements for detecting features of a given size during archaeological survey (e.g., Banning 2002). UI-OSA recommends 1 point per 1.25–2m^2 as the minimum ground point density needed for mound detection in the upper Midwest.

For example, in the case of the Scott County data examined for this project, it was immediately apparent from the ground points that, in relatively level areas, mass points had been excessively thinned to facilitate the machine-generation of smooth contour lines (Figure 2.5). Even with Lewis traverses to guide the search, the BE DEM was of little use in detecting many of the known mounds.

This specific problem should never occur in LiDAR gathered to FEMA, USGS, or similar specifications. However, the archaeologist must be aware that LiDAR data can be acquired for other purposes. Indeed, the thinning we discovered in the Scott County data, although not suited to our purpose, complied with Scott County's RFP, and was the vendor's approach to meeting the explicit specifications of its contract. The contract required that they deliver only high resolution contour maps, and not create a fully functional, multiple application, LiDAR dataset. Our major frustration with the Scott County data is that airborne collection would have generated a complete LiDAR data set under leaf-off conditions that might have produced an excellent BE DEM. The bulk of this data were not delivered to the county, and we were unable to obtain the data from the vendor.

If the archaeologist finds problems with the as-delivered BE DEM and ground point data, the data can still be used. Transforming the BE DEM into a 3 D surface allows dynamic lighting, rotation, and vertical exaggeration to be used to bring out low relief features. The 2D map can also be manipulated by image processing to enhance features. Finally, mass point data from LAS files can be examined in software environments such as 3D Analyst, MARS, and LP360, to visualize the entire point cloud in three dimensions or in 2D cross sectional profiles (Figure 2.11–12).

The above methods are, of course, more than just alternative solutions to working with poor data. In a thorough LiDAR survey, UI-OSA would recommend that all methods be used. As discussed in

Chapter 2, there are situations in which the archaeologist will need to generate his/her own LAS files, or perform a custom ground-nonground classification. Often, the best solution for dealing with data quality issues or obtaining supplemental data and metadata is to consult directly with the data provider. UI-OSA has found that, especially when working with statewide LiDAR data, one of the best resources an archaeologist can have is to be on a first-name basis with the state agency's LiDAR staff.

CONCLUSIONS

The implementation of Minnesota's Clean Water Legacy Act Amendment has created a unique opportunity for the State of Minnesota to fund large-scale, statewide projects of long term value to the preservation community, as well as the humanities and archaeological science. LiDAR is a relatively new technology, particularly for archaeology in the United States. The data are costly to acquire. Statewide collection projects, such as Minnesota's and Iowa's, require funding partnerships from multiple state and federal agencies. Archaeologists and the historic preservation community generally lack funding to acquire all but site- or locality specific LiDAR, as in the case of the National Park Service's Midwest Archaeological Center on-going effort to acquire LiDAR for the archaeological resources it owns or administers (Anne Vawser Wolley, personal communication, 2009).

Not all LiDAR data is acquired to similar specifications. Even within a single, large-area acquisition project, despite stringent standards, the quality of data actually obtained is all too often at the mercy of constraints such as weather delays, equipment failure, and other events that can result in flights having to extend beyond optimum leaf-off conditions. Although the Obscured Areas identified by Crow Wing County's vendor (Figure 2.4) is an extreme example, such areas will exist in state- or county-scale LiDAR datasets. The possibility always exists that an archaeological site or survey area will fall within such an area. It is one of several possibilities that archaeologist using the datasets must be able to anticipate, identify, and control for.

As a final caveat, even if collected to stringent standards, LiDAR data will never be perfect. This is particularly important in archaeology, because the kinds of features we wish to view are often small and low relief. The archaeologist using LiDAR must always anticipate that areas as small as a mound, or even as small as a mound group, may require special measures to obtain useful data. Many and perhaps most LiDAR identifications will require field verification. For example, in this project, LiDAR survey of 21CW97 revealed outside the known site boundaries that very clearly depicted what most archaeologists would probably agree was a potential mound group. On field examination, the features were found to be hummocks in a manmade wetland.

The Once and Future Legacy: Prospects for Archaeological LiDAR in Minnesota

UI-OSA is confident that Minnesota, under the leadership of the Minnesota DNR and Minnesota Geospatial Information Office, will acquire a high resolution data set that will prove highly effective for locating known mounds and finding new sites. According to Timothy Loesch, the DNR's GIS Operations Supervisor (personal communication May 2010), project standards will be established to meet or exceed the U.S. Geological Survey National Geospatial Program's *LiDAR Guidelines and Base Specification* (USGS, NGP 2010). The NGP has recognized that LiDAR collections have grown exponentially in the last few years, yet there are very few specifications set to standardize these collections. As a result, the diverse datasets have made it difficult to conduct projects that require LiDAR data from multiple sources.

The NGP requests with their new standards that all collected points be delivered in an LAS format. The availability of these datasets for Scott County would have greatly improved the success rate of mound identification in this study, since mounds obscured by vegetation, misclassification, or over-thinning can often be detected in the original point clouds.

Regarding misclassification, USGS, NGP (2010) acknowledges that a plethora of collection systems, classification software/algorithms, and methods for data assessment are currently in use in the United States. They are asking the remote sensing and GIS community to develop best practices. The NGP standards do not directly address point classification methodology, but do give specifications that address classification accuracy, classification consistency and a minimal classification scheme of six classes (USGS, NGP 2010). While Nominal Pulse Spacing (NPS) was not an issue in this project, the NGP standards state an NPS of 1–2 m during collection which can vary due to terrain and ground cover conditions. This collection density has proven in this project to be sufficient for creating good elevation point coverage of burial mounds even in deciduous forests. These positive steps toward standardizing LiDAR data will without question increase the number of reliable datasets that archaeologists can use for archaeological prospection of subtle features with less worry of data incompatibilities or inconsistencies.

EPILOG

In the afternoon of March 9, 2010, Minnesota State Archaeologist Scott Anfinson received an email from Mike Magner, the DNR Forestry Archaeologist. Magner was forwarding an email he had received from John Carlson, a DNR Forestry colleague. Carlson wrote,

> "With LIDAR data we have been able to see where most of our Indian mound sites are on State land. In the Vinegar Ridge area… I noticed on the LIDAR image that there are at least two more mounds. One of them looks like it has been dug up. Did you know about this site? See attached map" (Anfinson, email to authors, 3/9/2010, on file at UI-OSA).

The map (Figure 4.1) clearly depicts the mound-like features in question. Anfinson forwarded the map to the authors, commenting,

> "It demonstrates the widespread and increasing interest in LiDAR. We do not have a recorded mound at this location in Houston County. The USGS map shows the exact location as uninteresting and not even containing a well developed terrace on which to place a mound. I might look at it in the field this summer if I get down that way."

The Houston County data were acquired in Phase I of the Minnesota Elevation Mapping Project, and reflect the excellent image quality possible with the data. Anfinson's comment underscores not only the importance of the new data for detecting previously unknown sites, but also the continuing need for field verification, and, implicitly, the logistical difficulties of the Mn-OSA, with its small staff, of doing so.

At the same time, as Carlson's email demonstrates, many nonarchaeologists recognize a need for preservation, have the technological skills to identify possible sites, and the ability, because of their numbers and dispersal across the state, to have a role in their stewardship.

Publicly available LiDAR data pose a risk to mound sites, in that they make it difficult if not impossible to protect site confidentiality. The sooner archaeologists start using the technology for large-area reconnaissance for unknown mound sites, the sooner we can develop programs and social networks to monitor and protect them.

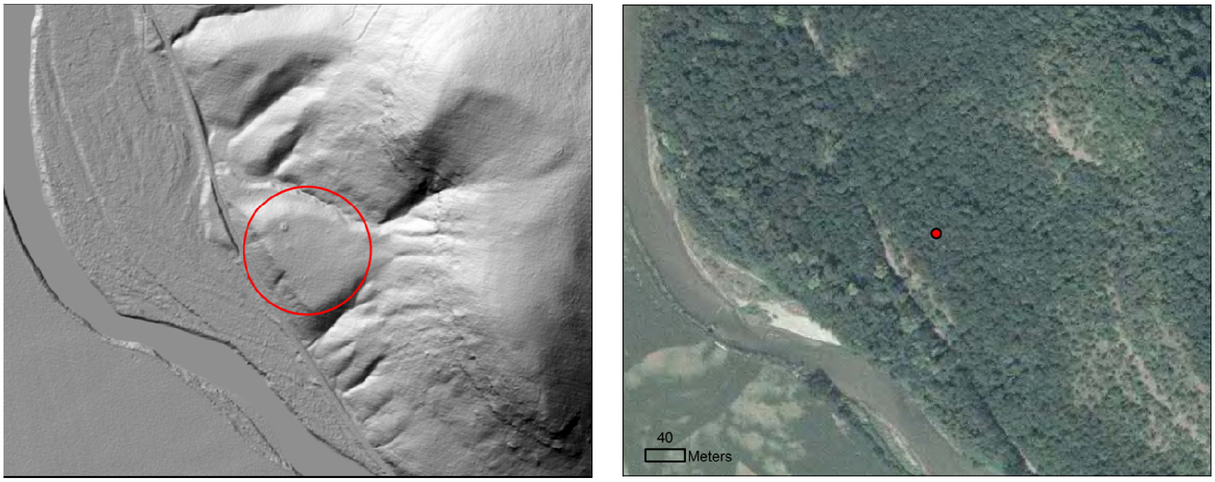

Figure 4.1. Possible mound site visible through forest cover, Houston County, Minnesota. Shaded relief image courtesy of John Carlson, Minnesota DNR.

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Appendix A: Glossary

Unless otherwise indicated, definitions are quoted from the on-line GIS Dictionary (http://resources.arcgis.com/glossary) maintained by the Environmental Science and Research Institute (ESRI). Text in brackets is added by the authors.

Absolute Accuracy	The value expressed in feet or meters that reports the uncertainty in vertical or horizontal positions due to systematic and random errors in measurements in the location of any point on a geospatial dataset relative to the defined vertical or horizontal datum at the 95 percent confidence level. The absolute vertical accuracy is normally different than the absolute horizontal accuracy (Maune 2007).
Alpha sites	A Minnesota site file designation of an archaeological site that requires field confirmation before a SITS designation can be given.
ASCII	Acronym for American Standard Code for Information Interchange. The de facto standard for the format of text files in computers. Files with the extent "txt" are often ASCII files.
BE DEM	[Acronym for Bare-Earth Digital Elevation Model] A *DEM* created from *last return* points, at which the laser beam reached the ground surface ("bare earth") without being blocked by a building, tree, or other above-ground object.
Classification	The process of sorting or arranging entities into groups or categories; on a map, the process of representing members of a group by the same symbol, usually defined in a legend.
COGO	Acronym for coordinate geometry. A method for calculating coordinate points from surveyed bearings, distances, and angles.
DEM	Acronym for digital elevation model. The representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEMs are typically used to represent terrain relief.
Differential GPS	The underlying premise of [a] Differential Global Positioning System (DGPS) requires that a GPS receiver, known as the base station, be set up on a precisely known location. The base station receiver calculates its position based on satellite signals and compares this location to the known location. The difference is applied to the GPS data recorded by the roving GPS receiver (Chivers 2003).
Feature Class	In ArcGIS, a collection of geographic features with the same geometry type (such as point, line, or polygon), the same attributes, and the same spatial reference. Feature classes can be stored in geodatabases, shapefiles, coverages, or other data formats. Feature classes allow homogeneous features

to be grouped into a single unit for data storage purposes. For example, highways, primary roads, and secondary roads can be grouped into a line feature class named 'roads.'

Geodatabase	A database or file structure used primarily to store, query, and manipulate spatial data. Geodatabases store geometry [as a point, line, or polygon], a spatial reference system [a coordinate system such as latitude/longitude], attributes [that describe the spatial feature], and behavioral rules for data [that stipulate interrelationships within and among different spatial feature data sets]
GIS	Acronym for geographic information system. An integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed
Hillshade	[or Shaded Relief] Shadows drawn on a map to simulate the effect of the sun's rays over the varied terrain of the land. [Most often applied to a DEM to depict shaded relief patterns of the landscape.]
IMU	[Acronym for Inertial Measurement Unit] A device used in precision navigation of airborne vehicles [that] uses three gyroscopes and three accelerometers, orthogonally-mounted on an airborne mapping sensor (e.g., camera or LiDAR system), to measure the current rotation and acceleration. These measurements are summed to determine the change from the initial position of the aircraft (National Oceanic and Atmospheric Administration 2007).
Infrared	The portion of the invisible spectrum consisting of electromagnetic radiation with wavelengths in the range of 750 nanometers to 1 millimeter (Maune 2007).
Interpolation	The estimation of z-values at a point with x/y coordinates, based on the known z-values of surrounding points. There are many different forms of interpolation such as: ANUDEM, Inverse Distance Weighted, Kriging, Natural Neighbor and Spline (Maune 2007).
JPEG (JPG)	Acronym for Joint Photographic Experts Group. A lossy image compression format commonly used on the Internet. JPEG is well-suited for photographs or images that have graduated colors. [“Lossy” means that image resolution is sacrificed in favor of creating a smaller-sized image.
LAS	LASer File Format. The LAS file format is a public file format for the interchange of 3-dimensional point cloud data between data users. Although developed primarily for exchange of LIDAR point cloud data, this format supports the exchange of any 3-dimensional x,y,z tuplet (American Society for Photogrammetry and Remote Sensing 2009).

Last return The last significant measurable portion of a return LiDAR pulse (Maune 2007).

Letter sites see Alpha sites

LiDAR Acronym for Light Detection and Ranging.

Mass Points Irregularly spaced points, each with x/y location coordinates and z-value, typically (but not always) used to form a TIN. When generated manually, mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles. However, when generated automatically, e.g., by LiDAR or IFSAR scanners, mass point spacing and pattern depend upon the characteristics of the technologies used to acquire the data (Maune 2007).

Nadir A single point, or locus of points, on the surface of the Earth directly below a sensor as it progresses along its line of flight (Canada Centre for Remote Sensing 2005).

Nanometer One billionth of a meter (10^{9} m), equivalent to 1,000 microns.

Point A geometric element defined by a pair of x,y coordinates

Polyline In ArcGIS software, a shape defined by one or more paths, in which a path is a series of connected segments.

Polygon In ArcGIS software, a closed shape defined by…a path that starts and ends at the same point…

Populate The act of storing information in previously created data tables and GIS feature classes. When first created, these data entities have a framework comprised of attributes, each defined to accept a specific kind of data, such as text, numbers, dates, or in the case of GIS, feature geometry. The entity is therefore like a newly planted subdivision, ready to be "populated."

Raster A spatial data model that defines space as an array of equally sized cells arranged in rows and columns. Each cell contains an attribute value and location coordinates. [DEMs are an example of a raster data set in which each cell is assigned a value for its elevation]

Return Intensity Intensity is a measure, collected for every point, of the return strength of the laser pulse that generated the point. It is based, in part, on the reflectivity of the object struck by the laser pulse. Other descriptions for intensity include return pulse amplitude and back scattered intensity of reflection (ESRI 2010).

RMSE [A statistical measure for comparing how well one map corresponds to another in terms of its scale and accuracy of depiction of features.] The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points (Maune 2007).

Shapefile	A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.
SITS	Acronym for Smithsonian Institution Trinomial System. A national system for designating archaeological sites comprised of three parts: a two-digit code for the state; a 2-letter code for the county, and an whole number representing the individual site, most often assigned in the order in which sites are recorded in a county.
Stretch Rendering	A display technique applied to the histogram of raster datasets, most often used to increase the visual contrast between cells.
Vector	A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells.
WGS	[Acronym for World Geodetic System] A set of quantities, developed by the U.S. Department of Defense, determining geometric and physical geodetic relationships on a global scale, based on a geocentric origin and a reference ellipsoid. The current WGS-84 is based on the Geodetic Reference System 1980 (GRS 80) (Maune 2007).
WMS	[Acronym for Web Map Server or Service]. An open source internet map service specification that delivers web-based, interactive map[s] that allows you to display and query the layers on the map.