The Jerusalem and Tolna Outlets in the Devils Lake Basin, North Dakota Edward C. Murphy, Ann M.K. Fritz, and R. Farley Fleming North Dakota Geological Survey 1997 (Revised 2002) R.I. 100

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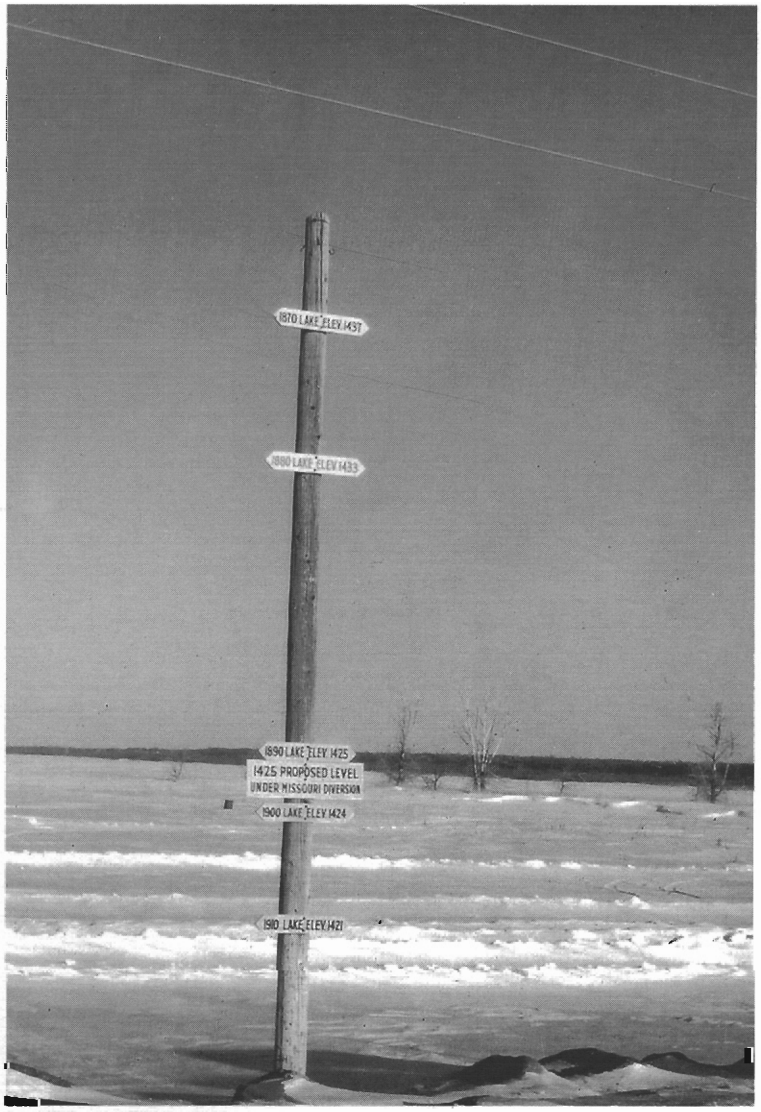

Report of Investigation No. 100
North Dakota Geological Survey
John P. Bluemle, State Geologist
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On the Cover: A pole erected in 1948 to enable motorists to visualize the historical fluctuations of Devils Lake. The pole was located near the junction of State Highways 57 and 20, about four miles south of Devils Lake. The photograph was taken by Dr. Gordon Bell in March, 1962. Dr. Bell estimated the lake level to be 1,417 feet at the time he took the picture. In October, 2001, the lake was at an elevation of 1,447.1 feet, approximately seven feet above the top of this pole.

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ABSTRACT

Devils Lake is located within a large, closed drainage basin in northeastern North Dakota. We know from historical accounts and a previous NDGS investigation (Bluemle, 1991) that the water levels in Devils Lake fluctuate to a great degree, several tens of feet in recent years. When the water level in the lake reaches an elevation of 1446.6 feet, water flows through the Jerusalem Outlet to Stump Lake. When the water level in the combined Devils Lake-Stump Lake system reaches an elevation of 1459 feet, water will flow to the Sheyenne River through the Tolna Outlet. The purpose of this investigation was to learn more about the geologic history of the channel-fill deposits in the Jerusalem and Tolna outlets with an emphasis on the amount of sedimentation that had taken place since 1889, the time of North Dakota's statehood. Pieces of wood, bone, and organic-rich sediment can be dated by radiocarbon methods (carbon-14). Cultivated grasses such as wheat, oats, and barley, and opportunistic weeds such as Russian thistle *(Salsola)*, were introduced in the Devils Lake area between 1883 and 1895. Pollen from these plants can be used to determine the land surface at the time of statehood.

Drill holes and trenches were constructed through the channel-fill deposits at a site in each outlet during the first two weeks of March, 1997. The channel-fill deposits, consisting primarily of silt, clay, sand, gravel, and peat, range in thickness from a maximum of ten feet thick at the Jerusalem Outlet site to 20 feet thick at the Tolna site. We collected a total of 133 sediment samples, 50 from the Jerusalem site and 83 from the Tolna site. We submitted five pieces of wood and four organic-rich sediment samples for radiocarbon dating. In addition, 37 sediment samples (22 from the Jerusalem Outlet and 15 from Tolna Coulee) were submitted for pollen analysis.

At the Jerusalem site, sediments at a depth of seven feet were determined to be over 9000 years old while sediments at a depth of three feet were over 2000 years old. The top four feet of sediment was analyzed for pollen at this site. Pollen of the cultivated grasses was found to a depth of six inches below the land surface, but below this level pollen was poorly preserved. As a result of this poor preservation, we can only conclude that at least six inches of sediment has been deposited at the Jerusalem site in the last 100 years. It is doubtful that this 100-year level extends significantly deeper because sediments at a depth of three feet are over 2000 years old.

It was possible to reconstruct a more detailed geologic record from the deposits in the Tolna Coulee because of the abundance of carbon-rich material (wood and paleosols) that was present and the good pollen preservation. The dates obtained by the carbon-14 method indicate that sediments at a depth of 19 feet in the Tolna Coulee site were deposited nearly 9000 years ago while those at a depth of two feet are over 1000 years old. The top two feet of sediment was analyzed for pollen at the Tolna site. Pollen of cultivated grasses and Russian thistle all appear at the same horizon approximately one foot below the land surface. The first occurrence of both cultivated grasses and Russian thistle at the same horizon creates a high degree of confidence that approximately one foot of sedimentation has taken place at the Tolna site since the time of statehood (1889).

The results of this investigation suggest that one foot or less of sediment has been deposited during the last 100 years at the sites studied in the Jerusalem Outlet and Tolna Coulee.

Introduction

Background

In December, 1996 the Devils Lake Joint Water Resource Board requested that the North Dakota State Water Commission conduct a field study of sedimentation in the outlets leading from East Devils Lake into Stump Lake (Jerusalem Outlet) and from Stump Lake into the Sheyenne River (Tolna Outlet) (Ben Varnson, Chairman, Joint Board, written correspondence to David Sprynczynatyk, State Engineer, North Dakota Water Commission, dated December 11, 1996). Members of the Board were particularly concerned about the amount of "recent" sedimentation that had occurred in the outlet channels. The Water Commission was asked to coordinate this project with the North Dakota Geological Survey because of our prior experience with sedimentation studies in the outlets.

The fluctuating water levels of Devils Lake have been a concern to area residents for decades. In 1940, the lake stood at less than 1401 feet, some 40 feet below its current level *(Figure 1)*. In 1983, then Governor Olson issued a Disaster Emergency Proclamation for the area due to flood-damaged roads and property (Bluemle, 1983). During the late 1980s and early 1990s local residents expressed concern about declining lake levels that were caused by a three-year drought that began in 1988. In July, 1997, however, the water level in Devils Lake reached an elevation of 1,442.97 feet; this elevation was, up to that point in time, the highest water elevation ever recorded. The fluctuating water levels have caused some residents to demand an artificial means to control lake levels to protect their homes and property from flooding. North Dakota Geological Survey geologist Howard Simpson recognized these inevitable fluctuations in 1912 when he wrote that the future of Devils Lake " . . . may only be read from the past. Fluctuations in response to variations in rainfall may be repeated in the future as in the past and those of a cyclic nature undoubtedly be repeated. Periods of rise will follow periods of fall."

A proxy method of determining the magnitude and age of high and low water levels in the lake is to determine the relative age of the sediments in the outlets. Radiocarbon dating and pollen analysis are two useful tools scientists use to determine the relative age of sediment. Pollen analysis can be particularly useful in trying to determine "recent" sedimentation. The introduction and spread of Russian thistle by

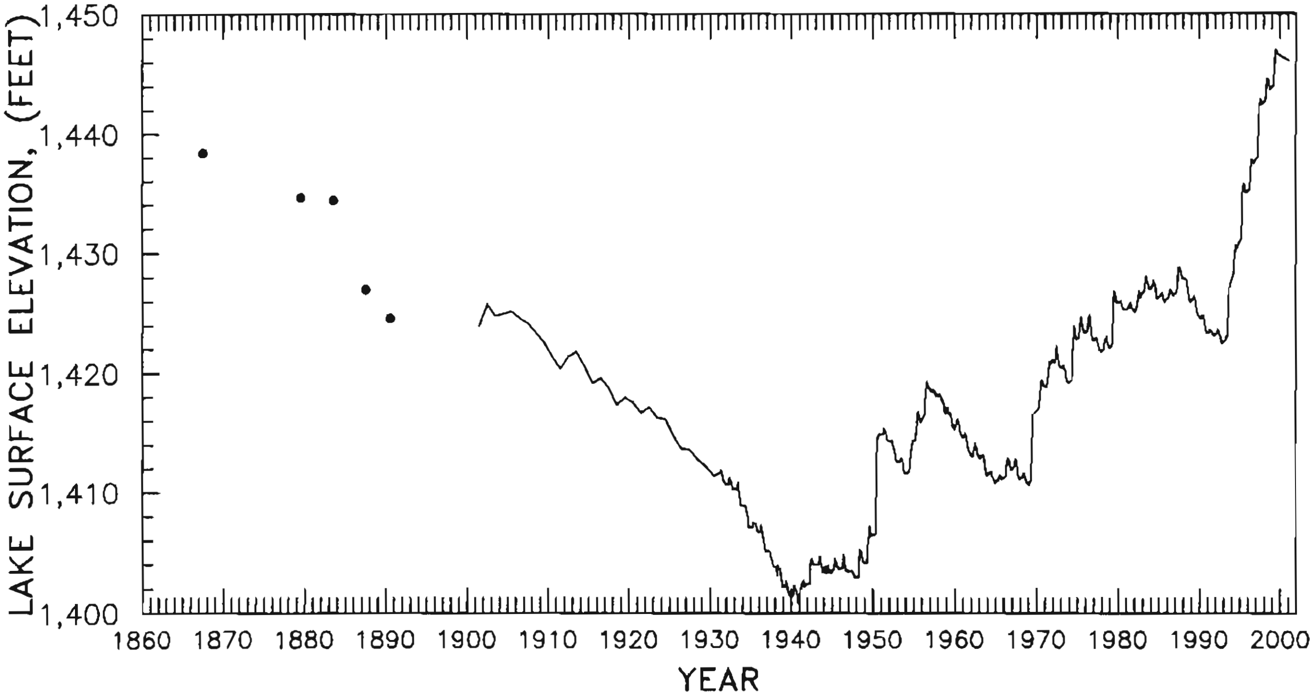

Figure 1. Lake elevations for Devils Lake. Only a few random readings are available from 1867 to 1900 The last value plotted is October 7, 2001. Modified from USGS web site *http://srv1dndbmk.cr.usgs.gov/public/dvlake/dvlake.por.html.*

early European settlers in the upper Midwest is well documented (Jacobson and Engstrom, 1989). Russian thistle was introduced in the Devils Lake region between 1894 and 1895. The presence of this pollen in undisturbed sediments indicates that these layers are not more than 100 years old. Radiocarbon dating, also called carbon-14 dating, is used to determine the age of organic material, such as wood, bone, and plant matter found in buried soils.

Objective

The objective of this field investigation was to determine the amount and age of sediments that have been deposited in the natural outlets of the Devils Lake and Stump Lake system. Emphasis was placed on identifying the amount of sedimentation that has taken place in these outlets over the last 100 years.

Study Site

Devils Lake is located in a large, closed drainage basin that extends from the southeastern edge of the Turtle Mountains in Rolette County to a series of recessional moraines and a widespread area of dead-ice moraines just south of the lake. The western, northern and eastern boundaries of the basin are poorly defined drainage divides (Pusc, 1993). As such, the reported area of the Devils Lake Basin varies from 3,500 square miles (Simpson, 1912) to 3,810 square miles (Ryan and Wiche, 1988). The lake itself is the largest natural body of water in North Dakota (Bluemle, 1981, 1983, and 1995) and has been increasing in size for the past eight years (1993-2001). Water levels have risen over 24 feet during this time, flooding pasture, farmland, homes, businesses, and roads. In October, 2001, the water elevation in the lake was 1,447.1 feet above sea level. In 1999, the water level in Devils Lake exceeded an elevation of 1,446.6 feet, and slowly began to flow into the Jerusalem Outlet *(Figure 2).* If the water level in the combined Devils-Stump Lake reaches an elevation of 1,459 feet, water will flow through the Tolna Outlet and into the Sheyenne River *(Figure 2).* The Sheyenne River flows to the Red River, which in turn flows north into Canada.

Previous Investigations

The geology of the Devils Lake area was first discussed by Warren Upham (1896) in his classic treatise on Glacial Lake Agassiz. In 1902, State Geologist Earle Babcock reported on the geology and water resources of the Devils Lake area. Ten years later, Howard Simpson (1912) wrote a more detailed account of the geology and hydrology of the area. All three of these early workers noted the presence of beach deposits significantly above present-day lake levels and the natural outlets for the lakes. They hypothesized that the beach sediments were deposited along the shores of a former glacial lake (named Glacial Lake Minnewaukan by Simpson, 1912) which formed as the last ice sheet retreated from the area. The geology and glacial stratigraphy of the Devils Lake region is described in detail by Aronow (1955, 1957), Bluemle (1973), and Hobbs and Bluemle (1987). Several additional studies have generated subsurface geologic, hydrologic, and geochemical data for the Devils Lake area (Downey, 1971; Hutchinson, 1977; Murphy et al., 1992; Pusc, 1992; and Wiche and Pusc, 1994).

There have been numerous studies concerning the postglacial history of this area. Examination of lake sediment lithology and mineralogy by Callender (1968) provides the first documentation on lake levels during specific intervals of the Holocene (approximately 7,000 years ago to the present time). A number of studies have documented the historically fluctuating lake levels and the hydrologic controls on the lake system (Wiche et al., 1986; Wiche, 1992; Pusc, 1993; and Wiche and Pusc, 1994). Several studies have been conducted on the lacustrine sediments of Devils Lake. Most of these studies focused on dating the Holocene-age sediments and on reconstructing the Holocene climate in this area (Van Alstine, 1980; Jacobson and Engstrom, 1989; Fritz, et al., 1994; and Lent, et al., 1995). The work of Jacobson and Engstrom (1989) was extremely useful to this project because it documented the early years of cereal grain production in the Devils Lake area and the arrival of Russian thistle in 1894 or 1895. Additional comments on the Holocene climate of the area are provided by Wiche and others (1996) and Fritz and others (1996). None of the previous studies, however, obtained sediment samples from the Jerusalem or Tolna outlets.

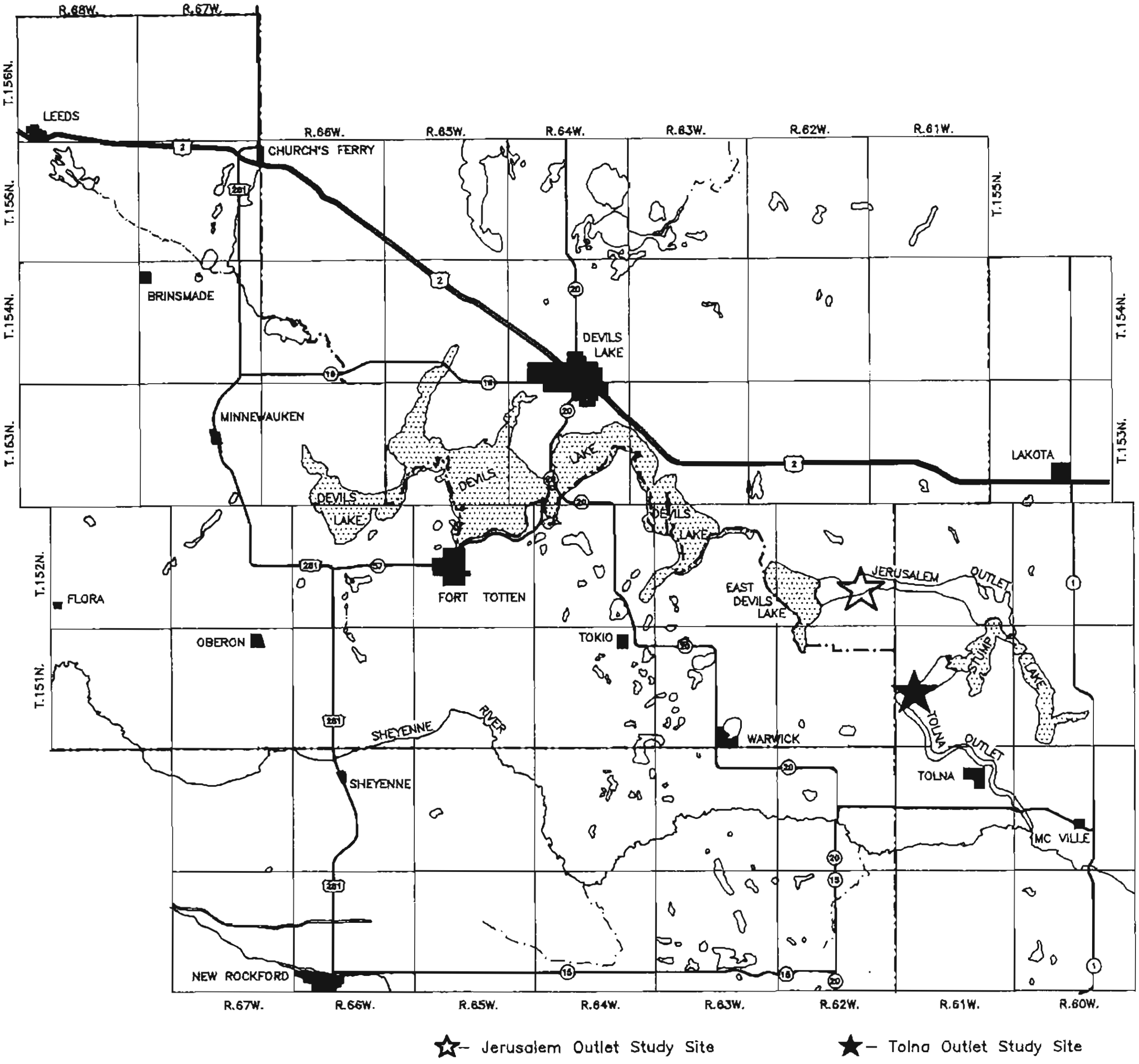

Figure 2. Location of the Jerusalem Outlet for Devils Lake and the Tolna Outlet for Stump Lake. Study sites are indicated by stars.

Two previous investigations of Devils and Stump Lakes and the associated outlets have been conducted by the North Dakota Geological Survey (Luther, 1989 and Bluemle, 1991). Beginning in 1987, personnel from the Geological Survey and North Dakota Health Department collected lake sediment and ice cores from Stump Lake. The Stump Lake chemistries obtained during the 1989 study were used to predict the effects of diverting water from East Devils Lake into Stump Lake (Luther, 1989).

In the late 1980s, the North Dakota Geological Survey attempted to determine the frequency of the water-level fluctuations in Devils Lake (Bluemle, 1991). The drought of the late

1980's made it possible to use a backhoe to gain access to the Jerusalem and Tolna outlets as well as the beach deposits on the northeast shore of Devils Lake. Buried soils in the beach and channel-fill deposits were sampled and radiocarbon dated. No pollen analyses were performed as part of Bluemle's project. Bluemle concluded that the radiocarbon dates obtained on the soils indicate that Devils Lake had risen several times to levels higher than 1,446.6 feet in the last 4,000 years. Bluemle's (1991) study provided the first conclusive data that Devils Lake had overflowed into Stump Lake in the last 7,000 years. The radiocarbon dates on the soils suggest that Devils Lake fluctuated more often and to a greater degree than was previously believed.

Field Methods

In contrast to Bluemle's (1991) earlier investigation during drought years, we were faced with the challenge of completing field work in extremely wet conditions. The high watertable throughout most of the outlet areas made access to the study sites difficult except when ground frost could support the weight of vehicles. To avoid access problems, field investigations commenced in early March. A major blizzard at the onset of the project and sub-zero temperatures throughout most of the two-week investigation created difficult working conditions. Trails drifted over several times at the Tolna site and drilling was hampered by frozen hydraulics.

Drilling

A truck-mounted Giddings Probe was used to auger holes in the Jerusalem and Tolna outlets *(Figure 3)*. A total of 11 holes were drilled during this project, three at the Tolna site and eight at the Jerusalem site. The auger holes ranged from seven to 26 feet deep, with an average depth of 16 feet. Three drill holes combined with the two trenches were sufficient to correlate the outlet stratigraphy at the Tolna study site. The base of the outlet and the channel-fill material was more variable at the Jerusalem site and required additional drill holes to properly define the sediment contacts at that site. *Appendix A* contains a description of the lithologies encountered in the drill holes.

Trenching

A track-mounted backhoe was used to construct seven trenches, two at the Tolna site and five at the Jerusalem site *(Figure 3)*. The trenches were generally ten feet long by 15 feet wide and varied in depth from 18 to 20 feet at the Tolna site and four to 13 feet deep at the Jerusalem site. Three of the trench walls were near vertical and the remaining wall was sloped to facilitate access. At the Tolna site, four to five feet of sediment was excavated at a time. We measured, described, and sampled the newly exposed section along one trench wall. We could no longer safely enter the trenches once they reached a depth of ten to 12 feet due to repeated wall collapse. From this depth on, the base of the trench was repeatedly cleaned until an undisturbed section could be removed by the backhoe bucket, often in 1.5- to two-foot intervals. Measurements, descriptions, and samples were taken from the undisturbed portion of the sediment retrieved from the trench bottom while it was still in the backhoe bucket. *Appendix B* contains the sediment descriptions from the trenches. All of the trenches were backfilled and mounded with sediment after we had completed sampling.

Sample Collection

We collected a total of 133 sediment samples from the study trenches, 50 from the Jerusalem site and 83 at the Tolna site. Typically, a two- to three-pound sediment sample was obtained from a specific vertical interval ranging from 2.5 inches to one foot. We sealed the sediment samples in two plastic freezer bags and allowed them to freeze. The samples were stored in a cool portion of the North Dakota Geological Survey warehouse in Bismarck until they were shipped to the laboratory for analysis.

We also collected wood and organic material for radiocarbon dating. As soon as wood or paleosols (buried soil horizons) were encountered in the trenches we double-wrapped the material in aluminum foil and allowed it to freeze. These samples were stored with the pollen samples until they were shipped to the laboratory for processing. Prior to shipment, we dried the wood and selected sediment samples at 200 degrees Fahrenheit to remove most of the moisture.

Figure 3. The truck-mounted soil probe (a) and backhoe (b) used to obtain sediment samples during this project. The photo of the truck was taken looking east from the Tolna site. The photo of the backhoe was taken looking southwest at the Jerusalem site.

Laboratory Methods

Pollen Analysis

We submitted a total of 37 organic-rich sediment samples for palynological processing to Geolabs in Medicine Hat, Alberta. We selected only organic-rich intervals because past palynologic projects have demonstrated that only the most organic-rich sediments contain preserved pollen. Samples, approximately 100 grams in weight, were submitted following standard chain-of-custody procedures. Approximately 15 to 20 grams of each sample were processed to separate pollen grains from the sediment according to standard laboratory procedures. The resulting pollen grains were mounted on glass slides to be viewed with a microscope.

Microscope slides were examined and pollen counts were made with a Bausch and Lomb compound light microscope with a binocular head. Pollen counts were made at 430X and 970X magnifications. Pollen identifications generally followed the approach outlined in Jacobson and Engstrom (1989), especially with respect to Russian thistle *(Salsola)* and grass cultivars. References consulted for identification included: McAndrews et al., (1973); Faegri and Iverson (1989); Bassett et al., (1978); Moore et al., (1991); and Wang et al., (1995) as well as reference pollen slides provided by the U.S. Geological Survey.

Radiocarbon Dating

The radiocarbon dating method is based on the incorporation and decay of radiogenic ^{14}C (a product of cosmic radiation) to ^{14}N. The method became common in the 1940's and 1950's and has been used routinely since that time. The method is applicable to alluvial and lacustrine deposits such as those found in the Jerusalem and Tolna outlets.

We submitted a total of nine samples to Beta Analytic Incorporated, in Miami, Florida for radiocarbon dating. Five of these samples were wood and four of the samples were organic-rich sediments (bulk low-carbon materials). The wood ranged in weight from seven grams (the minimum weight acceptable) to 115 grams and the organic-rich sediments ranged from 500 grams to 800 grams. Radiocarbon dates are summarized in *Appendix C*.

Geology

A series of sedimentary units overlying crystalline rock comprise the bedrock units in the Devils Lake region. The bedrock geology of the region is discussed in more detail by Hobbs and Bluemle (1987), Carlson and Freers (1975), and Bluemle (1973). The uppermost bedrock in the region is the gray shale and siltstone of the Pierre Formation. These rocks were deposited in a late Cretaceous seaway which is believed to have covered portions of North Dakota 82 to 65 million years ago. Following a long period of erosion during Tertiary time, the ancestral, or pre-glacial Cannonball River and its tributaries incised deep valleys into the soft shale, creating an irregular surface. During Pleistocene glaciation, beginning about three million years ago, the glaciers overrode and filled these valleys with sediment, otherwise smoothing and obscuring the underlying rough topography (Hobbs and Bluemle, 1987).

Warren Upham (1896) first speculated that Devils Lake and Stump Lake " . . . having very irregular outlines, with numerous windings and long bays or arms, probably lie in valleys of a preglacial river and its tributaries, elsewhere filled with dirt". Since that time, geologists have found strong evidence that Upham was essentially correct (Hobbs and Bluemle, 1987).

As the ancient Cannonball river system eroded the Pierre Formation, it deposited sand and gravel which now comprise the Spiritwood aquifer, one of the largest channel aquifer systems in the state. A large portion of Devils Lake overlies this aquifer system *(Figure 4)*. Sediments deposited by the ancestral Cannonball River may underlie only a small portion of the Tolna Outlet and none of the region occupied by the Jerusalem Outlet *(Figures 5 and 6)*. Although subsurface data from within these outlets is limited, the information that is available indicate that the Jerusalem Outlet occupies, at least in part, a former glacial meltwater channel. This channel, identified as the Starkweather diversion trench by Hobbs and Bluemle (1987), originates north of Cando and extends into eastern Nelson County *(Figures 4 and 5)*. The Jerusalem Outlet is underlain by 200 feet or more of glaciofluvial sand and gravel, till, and glaciolacustrine clays *(Figure 6)* and appears to have been active during most of the Wisconsinan period. In

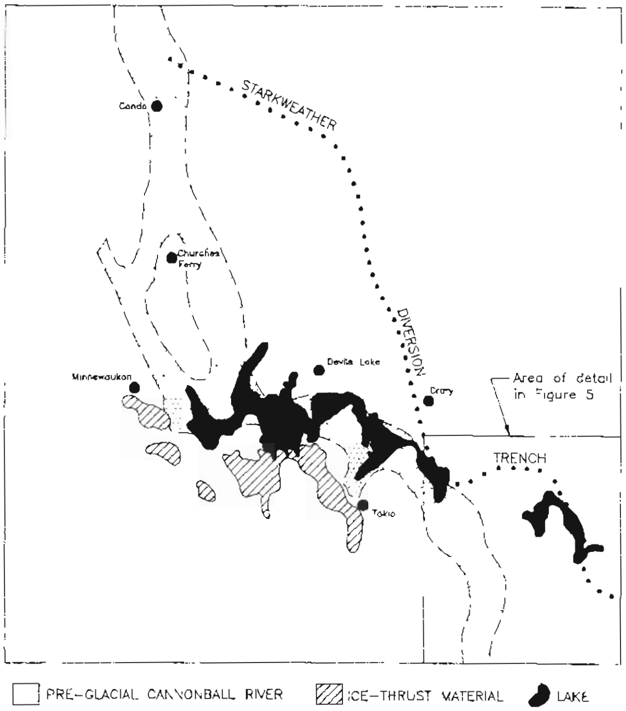

Figure 4. Generalized map of the Devils Lake area showing the position of Devils Lake and Stump Lake relative to ice-thrust topography, pre-glacial and glacial drainages. Modified from Hobbs and Bluemle (1987) with additional data from Pusc (1993)

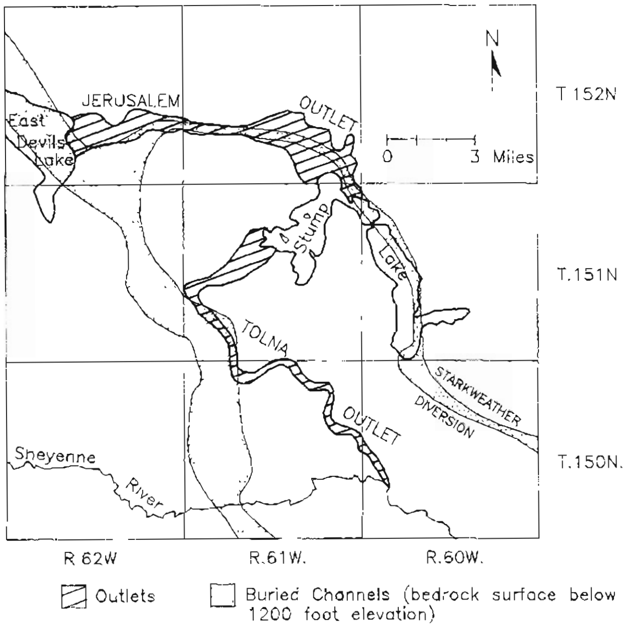

Figure 5. Generalized map of the East Devils Lake and Stump Lake area showing the relationship between the natural outlets and the underlying buried channels. Buried channel data from Pusc (1993)

contrast, the narrower, more steeply sided Tolna Outlet does not appear to have been active until the end of the Late Wisconsinan (10,000 to 12,000 years ago). In addition, the Jerusalem Outlet likely has held water more often than the steeper Tolna Coulee and therefore was subjected longer to current (including wave) erosion.

The present-day surface of the Devils Lake region is covered by glacial sediment deposited during the last three million years when large sections of North Dakota were periodically covered by glaciers. The deposits consist of clayey till with lesser amounts of outwash-derived sand and gravel. The Pleistocene deposits in the region vary in thickness from less than 50 feet to over 600 feet (Hobbs and Bluemle, 1987). The thickest glacial deposits occur in the buried pre-glacial valleys and glaciofluvial channels discussed above.

A series of terminal moraines, the North Viking and Heimdal, are present just south of the Devils Lake Basin. These moraines extend from Minnewaukan to the north of Tolna, bound the southern edge of most of Devils Lake, and encompass most of Stump Lake. Upon further inspection, geologists found that the North Viking and Heimdal moraines contain blocks of ice-thrust material. As more subsurface data became available, geologists were able to determine that the Devils Lake basin formed as a result of large scale glacial thrusting at the end of Late Wisconsinan time (Bluemle, 1981; Bluemle and Clayton, 1984). Sullys Hill, a prominent landmark in the North Viking moraine, is largely an ice-thrust block of Pierre shale that was excavated from the adjacent Devils Lake basin by the advancing glacier.

As the Late Wisconsinan glacier receded, Glacial Lake Minnewaukan formed along the front end of the ice in the present area of the Devils Lake basin (Simpson, 1912). Glacial Lake Minnewaukan expanded to the north as the glacier receded and stabilized at a maximum elevation of approximately 1,453 feet (Hobbs and Bluemle, 1987). At this elevation, water presumably flowed freely from glacial Lake Minnewaukan through the Jerusalem and Tolna outlets and into a meltwater trench now occupied by the Sheyenne River. Fluvial and lacustrine deposition, as well as slopewash and eolian deposits during the last 10,000 years, have raised the minimum overflow elevation to 1,459 feet.

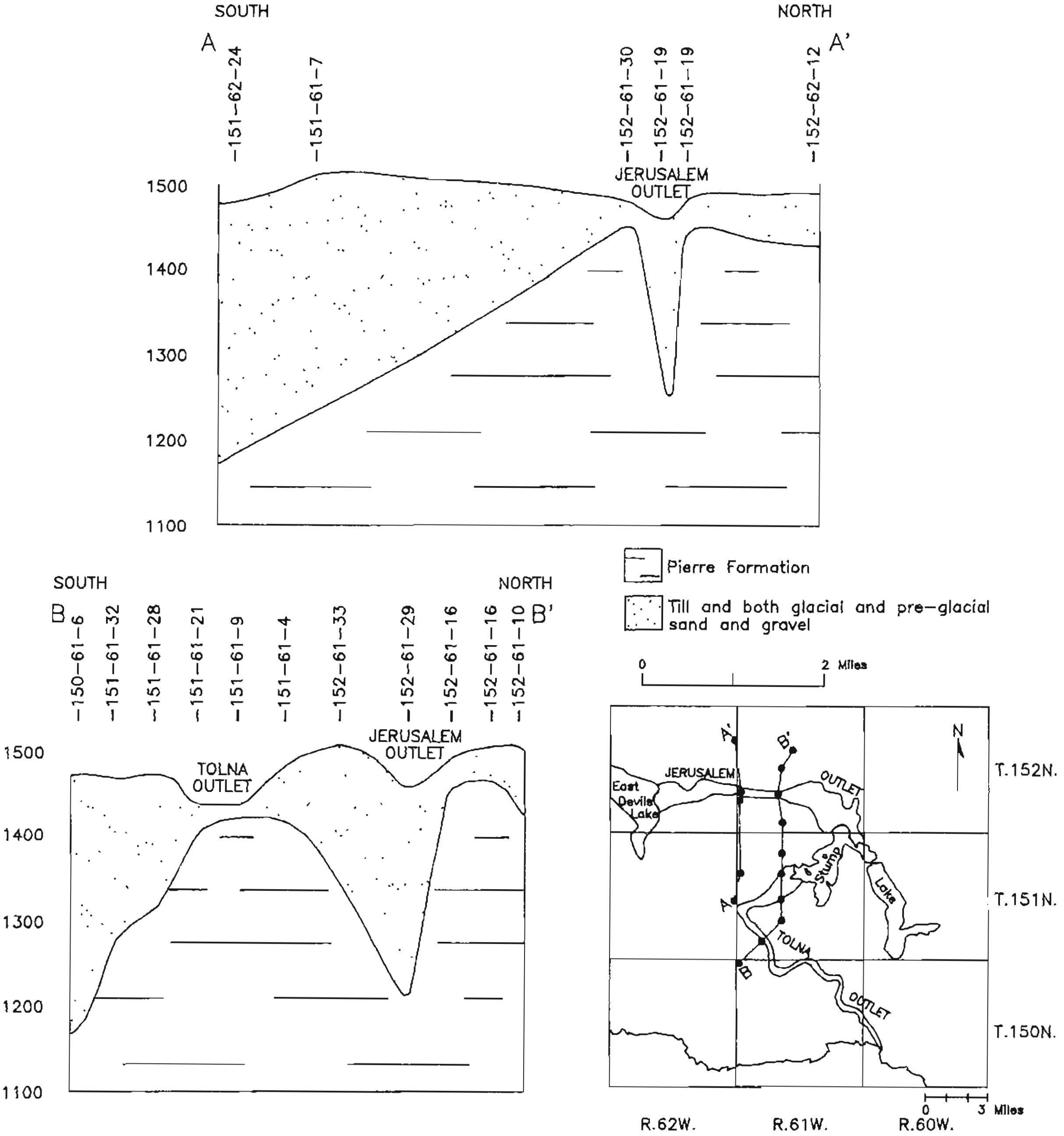

Figure 6. Generalized cross-sections in the East Devils Lake-Stump Lake area. Well locations are given by township, range, and section number.

At the end of glaciation in this region, approximately 10,000 years ago, the lack of glacial meltwater caused glacial Lake Minnewaukan to shrink in size creating the present-day Devils Lake and Stump Lake systems. During the Holocene, the water levels in these lakes repeatedly rose and fell in response to changes in climate, at times overflowing into the Sheyenne River through the natural outlets.

Jerusalem Outlet

The Jerusalem Outlet extends for approximately 9.5 miles from the eastern edge of East Devils Lake (T152N, R62W section 28) to the northern edge of West Stump Lake (T152N, R61W sections 35 and 36). The east-west trending channel is over 1.5 miles wide at East Devils Lake and exceeds two miles in width where it enters West Stump Lake. However, through most of its course it is less than a half mile wide. The surface of the relatively flat channel lies approximately 50 feet below the surrounding countryside *(Figure 7)*.

Stratigraphy

The study site (nw/ne/sw section 24 T152N, R62W) was chosen by the State Water Commission and Devils Lake Joint Board because it is situated on a drainage divide. Eight holes and four trenches were completed along a 950-foot north-south profile across a portion of the outlet *(Figure 8)*. Geologic logs of the drillholes and trenches are in *Appendix A and B*, respectively. Throughout the study area the channel-fill deposits are underlain by highly fractured, weathered till. The channel-fill deposits are from three feet to ten feet thick and are an average of six feet thick at this site. The majority of channel-fill deposits are obscurely bedded, clayey silt. The silt is likely a mixture of slopewash from the surrounding valley walls and wind-blown material. A north-trending ravine, just north of the site, likely provided additional slopewash to this area *(Figure 8)*.

In trench JT5, sand and gravel are overlain by snail-bearing silt and silty clay. This sequence is overlain by a paleosol that has a radiocarbon age of 9,020 ± 80 years BP *(Figures 9 and 10)*. In an adjacent trench (trench JT1) this paleosol was overlain by fluvial deposits, thereby providing a maximum age for this fluvial event. Aquatic snails and clams were observed only in the lower half of the trenches *(Figure 9)*.

The age obtained from the paleosol at this site, approximately 9,000 years BP, was significantly older than was anticipated. The date suggests that sedimentation rates at this site were greater immediately following deglaciation than for most of the last 9,000 years. Three-fourths of a mile east of this site another paleosol, radiocarbon dated at 2,380 ± 120 years BP, was encountered at a depth of four feet (Bluemle, 1991). The channel-fill deposits were over 12 feet thick at Bluemle's site and were dominated by fossiliferous lacustrine clays, significantly different than the lithologies encountered at this study site *(Figure 11)*.

An organic-rich silty clay from a depth of 2.8 to three feet in trench JT1 was determined to be

Figure 7. The study site in the Jerusalem Outlet (sec. 24, T152N, R62W). The study area is marked by the north-south trending trail in the background. Photo taken looking southwest from the north wall of the outlet.

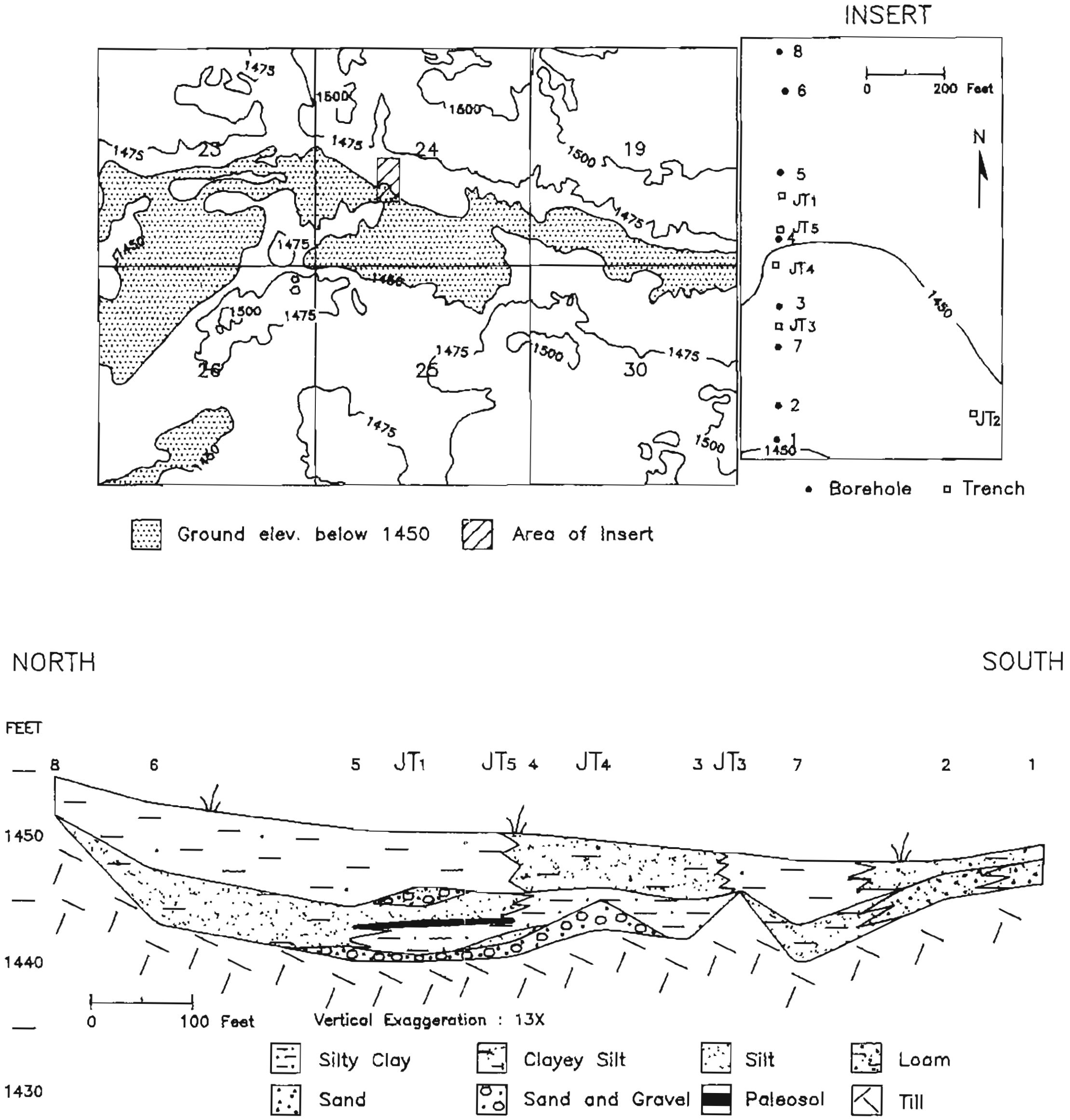

Figure 8. Topographic map and geologic cross-section of the Jerusalem Outlet

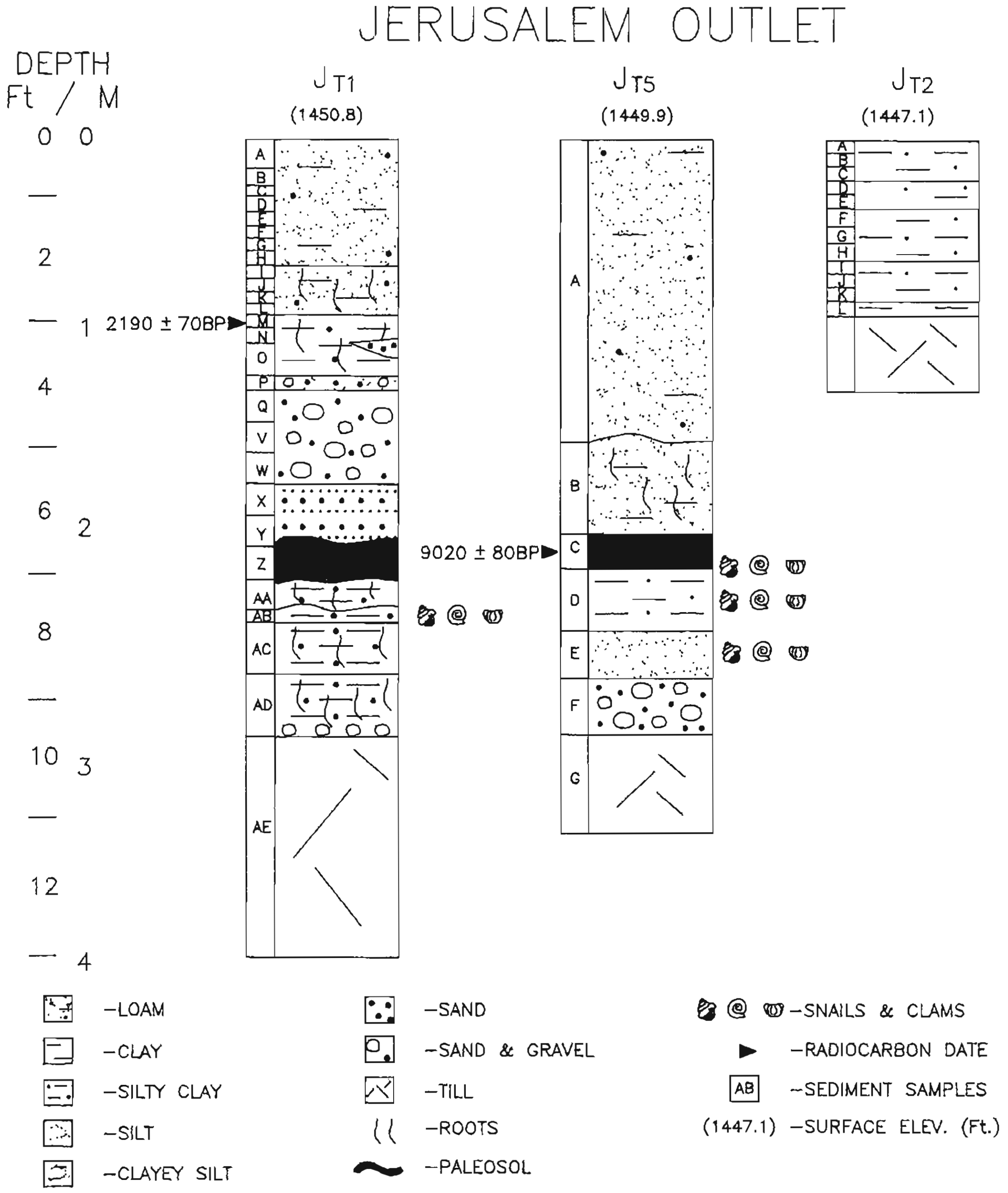

Figure 9. Stratigraphic columns for Jerusalem trenches JT1, JT2, JT5.

Fgure 10. Sediment exposed on the west wall of trench JT1 in the Jerusalem Outlet. Arrow points to a paleosol. The trench was 9 feet deep at the time this photo was taken.

approximately 2,200 years BP *(Figures 9 and 11)*. If the paleosols at a depth of seven feet in trenches JT1 and JT5 are equivalent, the average rate of sedimentation from three to seven feet at this site is 0.06 feet per 100 years as compared to 0.1 feet per 100 years for the top three feet. These relatively low rates of deposition suggest that erosion was prevalent during much of the Holocene at this site.

Pollen

Sediment samples were submitted for pollen analysis from trenches JT1 and JT2 in the Jerusalem Outlet. Samples were submitted for the top 2.75 feet of trench JT2 and for the interval from two to 3.75 feet in trench JT1. Samples were not submitted for analysis from the upper two feet of JT1 because the location has periodically been farmed and there was concern that discing and plowing had significantly altered the near-surface sediment. Trench JT2 was excavated in a cattail slough where it was believed that farming had not taken place.

Scans of samples in trench JT1 (samples JT1-I through JT1-O shown on *Figure 9*) revealed that all of the pollen assemblages were too sparse to make statistically reliable counts or to construct pollen profiles. *Appendix D* lists pollen occurrence and raw count data. The samples contained relatively few pollen types, including pollen of pine (*Pinus*), grasses (Gramineae), sunflowers (Compositae), opportunistic weeds (Chenopodiaceae), cattails (*Typha*), and sedges (Cyperaceae). No pollen grains of Russian thistle or cereal grains were observed. However, the absence of this pollen from such sparse samples is not evidence of the absence of those plants from the region. All of the samples contained abundant dark-brown to black plant debris.

Scans of samples from trench JT2 (samples JT2-A through JT2-L shown on *Figure 9*) indicate that most samples contained pollen assemblages that were too sparse to make statistically reliable counts *(Appendix D)*. The sparse samples from JT2 were similar to the samples from trench JT1 in that they contained dark-brown to black plant debris (charcoal) that probably indicates fire. These samples also contained pollen of pine, grasses, cattails and sedges, opportunistic weeds (Chenopodiaceae), and sunflowers (Compositae). None of the sparse samples contained any Russian thistle or cultivated grains. As with the sparse samples from JT1, the JT2 samples provide no basis for making an age interpretation.

Samples JT2-A through JT2-C contained sufficient pollen for statistically reliable counts to be made *(Appendix D)*. These samples represent the top six inches of sediment, and all three samples contained pollen of cultivated grasses and a trace of Russian thistle (*Salsola*). In addition, they contained very high relative abundances of opportunistic weeds (Chenopodiaceae) pollen (18-25%). Chenopods are opportunistic plants that rapidly colonize cleared areas, such as occur after fires (natural and anthropogenic) or clearing for agricultural purposes. Taken together, these data suggest

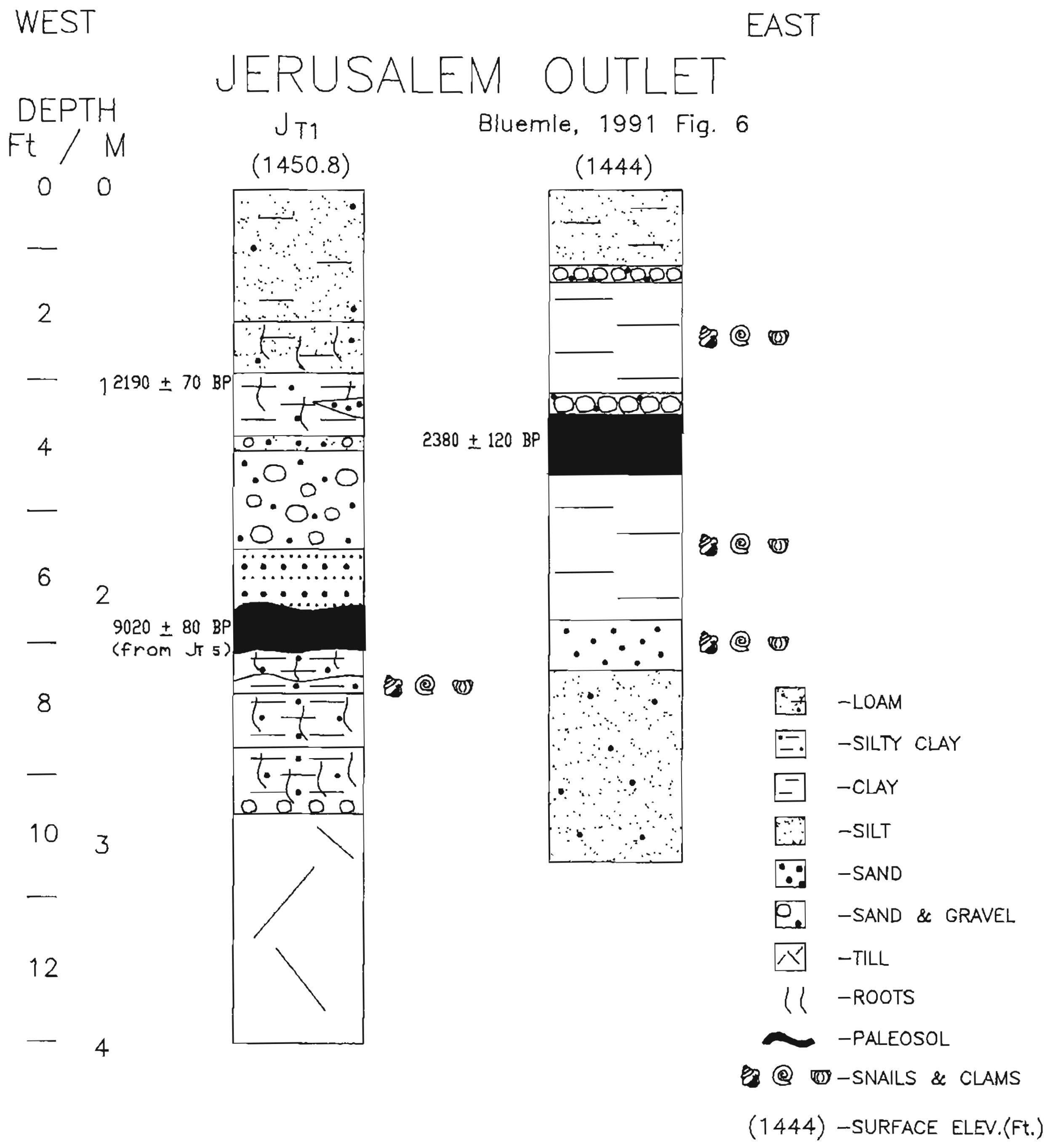

Figure 11. Comparison of lithologic columns from the Jerusalem Outlet. Bluemle's (1991) site is located 0.75 miles east of the Jerusalem site studied in this report.

that sediments in the interval spanning JT2-C through JT2-A were deposited during or after settlers from Europe moved into the area.

Unfortunately, it was not possible to identify the earliest occurrence of the cultivated grasses and Russian thistle at the Jerusalem site due to the poor preservation of pollen below a depth of six inches. The only conclusion that could be made concerning the 100-year-old land surface at this site was that it occurs below a depth of six inches. It likely does not occur significantly below this level because sediment at a depth of three feet is over 2000 years old.

Tolna Outlet

The Tolna Outlet is approximately 13 miles long, extending from the southwestern edge of West Stump Lake (T151N, R61W sections 17 and 20) to the Sheyenne River (T150N, R60W section 19) *(Figures 2 and 12)*. The channel trends to the southwest at its head near Stump Lake and then turns and trends southeast from the town of Tolna to the Sheyenne River. The Tolna Coulee is much narrower than the Jerusalem Outlet, ranging from a few hundred to a thousand feet wide at its base. The base of the Coulee has an approximate gradient of 11 feet per mile and lies 50 to 100 feet below the surrounding countryside. Because of its morphology, the Tolna Coulee is presumably younger than the Jerusalem Outlet, unless its shape is more of a reflection of how often it was active. The study site was chosen because it is within the area of highest outlet elevation and was easily accessible *(Figure 13)*.

Stratigraphy

The channel-fill deposits in the Tolna Coulee are 15 to 25 feet thick and consist of peat, clay, silt, sand, and gravel *(Figures 13 and 14)*. The channel-fill deposits along the southern end of the site are underlain by glacial till *(Figure 13)*.

Figure 12. The study site in the Tolna Coulee. The trenches are located midway between the two vehicles. Photo taken looking north from southern edge of coulee.

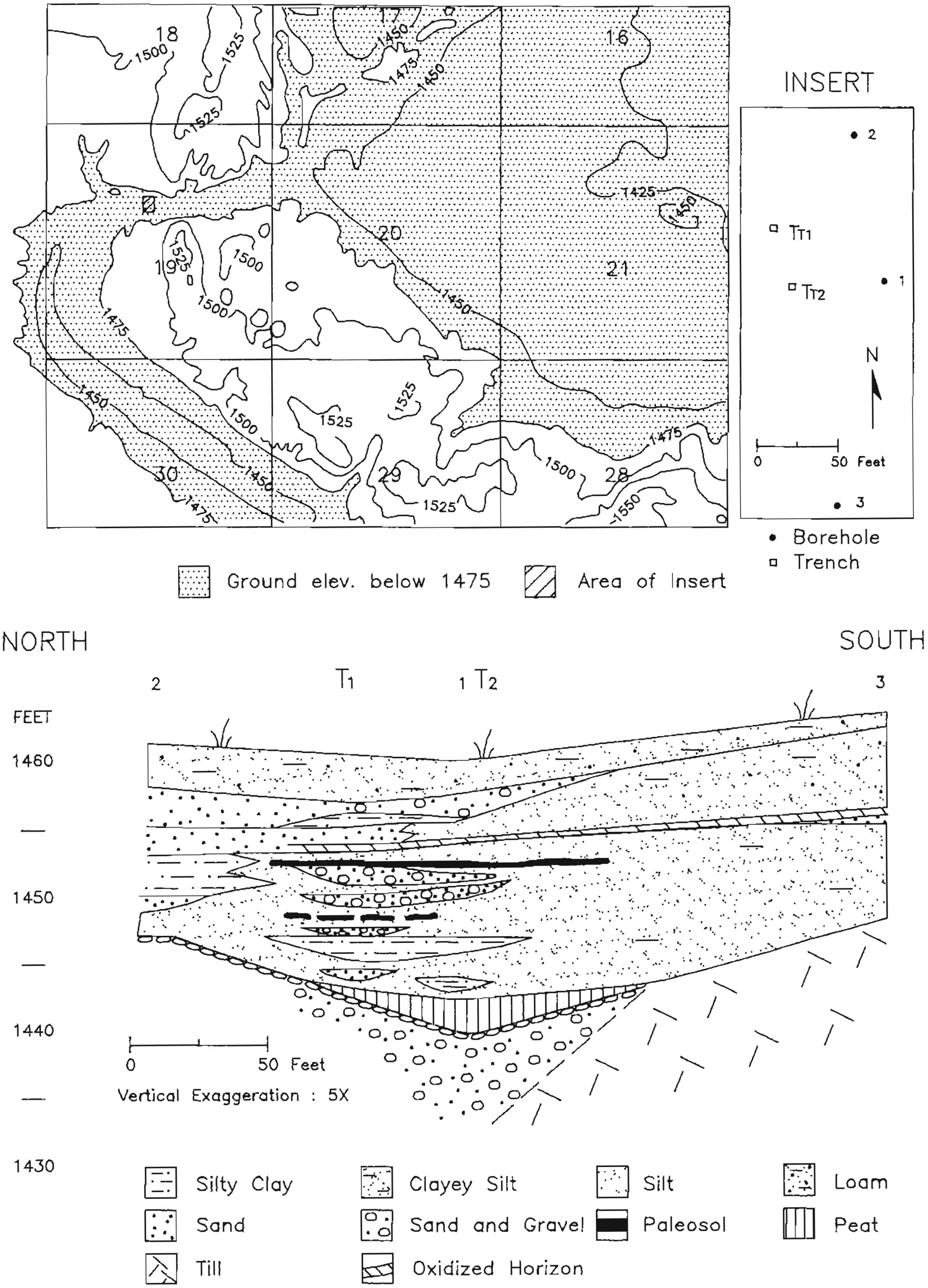

Figure 13. Topographic map and geologic cross-section of the Tolna Outlet

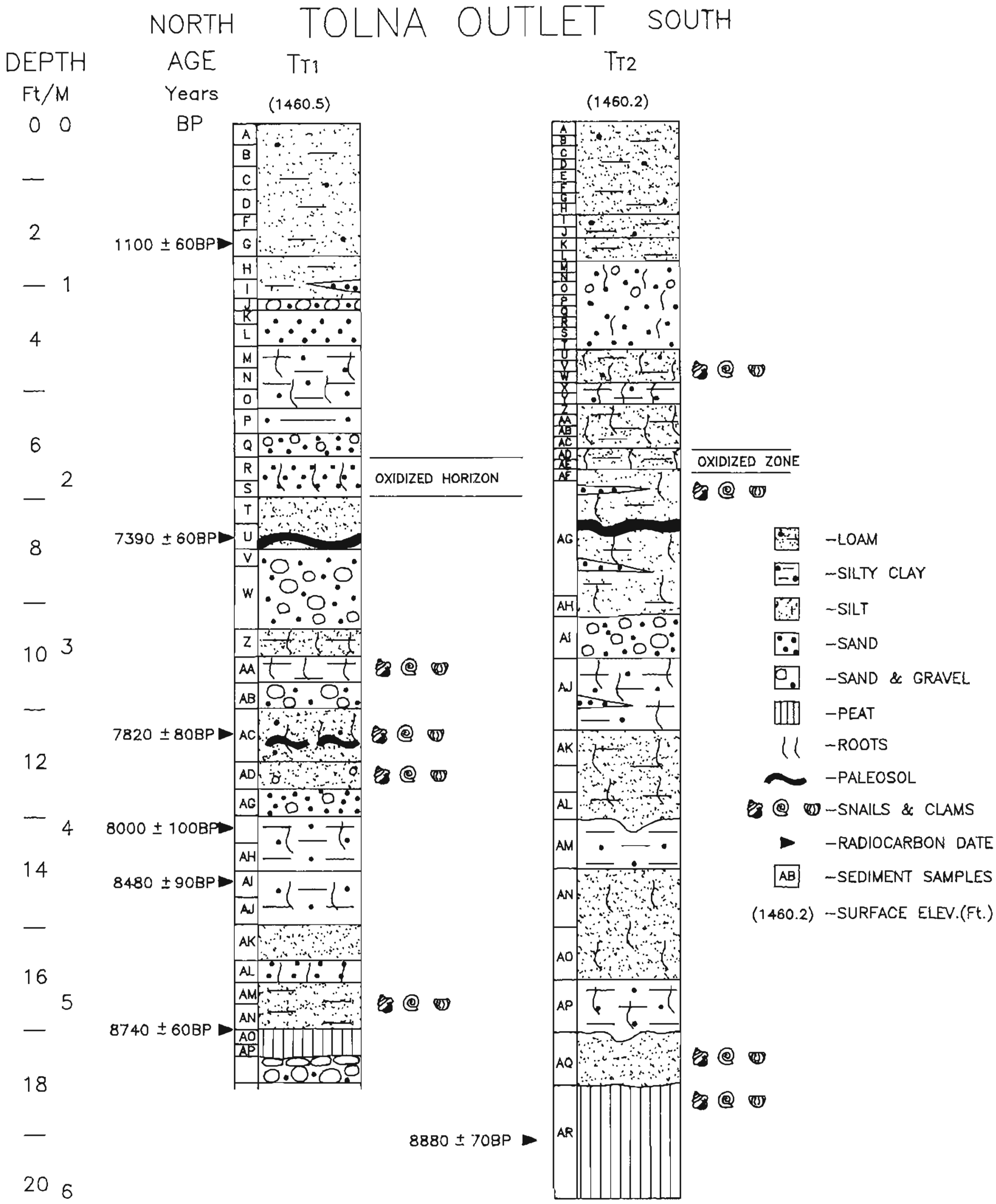

Figure 14. Stratigraphic columns for Tolna trenches TT1 and TT2.

Near the center of the Coulee, in excess of six feet of sand and gravel was encountered at the base of the channel-fill sediments. This coarse unit was likely deposited by meltwater at the end of glaciation. A layer of flat rocks overlies the sand and gravel suggesting that an extended period of weathering took place resulting in a lag deposit. Two to four feet of peat overlies the rock layer *(Figure 15)*. Radiocarbon dates on wood from the peat indicate that it began forming prior to 8,900 years BP and stopped accumulating approximately 8,700 years BP. The peat contains a high percentage of horsetail or scouring rushes (*Equisetum*) as well as numerous snails and clams.

Evidence of at least seven fluvial events has been preserved in the channel fill deposits of trench TT1. Fluvial events are marked by layers of coarse grained sediments, presumably washed into the Coulee by water flowing from Stump Lake. These sediments were deposited at times when water levels in the Devils Lake and Stump Lake systems were sufficiently high to cause water to flow into the Sheyenne River through Tolna Coulee. It is likely that additional flood events occurred in this Coulee but are not recorded in the sediments at this site. The sedimentological evidence is missing either because floods were of insufficient size and duration, or because it was removed by the scouring action of subsequent flood events.

Seven wood-bearing or organic-rich horizons were radiocarbon dated, which has allowed approximate ages to be established for many of the fluvial events *(Appendix C)*. At least two major flood events occurred during the nine-hundred-year interval between 7,800 to 8,700 years BP *(Figure 14)*. The earlier event occurred sometime between 8,740 years BP and 8,480 years BP *(Figure 16)*. The later of these two events occurred approximately 8,000 years BP. A paleosol formed approximately 7,800 years BP indicating that the site was dry for an extended period of time, long enough for a soil profile to develop. At least two more flood events occurred during the next 400 years (approximately 7,800 to 7,400 years BP) *(Figure 14)*. The later of these two events is one of the thickest Holocene sand

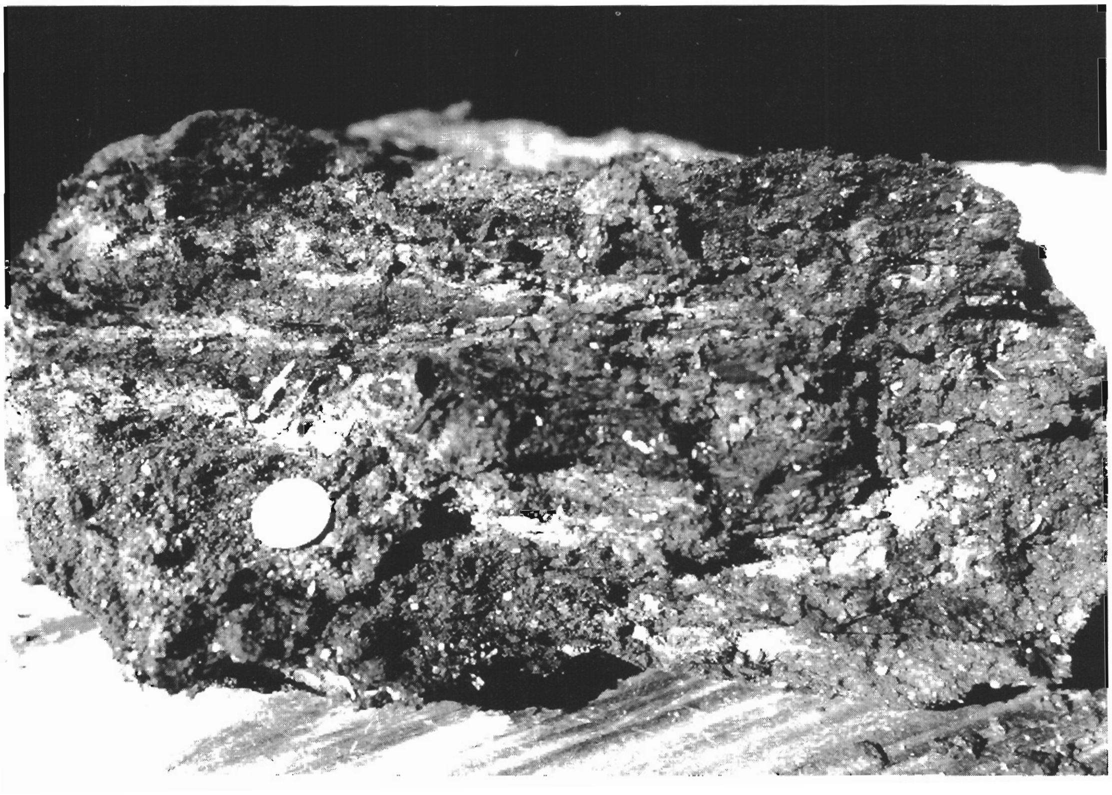

Figure 15. A peat sample from the base of trench 1 in the Tolna Coulee. This peat was deposited approximately 8800 to 8900 years BP.

Figure 16. A wood sample submitted for radiocarbon dating from the Tolna site. The piece of wood came from a depth of 17 feet in TT1 and was dated at 8740 ± 60 years BP.

and gravel deposits preserved at this site. An additional paleosol, at a depth of eight feet, was radiocarbon dated at 7,390 years BP. This paleosol is better developed than the one at a depth of 11.5 feet below the surface, indicating that the base of the Coulee likely remained exposed (dry) for a longer period of time at this horizon than it did 7,800 years BP. An oxidized concretionary zone (stained and cemented by iron oxide) occurs at a depth of six to seven feet (approximately one foot above the upper paleosol) indicating another prolonged dry period *(Figures 14 and 17).* The oxidized horizon is sandwiched between an underlying lens of sand and an overlying lens of sand and gravel suggesting that the prolonged dry period occurred between the events that deposited these fluvial units. A scour surface was not observed at the oxidized horizon. At least one additional fluvial event, a coarsening upward sequence, is recorded in TT1 at a depth of three to four feet below the land surface. The upper two to three feet of section consists of dark brown to gray silty clay and loam. Loam at a depth of 1.7 to two feet was dated at 1,100 years BP *(Figure 14).* No scour surfaces or lag deposits were observed within this interval. The heavily roted loam and clayey silt layer appear to have formed primarily from a mixture of slopewash and windblown sediment.

Trench TT2, while only 30 feet south of trench TT1, contains fewer and much thinner sand and gravel lenses than TT1 *(Figure 14).* Trench TT2, located nearer to the center of the outlet channel, contains an additional 2.5 feet of channel fill sediments as compared to TT1. The channel fill deposits are 20 feet thick in TT2 compared to 17.5 feet thick in TT1. Both the oxidized horizon and the upper paleosol (at eight feet below the land surface) are present in the two trenches.

The rate of sediment accumulation in TT2 was much higher from 7,390 to 8,880 years BP (0.7 feet per 100 years) than it was for either of the periods from 1,100 to 7,390 (0.1 feet per 100 years) or from 1,080 BP to the present (0.2 feet per 100 years). The average rate of sediment accumulation for the entire channel fill sequence at this site is 0.1 feet per 100 years.

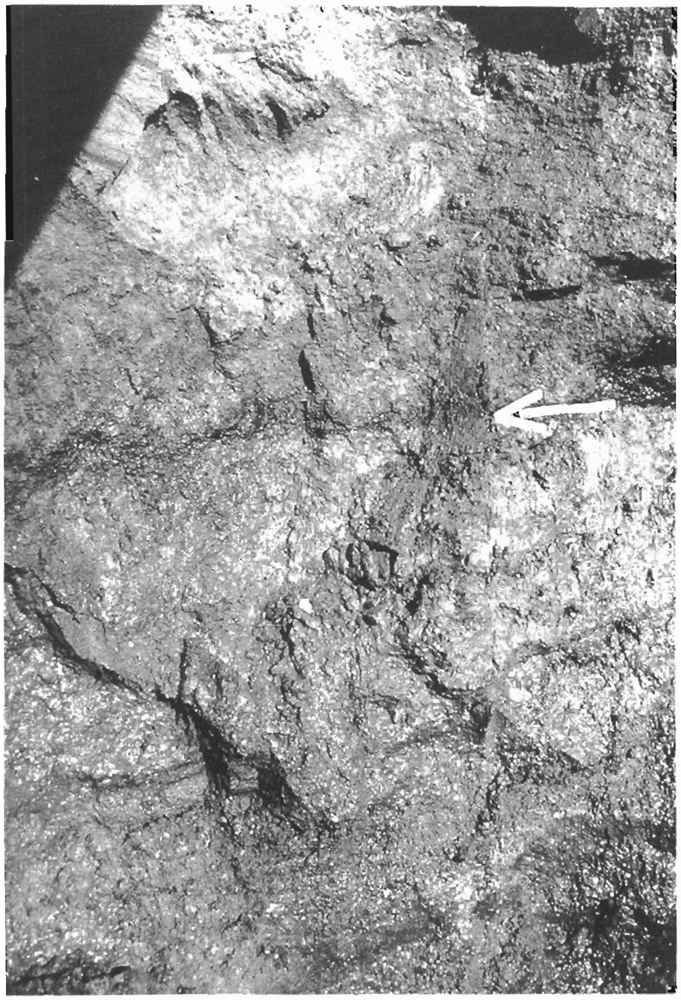

Figure 17. Sediment exposed along the wall of trench TT1. The arrow points to an oxidized layer at a depth of 6.5 feet. Layers of saturated silt and sand are present at the base of the photograph.

Pollen

The pollen from the Tolna site was generally much better preserved than pollen from the Jerusalem trenches *(Appendix D)*. The samples did not contain as much charcoal debris as those from the Jerusalem site, but they did contain an abundance of fungal material. All of the sediment samples contained adequate pollen assemblages for counting except samples TT2-D and TT2-I.

The best quality samples were all dominated by pollen of the sedge family (Cyperaceae) with minor amounts of cattail pollen. This pollen assemblage strongly suggests deposition in a wetlands setting that contained sedges and cattails. The dominance by sedge pollen is in contrast to the assemblages reported by Jacobson and Engstrom (1989) from Devils Lake. Although sedge pollen was an important component of their assemblages, their pollen spectra show dominance by pine (*Pinus*) and oak (*Quercus*). In comparison, the Tolna samples contain relatively low amounts of pine and very little oak pollen.

Samples TT2-E through TT2-A contain pollen assemblages that suggest the presence of European settlers during deposition of the sampled sediments. Traces of Russian thistle (*Salsola*) were observed in samples TT2-E and TT2-A *(Figure 14* and *Appendix D)*. Pollen of cultivated grasses (wheat, rye, and barley) was observed in samples TT2-E through TT2-A, with a general trend of higher amounts towards the top of the trench. One of the most striking changes in relative abundance patterns occurs between samples TT2-F and TT2-E *(Figure 18)*. All samples below TT2-E contain less than 1% opportunistic weed (Chenopodiaceae) pollen. Samples TT2-E through TT2-A show higher relative abundances of this pollen type. The sudden appearance of both the cereal grains and Russian thistle at this horizon (T2-E, at a depth between 0.83-1.04 feet) strongly suggest that this interval corresponds with the beginning of large-scale farming in the area *(Figure 18)*. Therefore, we conclude that the top one foot of sediment at the Tolna site was deposited within the last 100 years.

Discussion

North Dakotans who lived through the Dust Bowl of the 1930s tell remarkable stories of the amount of material eroded and deposited by the wind during these drought years. Photographs from this era depict buildings and fences being overrun by sand dunes *(Figure 19a and b)*. In at least some cases families had to periodically shovel sand and silt out of their attics to keep the rafters from caving in under the weight of the windblown sediment.

It is conceivable that large amounts of windblown sediment settled onto the bottom of the Jerusalem and Tolna outlets during the 1930s. Deposition most likely occurred in areas where the outlet channels are at right angles to the prevailing northwesterly wind. Conversely, areas of the outlet channels that were exposed to the prevailing wind may have experienced erosion in the 1930s. The channel trends east-west at the Jerusalem study site. The study site also is situated upon a topographic high in the channel which may have encouraged erosion rather than deposition of windblown sediment during the 1930s.

Bluemle's (1991) study of the Devils Lake area identified at least four general periods in geologic time when Devils Lake overflowed into Stump Lake. Sand and gravel layers were used to identify fluvial events, whereas paleosols, oxidized horizons, sediments containing terrestrial snails, and rooted sediments were used as indicators of dry land conditions. The oldest overflow that Bluemle was able to date occurred approximately 4,000 to 5,000 years ago, the second occurred about 2,500 years ago, the third around 1,800 years ago, and the fourth event he recognized occurred approximately 700 years ago. Most of Bluemle's evidence was generated from a study of beaches along Devils Lake and from sediments in the Jerusalem Outlet. The majority of radiocarbon dates obtained during our study came from the Tolna Outlet. In order for Stump Lake to overflow through the Tolna Outlet, Devils Lake must first overflow into Stump Lake. Therefore, the overflow events that are recorded in the Tolna study site indirectly indicate overflow events from Devils Lake.

Sufficient sedimentological evidence exists from the Tolna Outlet to document at least six times in the Holocene (the last 10,000 years BP) when water from the Devils Lake/Stump Lake system overflowed into the Sheyenne River *(Figure 20)*. At least two major flood events are recorded between the years 7,800 to 8,700 BP. Two more flood events occurred over the course of the next 400 years (7,800 to 7,400 BP). At least one additional fluvial event occurred prior to 1,100 years BP. No obvious fluvial events are recorded in sediments less than 2,200 years old at the Jerusalem site or 1,100 years old at the

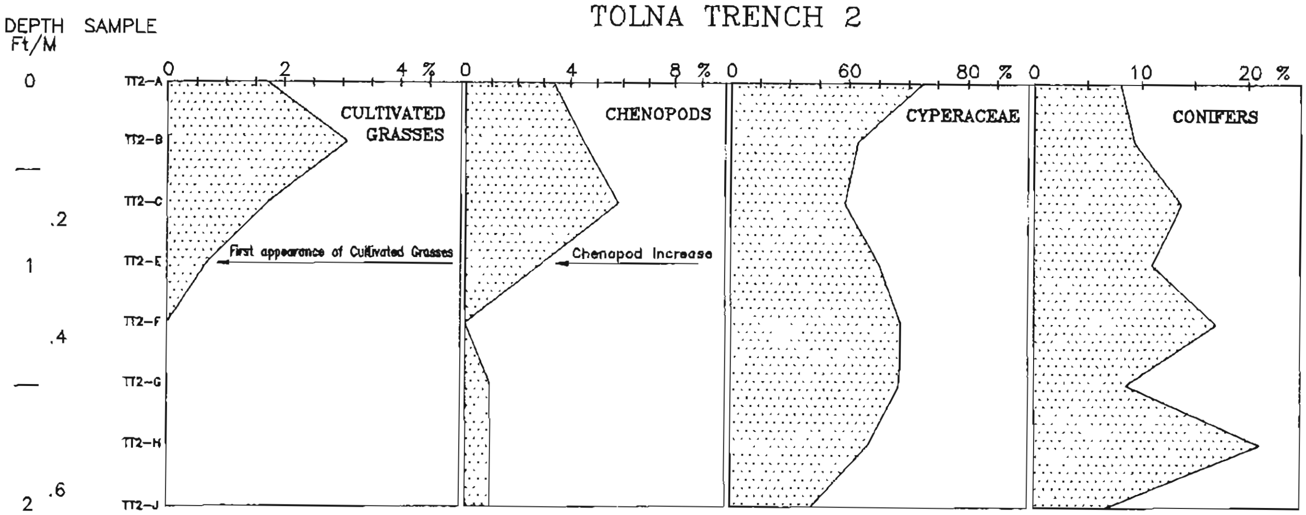

Figure 18 Pollen profiles for sediment samples from Tolna trench TT2.

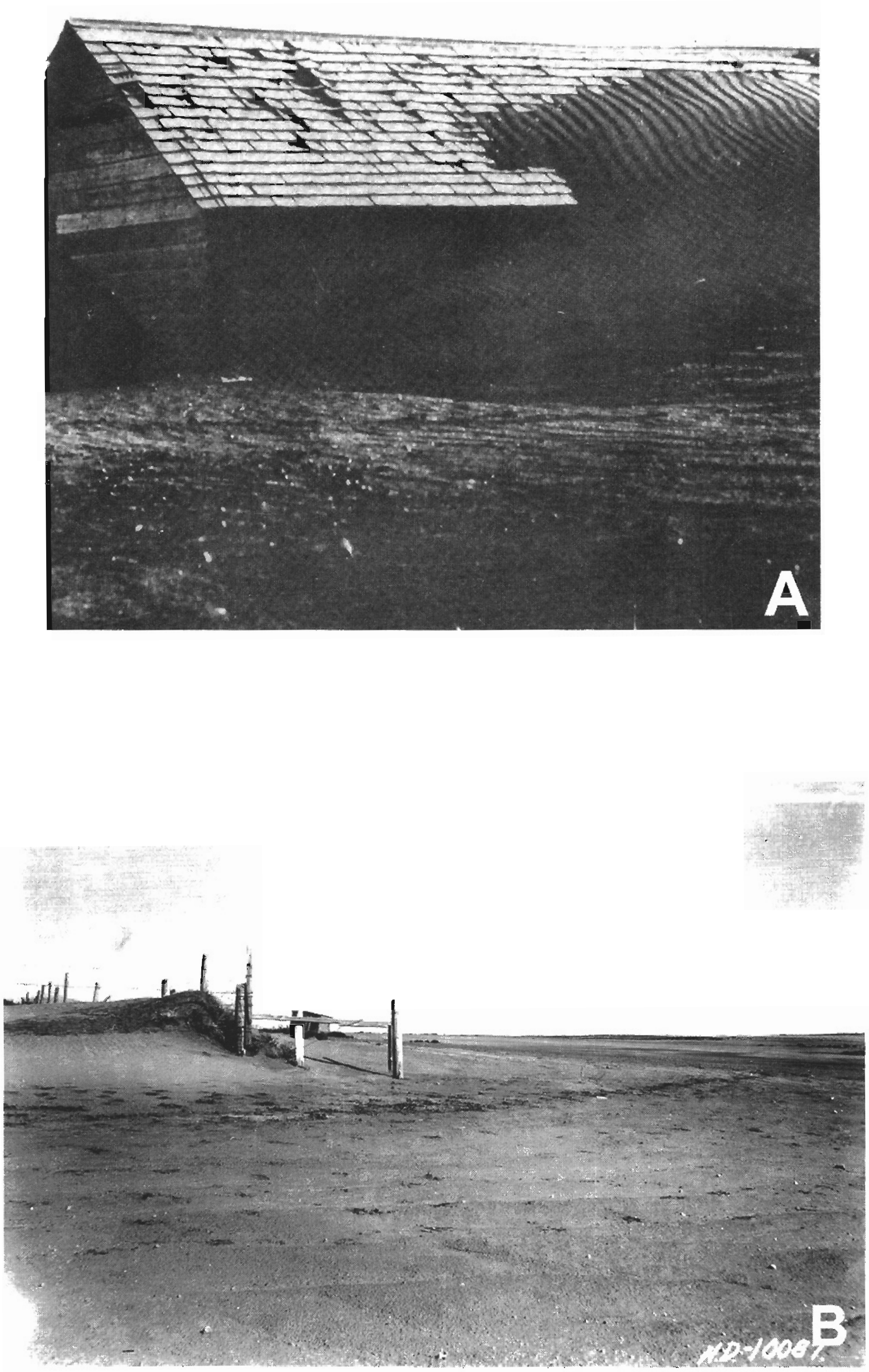

Figure 19. Eolian dune deposited in the Upper Great Plains during the drought of the 1930s. A). An eolian dune has engulfed part of a wall and the roof of a barn. B). Windblown sediments have piled up along a fence line near McKenzie, N.D Photos courtesy of the State Historical Society of North Dakota.

Tolna site. The results of this study have provided some of the older information that was missing from the time\event diagram constructed by Bluemle (1991) for Devils Lake. Unfortunately, no dates have been obtained from sediments in these outlets from 3,000 to 7,000 years BP.

Most pollen studies center around analyses of lake sediments. Lakes generally are the best settings for preserving a nearly continuous record of sedimentation. In addition, Holocene lacustrine sediments have generally not been exposed to oxidizing conditions which can easily destroy pollen grains. Coulees or ravines that only periodically contain standing water are not ideally suited for preserving a continuous pollen record. Therefore, the lack of preserved pollen in the sediments at the Jerusalem site is not surprising.

Results from the Tolna site strongly suggest that the first evidence of European settlement occurs at the level of sample TT2-E at a depth of one foot, and that sediments above that sample were deposited after the region was settled. The relative abundance of opportunistic weeds (Chenopodiaceae) increases in and above sample TT2-E, suggesting the clearing of land for agricultural purposes. In addition, samples in this interval contain pollen of cultivated grasses and traces of Russian thistle (*Salsola*). Taken together, these lines of evidence suggest that, at about the time of deposition of sample TT2-E, European settlers had begun clearing land for settlement purposes. This activity resulted in an increase in the relative abundance of pollen from opportunistic weeds (Chenopodiaceae). In addition, the settlers (inadvertently) introduced Russian thistle (*Salsola*) as they began using cultivated grasses for agricultural purposes.

Results from the Jerusalem Trenches are less conclusive. None of the samples from Jerusalem Trench JT1 contained pollen assemblages that could be used for counting. Scans of these slides revealed the presence of a few pollen types, but

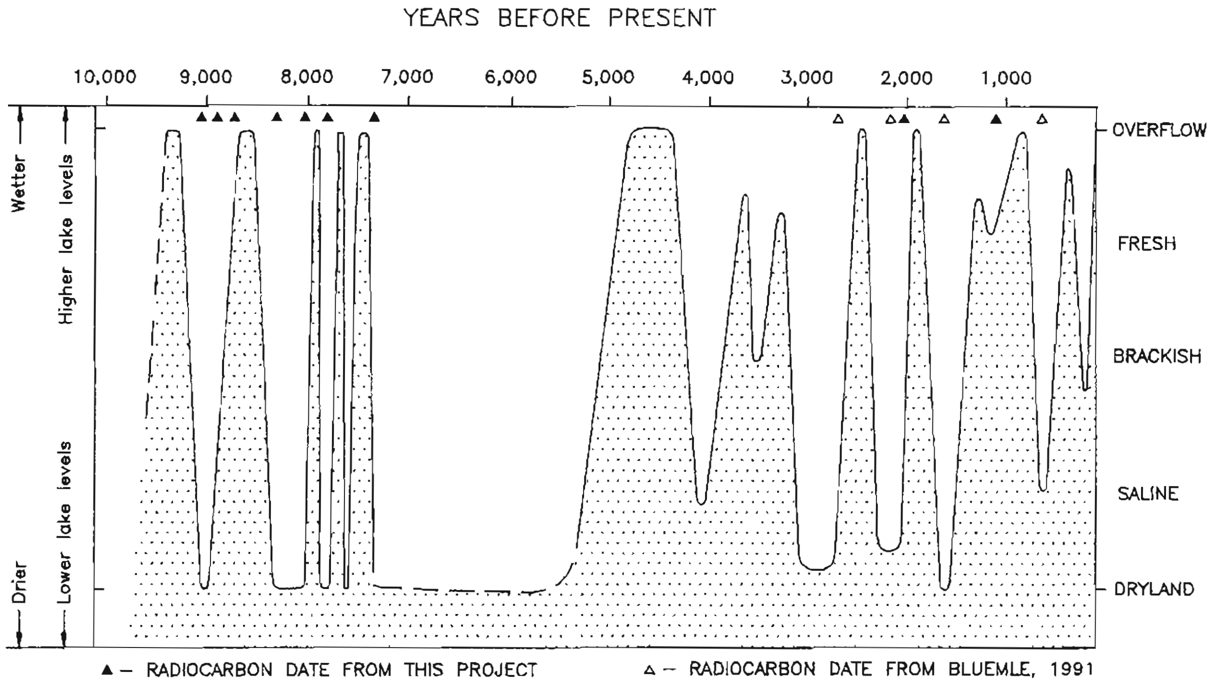

Figure 20. Time/event diagram for Devils Lake (modified from Bluemle, 1991) All of the dates indicated by open triangles were generated from beaches along Devils Lake and sediments in the Jerusalem Outlet All of the dates indicated by solid triangles were based on sediments in Tolna Coulee, except for 9,020 and 1,100 years BP—those two dates came from the Jerusalem Outlet.

none of the slides contained any opportunistic weeds or cultivated grains. Only three of the samples from Jerusalem Trench JT2 contained pollen assemblages that could be counted. All three of these samples contained evidence of Russian thistle and/or cultivated grasses. Thus, the earliest evidence of European settlement from the trenches in Jerusalem Outlet is from sample JT2-C, in Jerusalem Trench JT2 at a depth of 0.4 to 0.6 feet. Better pollen preservation may be found in low areas either east or west of the topographic high at this study site.

In our analysis, we cannot rule out the possibility that modern human activity (e.g., plowing in the latter part of the 20th century) has transported the critical pollen types downward. Mixing of near-surface sediments also can occur due to burrowing of rodents as well as the deep hoof prints of cattle and other animals in areas where the surface is moist. This will essentially homogenize the assemblages throughout the mixed interval and, potentially, lead to erroneous interpretations regarding the lowest occurrence of specific pollen. Therefore, careful evaluation of both sedimentological and historical evidence must be taken into consideration when interpreting pollen results.

Update

In May 2000, the State removed sediment that had accumulated in the Jerusalem Outlet (drainway) and restored the Outlet to its natural original condition, as defined by the State Engineer. As a result, water from Devils Lake would flow as it would have through the natural original drainway.

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Appendix A - Drill Hole Lithologies

Jerusalem Site
T152N, R62W, section 24

Hole 1 1485 fwl (from west section line) Elevation: 1449.1*
1520 fsl (from south section line)

0-1	Topsoil
1-3	Silt, yellow\brown, sandy, clayey, occasional pebbles, laminated
3-18	Till, yellow\brown

Hole 2 1485 fwl, 1620 fsl Elevation: 1448

0-1	Topsoil
1-3	Sand, yellow\brown, silty, pebbles, laminated
3-16	Till, yellow\brown

Hole 3 1490 fwl, 1890 fsl Elevation: 1448.7

0-1	Topsoil
1-4	Silt, brown to dark brown, clayey to sandy, occasional pebbles, roots
4-7	Silt, yellow/brown, clayey to sandy, laminated
7-10	Till, yellow/brown

Hole 4 1490 fwl, 2085 fsl Elevation: 1449.6

0-1	Topsoil
1-5	Silt, dark brown to black, clayey, some pebbles, roots
5-7	Silt, light brown, clayey, contains dark brown to black clay laminae
7-9	Silt, tan, clayey, shell fragments
9-10	Sand, tan to orange, fine grained, FeO stained
10-18	Till, yellow/brown

Hole 5 1495 fwl, 2265 fsl Elevation: 1450.4

0-1	Topsoil
1-6	Clay, dark brown to black, silty
6-9	Silt, yellow/gray
9-10	Sand and gravel, reddish orange, FeO stained
10-14	Till, yellow/brown

Hole 6 1510 fwl, 2485 fsl Elevation: 1452.2

0-1	Topsoil
1-5	Clay, dark brown, silty, roots
5-9	Silt, gray to tan, clayey, FeO stained
9-14	Till, yellow/brown

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* *Elevations determined by ND State Water Commission*

Hole 7 1490 fwl, 1780 fsl Elevation: 1448

0-1	Topsoil
1-5	Clay, dark brown, silty, occasional pebbles
5-8	Silt, yellow/brown to gray, clayey, some pebbles, laminated
8-10	Till, yellow/brown

Hole 8 1500 fwl, 2600 fsl Elevation: 1454.1

0-1	Topsoil
1-3	Loam, dark brown to black
3-7	Till, yellow/brown

Tolna Site
T151N, R61W, section 19

Hole 1 2845 fwl, 1700 fnl Elevation: 1460.7

0-3.5	Loam, dark brown, roots
3.5-4.5	Sand, brown, medium grained
4.5-6	Clay, gray/brown, silty, pebbles
6-8	Silt, green/gray, clayey
8-9.5	Sand and gravel, gray
9.5-13	Silt, gray to gray-green
13-15	Clay, gray/brown, silty
15-17	Silt, blue/gray, clayey
17-20	Peat
20-20.3	Rock
20.3-26	Sand and gravel, gray, poor recovery

Hole 2 2870 fwl, 1805 fnl Elevation: 1461

0-2	Loam, medium brown, pebbles
2-3	Loam, light yellow brown, pebbles
3-6	Sand, yellow/brown, medium grained, poor sorting, pebbles
6-8	Sand, blue to blue/gray, medium grained, silty
8-11	Clay, blue some black staining, silty, pebbles; some shale pebbles, occasional roots
11-12	Sand, green, fine grained, moderately sorted
12-14	Silt, medium to dark gray, clayey, some pebbles
14-14.2	Rock

Hole 3 2840 fwl, 1970 fnl Elevation: 1463.4

0-1	Loam, dark brown, pebbles
1-4	Silt, light gray, clayey, pebbles
4-7	Silt, yellow/brown, sandy, pebbles
7-7.3	Oxidized zone, orange/brown, FeO stained
7.3-8	Sand, green, medium grained, well sorted
8-15	Silt, blue, very fine grained sand
15-25	Till, blue/gray

Appendix B - Sediment Sample Descriptions

Key: [1]Sample Type: W = wood; S = paleosol; P = peat; D = grab sample of sediment.
Asterik (*) indicates sample was submitted for pollen analysis.
Cross (†) indicates sample was submitted for radiocarbon dating.

Project:	Devils Lake
Location:	NE 1/4 of SW 1/4 of Section 24, Township 152N, Range 62W
Surface Elevation:	1450.8 ft. MSL
County:	Ramsey
Observer(s):	Ann Fritz and Ed Murphy
Notes:	Ten (10) samples submitted for pollen analysis
Site:	Jersusalem Trench 1, Fisk Farm, south of house

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
0-0.5	loam, black	JT1-A	D
0.5-0.67	loam, black	JT1-B	D
0.67-0.92	loam, black	JT1-C	D
0.92-1.17	loam, black	JT1-D	D
1.17-1.38	loam, black	JT1-E	D
1.38-1.58	loam, black	JT1-F	D
1.58-1.79	loam, black	JT1-G	D
1.79-2.0	loam, black	JT1-H	D
2.0-2.25	clayey silt, dark brown-black, some very fine grained sand; roots; high organic content	JT1-I	D*
2.25-2.46	clayey silt, dark brown-black, as above	JT1-J	D*
2.46-2.67	clayey silt, dark brown-black, as above	JT1-K	D*
2.67-2.8	clayey silt, dark brown-black, some very fine grained sand; some pebbles; roots; high organic content	JT1-L	D*
2.8-3.0	silty clay, dark brownish-black; pebbles; some sand; roots common; high organic content	JT1-M	D*†
3.0-3.25	silty clay, dark brownish-black; pebbles; sand lenses; roots common; high organic content	JT1-N	D*
3.25-3.75	silty clay; dark brownish-black; sand lenses; roots common; high organic content	JT1-O	D*
3.75-4.0	sandy silt; brown; some pebbles	JT1-P	D
4.0-4.5	sand and gravel, sand matrix; gray/ brown; some pebbles are 3" long diameter; carbonate coating prevelant on pebbles	JT1-Q	D
4.5-5.0	course sand and gravel; gray/brown; some clay; some pebbles are 3" long diameter; carbonate coating prevelant	JT1-V	D
5.0-5.5	coarse sand and gravel; as above	JT1-W	D
5.5-6.0	sand and silt, banded, grayish brown to brown; medium to fine grained sand; sand lenses contain very little fines	JT1-X	D
6.0-6.5	sand and silt, banded, as above; lower surface is wavy	JT1-Y	D
6.5-7.0	clay, brownish-black; paleosol (buried soil horizon); fine roots	JT1-Z	D*
7.0-7.5	clay, dark brown-gray; silty; fine roots; lower surface is irregular	JT1-AA	D*
7.5-7.67	silty clay, tan; shells and snails abundant	JT1-AB	D
7.67-8.5	silty clay, light tan to gray; root traces are common; few shells; some thin tan silt layers; some iron oxide staining; gray clay is present, could be filled in burrows or depressions	JT1-AC	D*
8.5-9.5	silty clay, reddish yellow green; heavily rooted; iron staining at lower 6"; pebble layer present at base of unit	JT1-AD	D
9.5-13.0 Bottom of trench	sandy clay, yellow brown; unsorted and unstratified, some pebbles; iron staining; interpreted as glacial deposit (till)	JT1-AE	D

Project: Devils Lake
Location: NE 1/4 of SW 1/4 of Section 24, Township 152 N, Range 62W
Surface Elevation: 1447.1 ft. MSL
County: Ramsey
Observer(s): Ann Fritz and Ed Murphy
Notes: Twelve (12) samples submitted for pollen analysis (all samples from trench)
Site: Jersusalem Trench 2, located in cattail area, Fisk farm

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
0-0.21	silt, black; modern cattail roots	JT2-A	D*
0.21-0.42	silty clay, dark brown-black; modern roots	JT2-B	D*
0.42-0.63	silty clay, as above	JT2-C	D*
0.63-0.83	clay loam, dark brown-black; modern roots	JT2-D	D*
0.83-1.04	clay loam; as above	JT2-E	D*
1.04-1.42	silty clay, dark brown-black, roots	JT2-F	D*
1.42-1.63	silty clay, as above	JT2-G	D*
1.63-1.92	silty clay, as above	JT2-H	D*
1.92-2.13	silty clay, gray-black	JT2-I	D*
2.13-2.33	silty clay, dark brown and gray, mottled; small black inclusions (manganese oxide?)	JT2-J	D*
2.33-2.54	silty clay, as above	JT2-K	D*
2.54-2.75	clay, dark brown and tan mottled; white carbonate (?) nodules	JT2-L	D*
2.75 Bottom of trench	sandy clay; color; pebbles; glacial deposit		

Project: Devils Lake
Location: NE 1/4 of SW 1/4 of Section 24, Township 152 N, Range 62W
Surface Elevation: 1448.9 ft. MSL
County: Ramsey
Observer(s): Ann Fritz and Ed Murphy
Notes: No samples collected from this trench
Site: Jersusalem Trench 3, Fisk farm

Depth (In Feet)	Description
0-3.0	loam, dark brown
3.0-5.0 Bottom of trench	sandy clay, yellow brown; unsorted and unstratified, some pebbles; interpreted as glacial deposit (till)

Project: Devils Lake
Location: NE 1/4 of SW 1/4 of Section 24, Township 152 N, Range 62W
Surface Elevation: 1449.5 ft. MSL
County: Ramsey
Observer(s): Ann Fritz and Ed Murphy
Notes: No samples submitted for pollen analysis
Site: Jersusalem Trench 4

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
0-3.33	loam, dark brown, undulating lower surface; possible burrow fills	JT4-A	D
3.33-4.58	silty clay, tan to brown; iron staining	JT4-B	D
4.58-6.5	sand and gravel, brown to orange; some discernable layering	JT4-C	D
6.5-9 Bottom of trench	sandy clay, orange to brown; with clay, pebbles; unsorted and unstratified; interpreted to be a glacial deposit (till)	JT4-D	D

Project: Devils Lake
Location: NE 1/4 of SW 1/4 of Section 24, Township 152 N, Range 62W
Surface Elevation: 1449.9 ft. MSL
County: Ramsey
Observer(s): Ann Fritz and Ed Murphy
Notes: No samples submitted for pollen analysis from this trench
Site: Jersusalem Trench 5, located located immediately north of trench 4

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
0-4.67	silt, dark brown-black; frozen; bottom 6 inches burrowed and filled in with sand; organic rich	JT5-A	D
4.67-6.25	silty clay; yellowish brown to gray, base is heavily rooted, top is burrowed(?)	JT5-B	D
6.25-6.67	silty clay, black; paleosol, some sand lenses; shell fragments common	JT5-C	D, S (6.5')†
6.67-7.67	silty clay, light gray; shells dispersed throughout unit, but more prevalant in top	JT5-D	D
7.67-8.5	clayey silt, grayish orange; iron stained; root traces; few shells	JT5-E	D
8.5-9.42	gravel, reddish orange; iron stained; sand lenses	JT5-F	D
9.42-11.0 Bottom of trench	glacial till; yellow-brown and gray mottled.	JT5-G	D

Project: Devils Lake
Location: NW 1/4 of SW 1/4 of NE 1/4 of Section 19, Township 151N, Range 61W
Surface Elevation: 1460.5 ft. MSL
County: Nelson
Observer(s): Ann Fritz and Ed Murphy
Notes: No samples were submitted for pollen analysis from this trench
Site: Tolna Trench 1, Roger Johnson Farm

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
0-0.4	loam, dark brown; modern roots; organic rich	TT1-A	D
0.4-0.8	loam; as above	TT1-B	D
0.8-1.25	loam; as above	TT1-C	D
1.25-1.7	loam; as above	TT1-D	D
1.7-2.0	loam; as above	TT1-F	D
2.0-2.5	loam; as above	TT1-G	D H
2.5-2.9	clayey silt, gray brown; sand lense, organic horizons	TT1-H	D
2.9-3.3	clayey silt, gray brown; sand lense, organic horizons	TT1-I	D
3.3-3.5	sand and gravel, medium gray/brown; water seepage at this interval	TT1-J	D
3.5-3.75	sand, brown	TT1-K	D
3.75-4.2	sand, brown	TT1-L	D
4.2-4.6	silty clay, gray/brown; some iron oxide staining; root traces	TT1-M	D
4.6-5.0	silty clay, gray/brown; as above	TT1-N	D
5.0-5.4	silty clay, gray/brown mottled; some iron oxide staining; heavily rooted	TT1-O	D
5.4-5.8	silty clay, light brown; some pebbles	TT1-P	D
5.8-6.25	sand, green/gray; pebbles; black organic layers; iron oxide staining; top of oxidized interval	TT1-Q	D
6.25-6.7	sand, reddish orange; very fine grained; oxidized horizon; some black layers visible; rooted	TT1-R	D
6.7-7	sand, reddish orange; as above	TT1-S	D
7-7.5	clayey silt, green/gray; contains sand and gravel lenses; roots	TT1-T	D
7.5-8.0	clayey silt, green/gray; paleosol layer	TT1-U	D, S(8')†

Continued . . .

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
8.0-8.3	sand and gravel; blue-gray; rootlets visible; shale pebbles numerous	TT1-V	D
8.3-8.5	sand and gravel, blue-gray; large cobbles of shale and limestone	TT1-W	D
8.5-9.0	sand and gravel; blue-gray; rootlets visible; shale pebbles numerous	TT1-X	D
9.0-9.5	sand and gravel; blue-gray; as above	TT1-Y	D
9.5-10.0	clayey silt, some shaley sand; root traces; shells	TT1-Z	D, W (9.5-10)
10.0-10.5	silty clay, dark brown ; pebbly; ribbons slightly; many roots distributed throughout peds; many poorly preserved shells and snails,	TT1-AA	D
10.5-11.0	sand and gravel; some silt; shale predominants sand fraction, largest pebbles are dolomite/limestone	TT1-AB	D
11.0-12.0	silt, light gray; more sandy than 10-10.5 interval; wood/plant fragments; shells and snails are abundant; thin paleosol	TT1-AC	D S (11.5) W(11.5) †
12.0-12.75	silt, gray to gray-green; occasional pebble, fibrous wood/plant fragments common	TT1-AD	D, W(12.5)
	sandy clay, dark green; very fine grained sand	TT1-AE	D
	clayey silt, gray/brown; shell horizon; roots; some sand lenses	TT1-AF	D

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
12.75-13.0	coarse sand layer, some cobbles	TT1-AG	D
13.5-14.0	silty clay, dark gray/black; roots and wood present	TT1-AH	D,W (13')†
14.0-14.5	silty clay, gray brown; contains medium to coarse roots, wood fragments	TT1-AI	D, W (14-14.5)†
14.5-15.0	silty clay, gray brown	TT1-AJ	D
15.0-15.7	silt; wood/plant fragments	TT1-AK	D
15.7-16.5	silty sand, blue gray; very fine grained sand; roots and wood fragments	TT1-AL	D
16.5	silty clay, dark blue-gray; wood and plant fibers; scattered shells and snails	TT1-AM	D W (16-17) †
16.5-17.0	clayey silt, dark gray; wood and plant fibers; scattered shells and snails	TT1-AN	D, S
17.0 - 17.5	Peat, reddish-brown; wood, snails and shell fragments common	TT1-AO	P
	Peat; as above	TT1-AP	P
17.5-18.0 Bottom of trench	sand and gravel		

Project: Devils Lake
Location: NW 1/4 of NE 1/4 of SW 1/4 of Section 19, Township 151N, Range 61W
Surface Elevation: 1460.2 ft MSL
County: Nelson
Observer(s): Ann Fritz and Ed Murphy
Notes: Samples submitted for pollen and radiocarbon analysis are noted
Site: Tolna Trench 2, Roger Johnson farm

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
0-0.21	loam, dark brown; organic rich	TT2-A	D *
0.21-0.42	loam, dark brown; organic rich	TT2-B	D *
0.42-0.63	loam, dark brown; organic rich	TT2-C	D *
0.63-0.83	loam, dark brown; organic rich	TT2-D	D *
0.83-1.04	loam, dark brown; organic rich	TT2-E	D *

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
1.04-1.25	silty clay loam; dark brown; organic rich	TT2-F	D *
1.25-1.46	silty clay loam, dark brown; organic rich	TT2-G	D *
1.46-1.67	silty clay loam, dark brown; organic rich	TT2-H	D *
1.67-1.88	silty clay loam, yellow brown	TT2-I	D *
1.88-2.08	silty clay loam, dark brown and tan, mottled; becoming sandier than above units	TT2-J	D *

Continued . . .

Depth (In Feet)	Description	Sediment Sample ID	Sample Type[1]
2.08-2.29	clayey silt, light gray/brown; discontinuous boundary; inclusions of black silty clay loam	TT2-K	D
2.29-2.5	clayey silt, light gray/brown; as above	TT2-L	D
2.5-2.71	sand, light brown; medium to coarse grained sand, pebbles; roots	TT2-M	D
2.71-2.92	sand, light brown; as above	TT2-N	D
2.92-3.13	sand, light brown; as above	TT2-O	D
3.13-3.33	sand, light brown; as above	TT2-P	D
3.33-3.54	sand, light brown; as above	TT2-Q	D
3.54-3.75	sand, light brown; as above	TT2-R	D
3.75-3.96	sand, light brown; as above	TT2-S	D
3.96-4.17	silty sand, light gray brown; some clay horizons; sand sequence (from this point up to 2.5') is coarsening upwards	TT2-T	D
4.17-4.38	clayey silt; gray/brown; sandy; some thin organic layers; heavily rooted; some shell fragments	TT2-U	D
4.38-4.58	clayey silt, gray/brown; sandy; heavily rooted; snail shells	TT2-V	D
4.58-4.79	clayey silt, gray/brown; sandy; heavily rooted; some well preserved shell fragments	TT2-W	D
4.79-5.0	sandy clay, gray brown; iron staining, burrow fillings/root trails have manganese coats; some shell fragments	TT2-X	D *
5.0-5.21	silty clay; medium to coarse roots; oxidation occurring on root trails	TT2-Y	D
5.21-5.42	clayey silt; gray to brown; occasional pebbles; iron staining; medium to coarse roots	TT2-Z	D
5.42-5.625	clayey silt; as above	TT2-AA	D
5.625-5.83	clayey silt; as above	TT2-AB	D
5.83-6.04	silty clay, gray brown; sandy; heavily rooted; iron oxide staining	TT2-AC	D
6.04-6.25	clayey silt, dark green/gray to orange; silt lenses; iron oxide and mineralized root traces; iron oxide layers	TT2-AD	D
6.25-6.46	clayey silt, dark green/gray to orange; silt lenses; iron oxide and mineralized root traces; iron oxide layers	TT2-AE	D
6.46-6.67	clayey silt, dark green; occasional thin sand lense; root traces are abundant; woody root fragments; shells	TT2-AF	D*
6.67-8.8	clayey silt, dark green; some shells; occasional thin sand lense; paleosol layer	TT2-AG	D, S(7'9")
8.8-9.2	clayey silt, dark green; occasional thin sand lense	TT2-AH	D
9.2-10.0	sand and gravel, medium gray	TT2-AI	D
10.0-11.3	silty clay, gray; heavily rooted, some of the rooted zones have blue-green stains; intermittant sand lenses	TT2-AJ	D
11.3-12.0	clayey silt, dark brown to green-gray; some silty clay zones; some pebbles; roots and wood abundant	TT2-AK	D*
12.5-13.0	clayey silt, green-gray; contains wood fragments and roots	TT2-AL	D, W
13.0-14.0	silty clay, black-brown; irregular boundary between this unit and green-gray clayey silt from above; roots	TT2-AM	D
14.0-15.0	silt, black-brown; very coarse granular structure; contains plant fragments, roots and small pebbles; few shells	TT2-AN	D
15.0-16.0	silt, dark gray; contains plant fragments, roots	TT2-AO	D
16.0-17.0	silty clay, dark gray; contains plant fragments (horsetail {?}stem visible), roots	TT2-AP	D
17.0-18.0	silt, brownish gray to gray-green; contains fibrous plant matter and few seed pods; shells and snails are abundant but poorly preserved; irregular boundary with above unit	TT2-AQ	D*
18.0-20.0 Bottom of trench	peat, reddish brown to black; shells and snails are abundant but poorly preserved; wood and plant fragments common.	TT2-AR	D* P(19'), W(19')†

Appendix C - Radiocarbon Dates

NDGS Sample #	Beta Labs Sample #	C14 Age	Calendrical Calibration (2 sigma calibration)
JT1-M (low carbon)	104618	2190 ± 70 BP	
JT5-6.5 (low carbon)	104373	9020 ± 80 BP	8130 to 7950 BC
TT2-19 (wood)	104381	8880 ± 70 BP	8040 to 7870 BC 7815 to 7715 BC
TT1-17 (wood)	104380	8740 ± 60 BP	7950 to 7575 BC
TT1-14 (wood)	104379	8480 ± 90 BP	7605 to 7325 BC
TT1-13 (wood)	104378	8000 ± 100 BP	7235 to 7160 BC 7140 to 6580 BC
TT1-11.5 (wood)	104376	7820 ± 80 BP	6985 to 6825 BC 6795 to 6450 BC
TT1-8 (paleosol)	104375	7390 ± 60 BP	6370 to 6055 BC
TT1-G (low carbon)	104374	1100 ± 60 BP	800 to 1030 AD

The following information is from the Beta Analytic Inc. Radiocarbon Dating Services report:

Dates were reported as RCYBP (radiocarbon years before present, "present" = 1950 A.D.). The C14 age was determined in the lab by applying C13/C12 ratio corrections to the measured age. Calibrations of radiocarbon age determinations are applied to convert BP results to calendar years. The short term difference between the two is caused by fluctuations in the heliomagnetic modulation of the galactic cosmic radiation and, recently, large scale burning of fossil fuels and nuclear device testing. Geomagnetic variations are the probable cause of long term differences.

The parameters used for the corrections have been obtained through precise analyses of hundreds of samples taken from known-age tree rings of oak, sequoia, and fir up to 7,200 years BP. The Pretoria Calibration Procedure program has been chosen for these dendrocalibrations. It uses splines through the tree-ring data as calibration curves, which eliminates a large part of the statistical scatter of the actual data points. The spline calibration allows adjustment of the average curve by a quantified closeness-of-fit parameter to the measured data points.

Appendix D - Palynological Analyses

TABLE 1

Occurence Data for Jerusalem Trench #1

(X = observed as traces in scans, no counts made)

	JT1-I	JT1-K	JT1-L	JT1-M	JT1-O
Pinus sp.				X	X
Cyperaceae				X	X
Typha spp.				X	
Gramineae (feral)			X		X
Gramineae (cultivar)					
Chenopodiaceae	X	X			X
Salsola sp.					
Compositae/Liguliflorae			X	X	X
Compositae/Tubuliflorae			X	X	X
Ambrosia sp.					
Artemisia sp.					
Iva xanthifolia					
Shepherdia sp.					
Acer sp.					
Alnus sp.					
Betula sp.					
Quercus sp.					
Salix sp.					
Ulmus sp.					
Ephedra sp.					
Unknown Pollen					
Total					
Pediastrum spp.					
Mougeotia sp.					
Other Algae					
Sphagnum sp.					
Spores					
Unknown					

TABLE 2

Raw Count Data for Jerusalem Trench # 2

(X = trace amount not encountered in count)

	JT2-A	JT2-B	JT2-C	JT2-E	JT2-G	JT2-I	JT2-K	JT2-L
Pinus sp.	34	52	41	X				X
Cyperaceae	17	24	21		X			X
Typha spp.	17	16	3			X		
Gramineae (feral)	29	13	8				X	
Gramineae (cultivar)	7	6	3					
Chenopodiaceae	29	36	33	X				
Salsola sp.	X	X	X					
Compositae/Liguliflorae	10	11	9					
Compositae/Tubuliflorae	7	4	2					
Ambrosia sp.	0	0	0					
Artemisia sp.	2	0	1					
Iva xanthifolia	1	1	0					
Shepherdia sp.	0	0	0					
Acer sp.	0	0	0					
Alnus sp.	1	0	1					
Betula sp.	0	3	0					
Quercus sp.	1	1	0					
Salix sp.	0	3	3					
Ulmus sp.	0	0	0					
Ephedra sp.	0	0	0					
Unknown Pollen	3	3	5					
Total	158	173	130					
Pediastrum spp.	0	1	1	X	X	X	X	
Mougeotia sp.	0	0	0					
Other Algae	0	0	0					
Sphagnum sp.	0	1	0					
Spores	2	6	7					
Unknown	0	0	0					

TABLE 3

Pollen Percentages for Jerusalem Trench # 2

(X – trace amount not encountered in count)

	JT2-A	JT2-B	JT2-C
Pinus sp.	21.5%	30.1%	31.5%
Cyperaceae	10.8%	13.9%	16.2%
Typha spp.	10.8%	9.2%	2.3%
Gramineae (feral)	18.4%	7.5%	6.2%
Gramineae (cultivar)	4.4%	3.5%	2.3%
Chenopodiaceae	18.4%	20.8%	25.4%
Salsola sp.	X	X	X
Compositae/Liguliflorae	6.3%	6.4%	6.9%
Compositae/Tubuliflorae	4.4%	2.3%	1.5%
Ambrosia sp.	0.0%	0.0%	0.0%
Artemisia sp.	1.3%	0.0%	0.8%
Iva xanthifolia	0.6%	0.6%	0.0%
Shepherdia sp.	0.0%	0.0%	0.0%
Acer sp.	0.0%	0.0%	0.0%
Alnus sp.	0.6%	0.0%	0.8%
Betula sp.	0.0%	1.7%	0.0%
Quercus sp.	0.6%	0.6%	0.0%
Salix sp.	0.0%	1.7%	2.3%
Ulmus sp.	0.0%	0.0%	0.0%
Ephedra sp.	0.0%	0.0%	0.0%
Unknown Pollen	1.9%	1.7%	3.8%
Total	100.0%	100.0%	100.0%

TABLE 4

Tolna Trench #2 Raw Count Data

(X - trace amount not encountered in count)

	TT2-A	TT2-B	TT2-C	TT2-D	TT2-E	TT2-F	TT2-G	TT2-H	TT2-I	TT2-J
Pinus sp.	29	25	33		39	30	22	35	X	16
Cyperaceae	230	111	92	X	157	144	123	139	X	71
Typha spp.	5	2	0		2	1	2	0		6
Gramineae (feral)	19	18	13		20	18	14	24		52
Gramineae (cultivar)	6	8	4		1	0	0	0		0
Chenopodiaceae	12	12	14	X	7	1	2	3		2
Salsola sp.	X	0	0		X	0	0	0		0
Compositae/Liguliflorae	42	62	66		45	26	26	23	X	38
Compositae/Tubuliflorae	0	0	0		3	6	3	3		7
Ambrosia	4	3	2		1	0	0	0		2
Artemisia sp.	0	0	0		0	0	0	0		0
Iva xanthifolia	0	0	0		0	2	2	2		3
Shepherdia sp.	2	3	4		0	0	0	0		0
Acer sp.	0	0	0		1	0	0	0		1
Alnus sp.	0	0	0		0	0	0	0		0
Betula sp.	0	2	0		0	1	0	1		2
Quercus sp.	2	1	1		0	1	0	5		1
Salix sp.	1	0	0		0	1	0	0		0
Ulmus sp.	0	2	1		1	2	2	1		3
Ephedra sp.	0	1	0		0	0	0	0		0
Unknown Pollen	7	11	8		14	10	10	12		14
Total	359	261	238		291	243	206	248		218
Pediastrum sp.	1	1	1		2	0	1	0		0
Mougeotia sp.	0	0	1		0	0	0	0		0
Other Algae	2	1	4		0	1	4	1		4
Sphagnum sp.	1	0	1		3	5	4	2		2
Spores	0	5	5		1	1	2	6		3
Unknown	0	0	0		0	1	0	1		1

TABLE 5

Pollen Percentages for Tolna Trench #2

(X - trace amount not encountered in count)

	TT2-A	TT2-B	TT2-C	TT2-D	TT2-E	TT2-F	TT2-G	TT2-H	TT2-I	TT2-J
Pinus sp.	8.1%	9.6%	13.9%		13.4%	12.3%	10.7%	14.1%	X	7.3%
Cyperaceae	64.1%	42.5%	38.7%	X	54.0%	59.3%	59.7%	56.0%	X	32.6%
Typha spp.	1.4%	0.8%	0.0%		0.7%	0.4%	1.0%	0.0%		2.8%
Gramineae (feral)	5.3%	6.9%	5.5%		6.9%	7.4%	6.8%	9.7%		23.9%
Gramineae (cultivar)	1.7%	3.1%	1.7%		0.3%	0.0%	0.0%	0.0%		0.0%
Chenopodiaceae	3.3%	4.6%	5.9%	X	2.4%	0.4%	1.0%	1.2%		0.9%
Salsola sp.	X	0.0%	0.0%		X	0.0%	0.0%	0.0%		0.0%
Compositae/Liguliflorae	11.7%	23.8%	27.7%		15.5%	10.7%	12.6%	9.3%	X	17.4%
Compositae/Tubuliflorae	0.0%	0.0%	0.0%		1.0%	2.5%	1.5%	1.2%		3.2%
Ambrosia	1.1%	1.1%	0.8%		0.3%	0.0%	0.0%	0.0%		0.9%
Artemisia sp.	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%		0.0%
Iva xanthifolia	0.0%	0.0%	0.0%		0.0%	0.8%	1.0%	0.8%		1.4%
Shepherdia sp.	0.6%	1.1%	1.7%		0.0%	0.0%	0.0%	0.0%		0.0%
Acer sp.	0.0%	0.0%	0.0%		0.3%	0.0%	0.0%	0.0%		0.5%
Alnus sp.	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	0.0%		0.0%
Betula sp.	0.0%	0.8%	0.0%		0.0%	0.4%	0.0%	0.4%		0.9%
Quercus sp.	0.6%	0.4%	0.4%		0.0%	0.4%	0.0%	2.0%		0.5%
Salix sp.	0.3%	0.0%	0.0%		0.0%	0.4%	0.0%	0.0%		0.0%
Ulmus sp.	0.0%	0.8%	0.4%		0.3%	0.8%	1.0%	0.4%		1.4%
Ephedra sp.	0.0%	0.4%	0.0%		0.0%	0.0%	0.0%	0.0%		0.0%
Unknown Pollen	1.9%	4.2%	3.4%		4.8%	4.1%	4.9%	4.8%		6.4%
Total	100.0%	100.0%	100.0%		100.0%	100.0%	100.0%	100.0%		100.0%