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CPG/NGSC Field Trip Guide Book

Environmental Geoscience in the Red River Valley

Manitoba Geological Survey

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Environmental Geoscience in the Red River Valley

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FOREWARD

Since their inception, provincial geological surveys have played critical roles in the exploration and extraction of Canada's abundant natural resources. In Manitoba, the rapid growth in diamond exploration spurred on by multimedia geochemical surveys in the northern Superior Province and the adjacent Hudson Bay Lowland is only the most recent example of the positive influence geoscience can have on local economic development. However, the contributions of geoscience are not simply limited to opening up new areas for exploration or extending the lifespan of mature mines. Geoscience can also help us understand how the recent geological past can affect our world today. Ancient glaciations still impact communities built around Manitoba's lakeshores while the flat-bottomed remains of Lake Agassiz ensures that the Red River valley will always be affected by widespread spring flooding. Understanding these influences is critical to develop adequate flood protection, to ensure hydroelectric supplies and to plan many other important future initiatives.

The mandate of the Manitoba Geological Survey includes the study of recent or ongoing geological processes. Several recent projects have demonstrated that geoscience can provide considerable insight into issues that are both socially- and economically-relevant. Along with collaborators at the Geological Survey of Canada and local universities, MGS scientists have greatly improved our knowledge of the geological processes that continue to affect the lives of Manitobans.

We are very pleased that this field trip allows us the opportunity to showcase the recent accomplishments of our department related to environmental geoscience. Ongoing MGS research on flood hazards in the Red River valley has had an enormous impact on flood preparedness in southern Manitoba and is an excellent illustration of the potential contributions that provincial geological surveys can make to non-traditional problems and non-traditional clients. Join us as we follow the Red River through its recent geological history and examine its influence on the past, present and future of Manitoba.

Ric Syme
Director, Manitoba Geological Survey

RED RIVER FLOODS

More than any other large city in Canada, Winnipeg has suffered repeated physical, social and economic injury due to severe flooding. Although Winnipeg largely escaped the "flood of the century" in 1997 without bearing serious damage, the Red River still forced the evacuation of over 28,000 people in Manitoba and had a direct economic impact of roughly $500 million. Similar large floods threatened Winnipeg in 1979 and 1950 and caused extensive damage to the fledgling Red River Settlement in 1861, 1852 and 1826.

In order to improve flood safety in the Red River valley, we must decide what level of protection is required to safeguard against future extreme floods. Future flood risks are estimated from the pattern of high-magnitude floods in the past. However, since flood records for most Canadian rivers have been kept for less than 100 years, extrapolated return intervals for large floods, such as the "500-year" or "1,000-year" flood, are highly uncertain. Analysis at the start of the floodway project in 1962 indicated that it would protect Winnipeg from floods with a return period of 160 years. More recent estimates of the floodway's capacity range between 100-yr and 681-yr floods.

Flooding is a dynamic process that is often affected by geomorphic, geological and climatic change. Although these changes can occur very slowly, they may be very significant when considered over the time horizons used in the design of flood protection structures (typically between 100-1,000 years). The perspective offered by geoscientific research allows us to understand the subtle environmental processes that can either increase or reduce flood hazards over the long term.

Following the 1997 Red River flood, the Manitoba Geological Survey and Geological Survey of Canada initiated a large, multi-disciplinary research program on flood hazards in the Red River Basin. The main objective of this program was to provide a better understanding of the history and causes of past extreme floods and to determine how the risk of flooding changes over time. The project has focused on several separate lines of investigation, including efforts to develop limnological flood records from the south basin of Lake Winnipeg as well as studies of the alluvial geomorphology and sedimentology along the Red River. However, the project has also exploited the annual nature of tree growth to develop records of past flooding and climatic change in the Red River basin that extend back several centuries. Results provided by the joint MGS-GSC dendrochronology laboratory (established at Winnipeg in 1999) represent significant advances in the field of paleoflood hydrology and have also engaged the imagination of Manitobans through a series of popular lectures and media features.

This field trip will highlight research related to Red River flooding and demonstrate how the recent past can help us better protect Winnipeg and the rest of the Red River valley in the future (Fig. 1). We will leave Winnipeg at 8:30 AM and follow the Red River south towards its headwaters in the United States. A light lunch will be served at historic Fort Dufferin, near Emerson, Manitoba. We plan to be back in Winnipeg around 5:00 PM, which will give everyone time wander a bit before reconvening at the Forks for dinner.

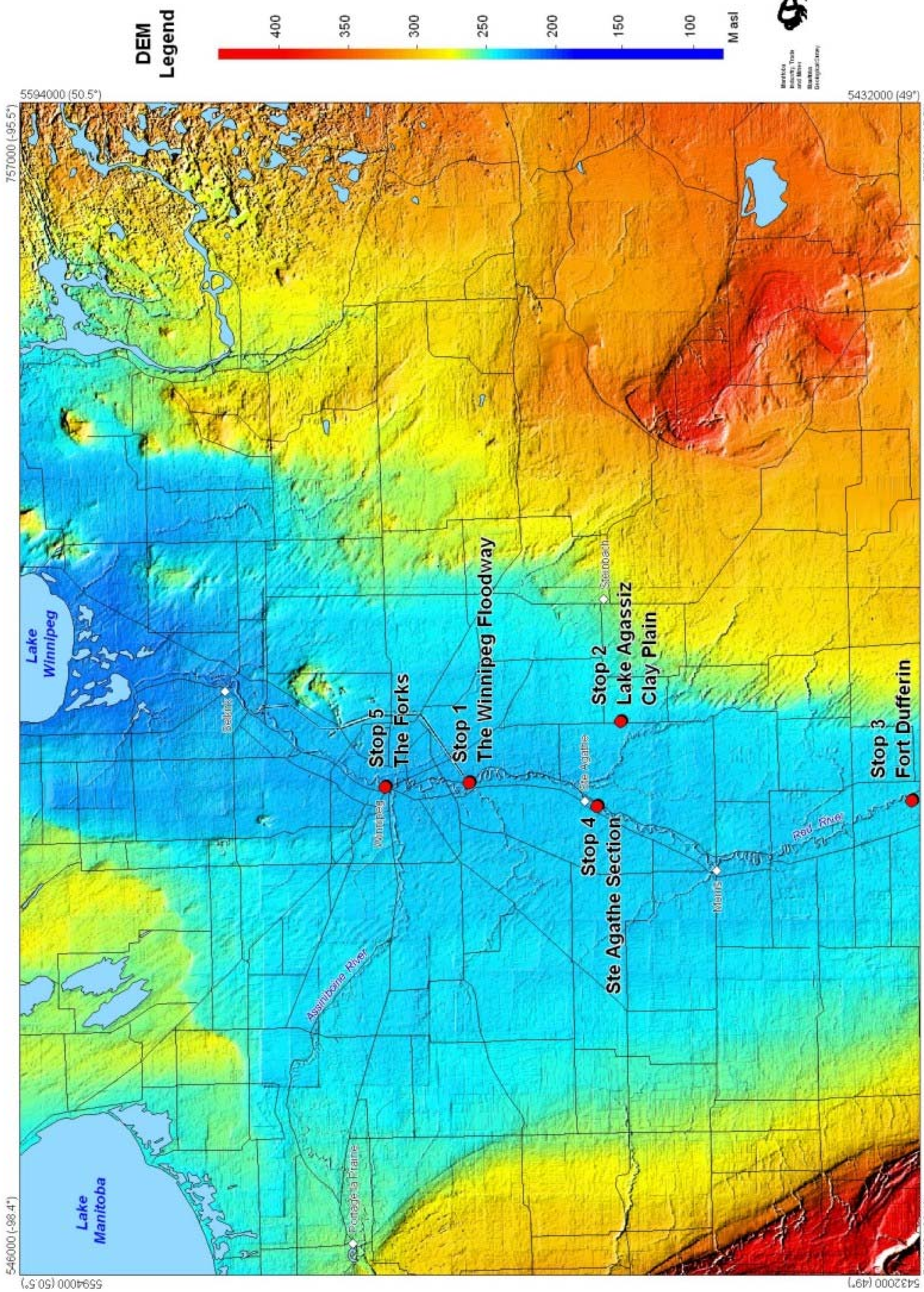


Figure 1: Field trip route map.

FIELD TRIP STOPS

STOP 1 – THE WINNIPEG FLOODWAY
The Winnipeg Floodway is Winnipeg's main line of defence against the fury of the Red River. Here we will discuss the ongoing challenges posed by flooding in a flat land.

The Red River originates in southern North Dakota and Minnesota at the confluence of the Bois de Sioux and Otter Tail rivers, and flows northward into Manitoba as a meandering single-channel river, ultimately draining 290,000 km^2 before its termination at the south end of Lake Winnipeg. Starting in the 1960s, flooding in southern Manitoba has been controlled by a series of structures designed to mitigate flood hazards; consequently, most people in the Red River basin now live and work inside areas protected by individual or communal flood dikes or diversions. Winnipeg's primary flood protection is the Red River Floodway, a 48-km long excavated channel that diverts river flow around Winnipeg and prevents stages within the city from rising above the city's primary dikes (Fig. 2).

Figure 2: The Winnipeg floodway narrowly contained flood flows in 1997. An additional rise of two feet would likely have overwhelmed Winnipeg's diking system and caused several billion dollars in damages.

A second excavated channel regulates the flow of the Assiniboine River (the Red River's main tributary) and can divert up to 700 m^3/s of its flow into Lake Manitoba. The natural zone of flooding in southern Manitoba has also been affected, to a lesser degree, by an extensive diking network southwest of Winnipeg, a number of ring dikes protecting smaller communities, and by elevated roads and railways.

Floodway facts

- Floodway construction began in 1962 and was completed in 1968.
- At the time of its construction, the project was the second largest excavation project in the word, exceeded only by the construction of the Panama Canal.
- The capacity of the floodway is 1,900 m^3/s (67,000 cfs).
- The final total cost of the floodway was $61.2 million, which is equivalent to $325 million today.

During the 1997 Red River flood, the design capacity of the floodway was slightly (and safely!) exceeded. However, rainfall or high winds during the flood peak could have caused a catastrophic dike failure in Winnipeg, with potential damages exceeding $10 billion. Recent engineering studies have proposed enhancing flood protection for Winnipeg, either by expanding the capacity of the Floodway or constructing a retention structure near Ste Agathe, Manitoba with estimated costs between $500 and $700 million.

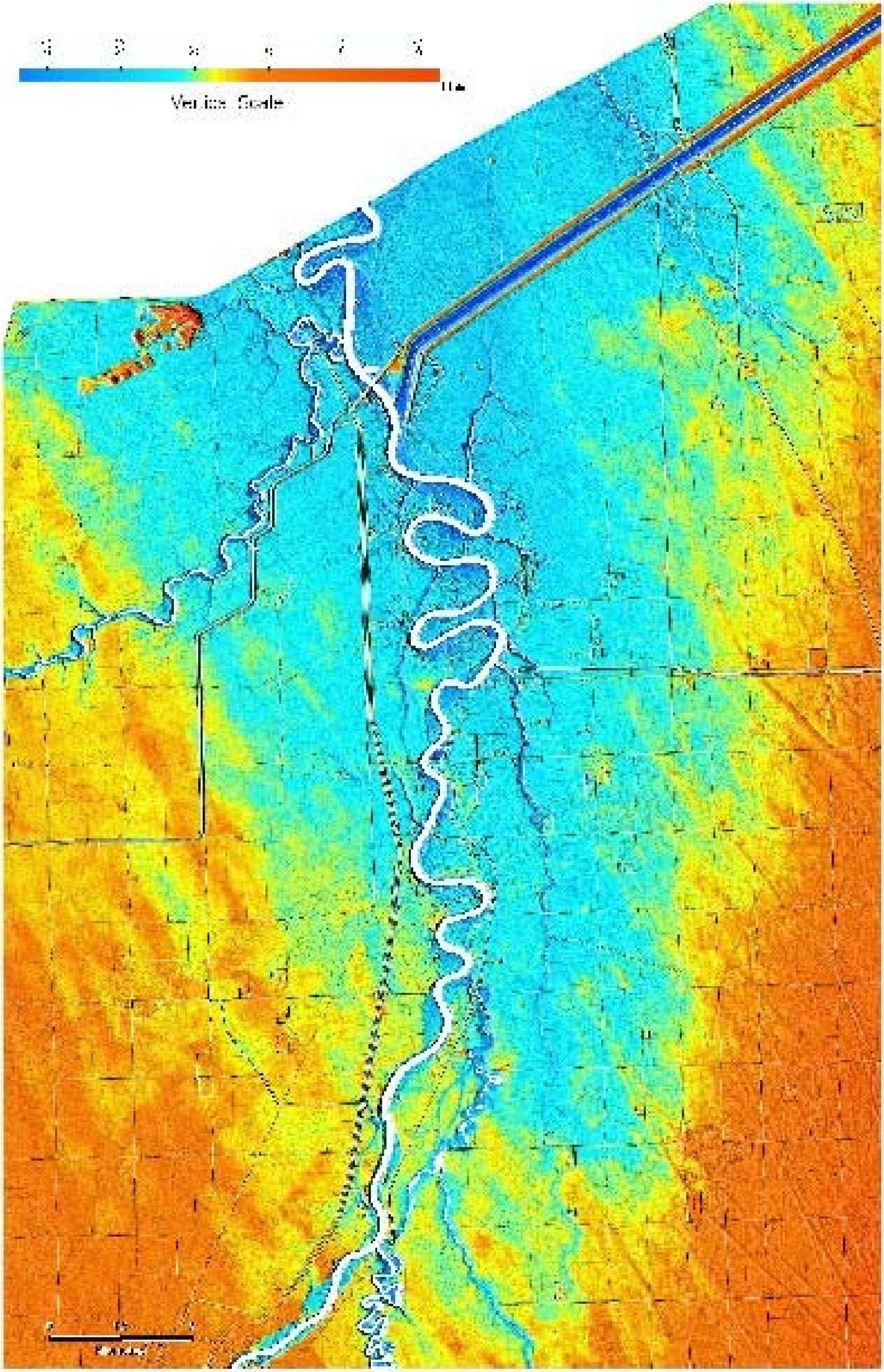
STOP 2 – THE LAKE AGASSIZ CLAY PLAIN

Snow and rain may contribute to severe Red River floods but the true villain is the geology of the Red River valley.

Large Red River floods are always caused by rapid spring snowmelt following a wet autumn and heavy winter snowfall. However, while weather is the instrument that initiates individual floods, the underlying cause of the severity of flood disasters in the Red River valley is the influence of glacial Lake Agassiz.

Glacial Lake Agassiz persisted in Manitoba from about 11,100 years ago, when the glacial ice margin retreated into southern Manitoba, to about 7,700 years ago, when glaciers retreated far enough north to re-establish drainage into Hudson Bay. During that period, drainage alternated between a southward route into the Gulf of Mexico and eastward flow into the north Atlantic Ocean, depending on glacial fluctuations in northwestern Ontario. Eastward drainage at about 10,900 years ago probably caused the cooling event known as the Younger Dryas. Lake Agassiz shoreline features now commonly slope more than of 0.5 m/ km to the southwest, due to isostatic rebound, providing a gauge to calculate the Red River's decreasing competency over time.

For most of its length, the Red River flows through clay-rich glaciolacustrine sediments up to 70-m thick. This material was laid down within the main basin of Lake Agassiz, which covered the Winnipeg area with more than one hundred meters of water. These deposits form a gently northward sloping plain that is extremely flat; the average gradient of the valley is 0.0001 (Fig. 3). When the valley cannot contain large flows, the river spills over to form a shallow flood zone that can extend up to 40 km across and cover several thousand square kilometres in Canada and the United States. In 1997, the Red River flooded more than 2,000 km^2 in Manitoba alone.



Iceberg furrows

The flat clay plain surrounding Winnipeg is marred by ridges and groves that can be up to 150 wide and stretch for more than 10 kilometres (Fig. 4). The ridges actually sit on top of grooves that were infilled and partially buried by silt.

The origin of these features has long puzzled geologists, with their formation attributed to a number of causes, including permafrost action and fracture patterns in the underlying bedrock. The ridges were actually caused by icebergs impinging on the bottom of Lake Agassiz. These scours were then infilled with silt from density underflows on the lake bottom. Once the lake drained, compaction due to de-watering caused the clay plain to decrease in volume, while the silt within the scours was unaffected. Because of this process, these negative erosional features slowly became upraised ridges.

The Centre for Cold Ocean Resources Engineering in St. John's, Newfoundland identified a series of low-angle thrust faults and high-angle normal faults bounding the trough below one of these ridges. Based on this information, they created a detailed model describing the construction of these infilled scours that has proven invaluable in the design of ocean bottom pipelines.

Figure 4: Iceberg ridges and furrows.

The Lake Agassiz clay plain also plays an important role in:

- ***Location of hog lagoons:*** *clay provides a good seal that prevents contamination of underlying aquifers. However, overland drainage can cause considerable problems close to riparian environments.*
- ***Riverbank stability****: glaciolacustrine sediments are far less stable than river alluvium.*
- ***Building foundation conditions****: clay and silt react very differently to wetting and drying. Swelling and contracting clay can cause structural damage if silt is present.*

STOP 3 – FORT DUFFERIN

This stop highlights the "unregulated, wild Red River in its natural state". We will present a brief history of the post at Fort Dufferin and discuss how trees growing on the banks of the Red River can provide a detailed record of past flooding and environmental change.

Local history

Fort Dufferin was constructed by the Boundary Commission to serve as their staging post for surveys of the Canada-US border (Fig. 5). The buildings were constructed early in 1873 and were subsequently used by the newly-formed North-West Mounted Police. On July 8, 1874, 275 officers and men of the North-West Mounted Police (along with 142 draught oxen, 93 head of cattle, 310 horses, 114 Red River carts, 73 wagons, two nine-pounder field guns, two mortars, mowing machines, portable forges and field kitchens) began their westward trek to establish order in the new Canadian territory. For most of the 20th century, the buildings were used as private barns and agricultural storage.

The record of the rings

The lovely oak forest that surrounds Fort Dufferin has generously donated tree-ring samples to several geoscience projects related to Red River flooding. Although oak trees in Manitoba can live for up to 300 years, the trees around Fort Dufferin are only about 100-120 years old. During the middle of the 19th century, woodcutting was a major industry in the Red River valley that supplied construction material and fuel. The current riparian forest in the valley reflects this historical clear-cutting so it is very rare to find trees that are older than 150 years.

Despite their age, the oaks in the Red River valley have provided an enormous amount of information about the history of severe floods and of past environmental change in southern Manitoba. *Dendrochronology* uses the information recorded in the structure of annual rings of trees to answer environmental and historical questions.

The power of tree-ring analysis lies in their annual, absolutely-dated record, which is unparalleled in geology. The current Red River oak record extends back to AD 1286 and documents changes in environmental conditions over the last seven hundred years. Unlike radiocarbon methods, tree-rings provide real calendrical dates, without any associated errors.

Figure 5: In the first years following its construction, Fort Dufferin was used by the International Boundary Commission, the North-West Mounted Police and as a customs and immigration station.

How do we get tree-ring records spanning the last 700 years when living trees are usually not more than 100 years old? The answer lies in the buildings around you and in the alluvial mud of the Red River itself. Our oak record includes tree-ring samples from several stands of trees between Winnipeg and Emerson but also has specimens taken from 19th century buildings like Fort Dufferin and from subfossil logs preserved in river alluvium. Pattern matching (called *crossdating*) compares sequences of wide and narrow rings so that older, dead trees can be dated and included in our record (Fig. 6).

Tales told by old trees

Extreme floods, such as the 1950 flood or larger, cause oak to develop distinctive anatomical markers, or 'flood rings', that can be used to identify older and previously unknown Red River floods (Fig. 7). Tree rings provide an extended flood record for the lower Red River (between Winnipeg and Morris) that extends from AD 1648 to 1999. This technique has identified seven high-magnitude floods during the last 350 years: 1997, 1979, 1950, 1852, 1826, 1762 and 1747. Although the five most recent flood rings are coincident with known high-magnitude floods, signatures in 1747 and 1762 predate local instrumental and historical flood records and represent previously unknown floods. Flood rings also document Red River floods in North Dakota and Minnesota in AD 1510, 1538, 1658, 1682, 1726, 1727, 1741, 1747 and 1762.

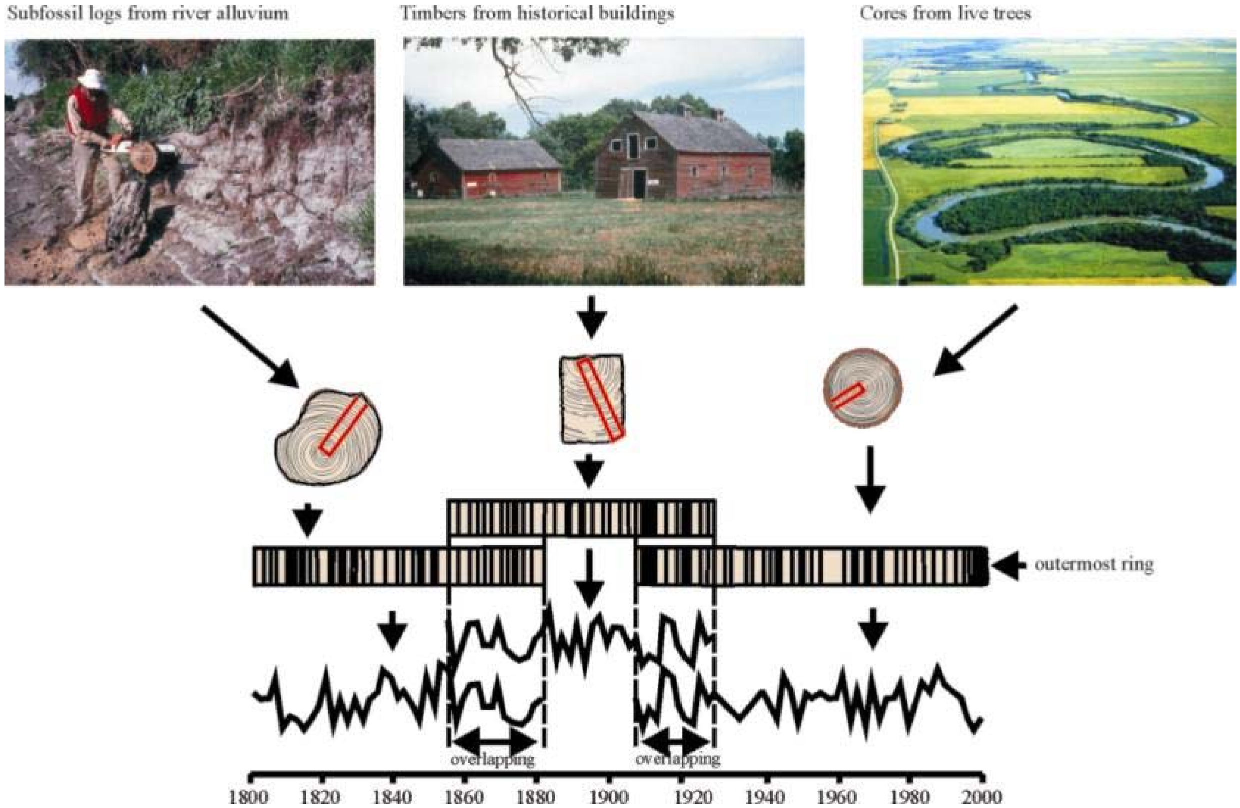


Figure 6: Tree-ring dating uses the outermost ring from living trees as a temporal "anchor" by which other samples, whose outermost ring dates are unknown, are then dated. The pattern of variation within overlapping tree rings allows the samples to be dated absolutely, with annual and sometimes seasonal accuracy. Samples in the Red River oak record are derived from living trees, timbers from 19th century buildings and subfossil logs recovered from river alluvium.

Major findings

- The 1826 flood was the most severe event since at least AD 1648.
- The risk of flooding has changed several times during the last 350 years. Although the mechanisms responsible for these changes are not yet understood, we clearly cannot assume that the pattern of recent flooding will continue indefinitely into the future.
- Future flood risks should use techniques that account for non-stationairity and non-randomness introduced by climatic and landscape changes.

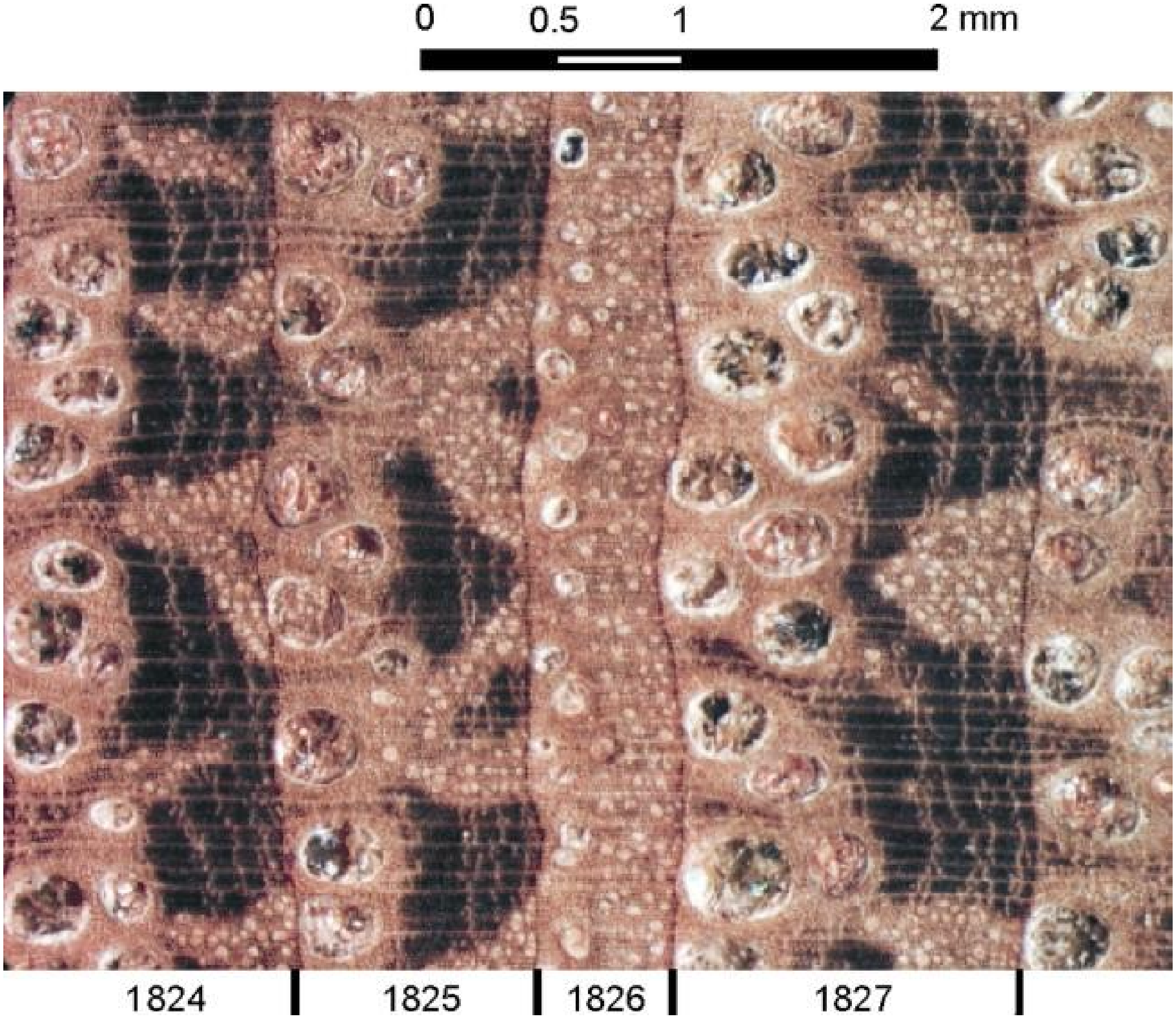


Figure 7: Severe spring floods, such as the 1826 Red River flood, inundates riparian trees and causes oaks to develop rings with unusual anatomical features. These unusual rings, called flood rings, can be used to identify and date extreme floods several centuries prior to historical and instrumental flood records.

Although intuition suggests that extreme floods would be more common under a wetter climate, specific climatic thresholds leading to shifts in regional flood hazards are difficult to determine. Estimated annual precipitation inferred from tree rings indicates that southern Manitoba's hydroclimate has been relatively stable over the last two hundred years (Fig. 8). Although this stability was interrupted briefly by pronounced wet intervals in the late 1820s and 1850s, conditions were much more variable and persistent prior to A.D. 1790.

- The Red River basin experienced extremely dry conditions between A.D. 1670 and 1775, with below normal precipitation occurring approximately two years out of three. Comparisons with limnological records from North Dakota and Minnesota suggest that the entire northeastern Great Plains were dry for nearly one hundred years around AD 1700.

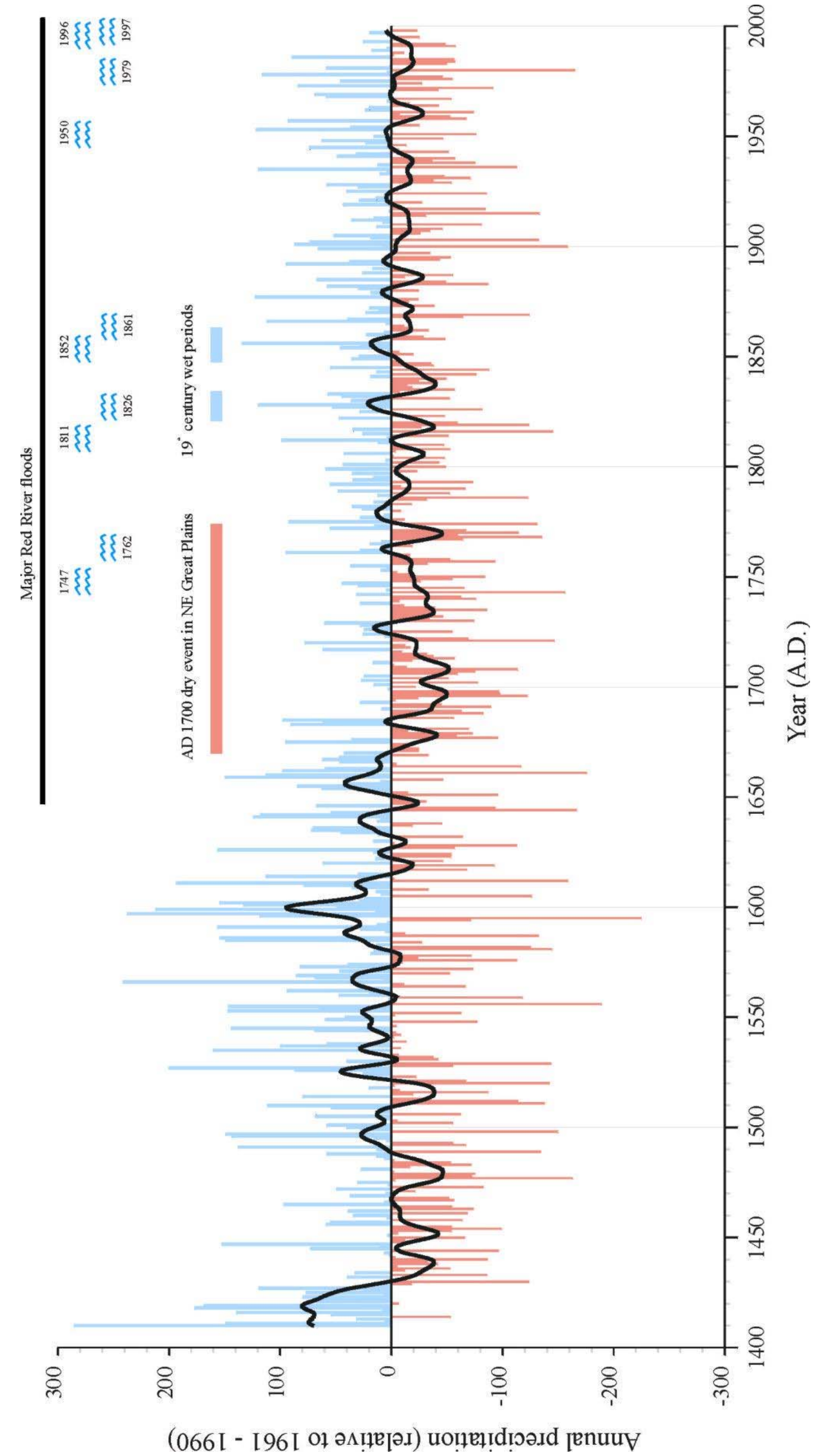


Figure 8: Tree-ring estimates of changes in annual precipitation at Winnipeg since AD 1400. The flood history of the Red River, derived from instrumental, historical and tree-ring evidence, notes floods with magnitudes equivalent to that of 1950 and larger.

LUNCH
We will provide a light lunch at Fort Dufferin, which, if the weather permits, will be served at the nearby picnic area.

STOP 4 – STE AGATHE SECTION
The unique character of the Red River valley is an important factor relating to extreme floods. But how are geological and geomorphological processes affecting flood risks over the long term?

At a section exposed near Ste Agathe, Manitoba, we will examine the rapids, the Red River terrace and river alluvium. This stop will focus on the Holocene history of the Red River, as revealed through alluvial stratigraphy. We will also discuss long-term changes in river erosion and river gradient and their effects on Red River valley flood risks. Ste Agathe is also the proposed site of the Red River retention structure, which currently is the only alternative to expansion of the Winnipeg floodway.

The geological setting of the Red River valley
Most of the sediment carried by the Red River is derived from the Lake Agassiz clay plain, and its alluvium comprises clay, silt and sand, with almost no coarse sand or gravel. Radiocarbon dating of wood, bone and charcoal suggests that the river has occupied its present position since the drainage of Lake Agassiz approximately 7,700 years ago. The river's course has also been extremely stable over the last 130 years and aerial photographs and maps indicate that the Red River's migration has been low to negligible.

Red River alluvial stratigraphy
This section is located along the east side of the river, three kilometres south-southwest of intersection of Highways 75 and 305 at the town of Ste Agathe, Manitoba. It is situated near the inflexion point between successive river meanders, at a natural cutbank about 11 m high and 200 m long. At low flows, a large gravel 'bar' projects into the channel and deflects the channel thalweg towards the opposite side of the channel. This feature is not an alluvial deposit, but is gravel lag that represents the top of an exhumed flute composed of till. Similar gravel lag 'bars' outcrop intermittently along the river in the general area of Ste Agathe.

The section exposes three stratigraphic units: modern dike deposits, 0-0.85 m thick, that are not part of the alluvial bank stratigraphy; weakly-bedded, overbank alluvium with paleosols, 0.85-2.4 m thick; and massive to weakly-bedded lateral accretion deposits, 2.4 to at least 10 m thick. A composite sample of bison teeth and six charcoal samples, located between 1.45 to 8.8 m deep, yielded radiocarbon ages ranging from modern to 5430 ± 70 ^{14}C yr. BP (Fig. 9). Discordant dates near the bottom of the section indicate slumping. Bison teeth at 6.10 m and charcoal at 6.70 m yielded identical ages of 5430 ± 70 ^{14}C yr. BP and give a minimum age for the start of the alluvial sedimentation.

Significance to flood hazards
Red River alluvium can be difficult to distinguish from glacial Lake Agassiz sediments. The presence of organic material and the mid- to late Holocene radiocarbon dates indicate an alluvial origin for these bank deposits. These deposits are part of an alluvial fill aggraded within the

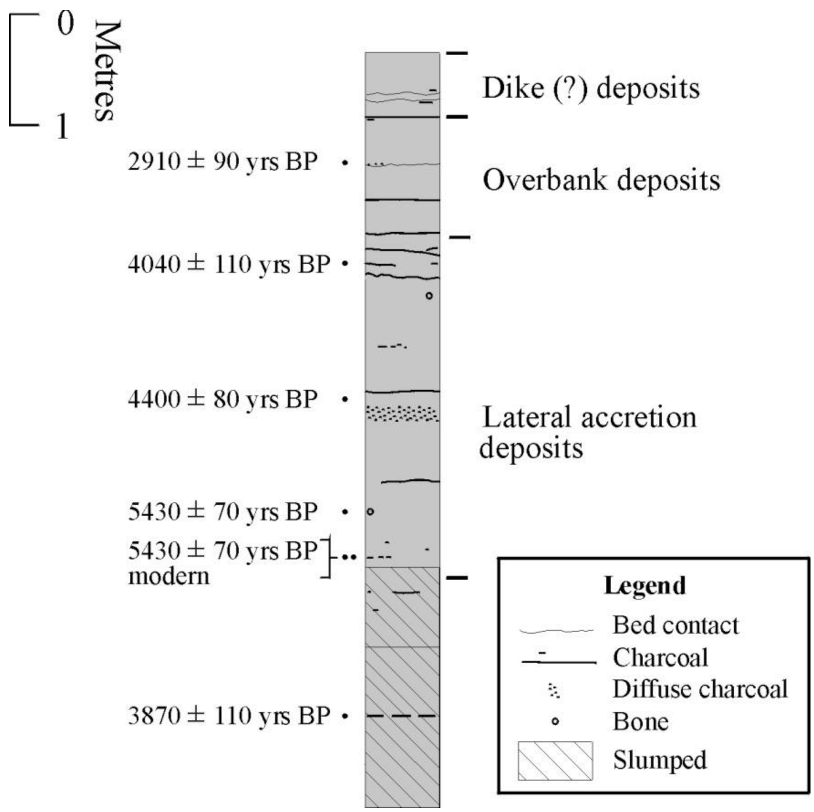


Figure 9: Diagram of the section Se04-1-97 alluvial deposits showing the location of the radiocarbon ages.

shallow river valley whose surface is slightly lower than the surrounding clay plain. The morphology of this shallow valley is an important geomorphic control on the character of Red River floods because the valley has an insufficient cross-sectional area to contain the more extreme flows of the river, given the very low gradient (~0.0001). Thus, high flows, such as occurred during the Red River flood of 1997, fill the shallow river valley, overtop the valley sides, and spread across the clay plain, forming a broad flood zone many kilometres wide.

The mid-Holocene age of the deeper alluvial deposits, in combination with additional radiocarbon ages elsewhere in the floodplain, indicate that the alluvial fill is the product of very slow lateral meander migration. Most meanders along the Red River have undergone only a single (and continuing) sequence of lateral channel migration that is consistent with the ridge and swale topography on the floodplain, and the sporadic occurrence of ox-bow lakes and channel scars along the river. The very low rate of lateral channel migration, and consequent enlarging of the cross-sectional area of the shallow valley, is not significantly altering the flood hazard along the river over timescales critical to flood protection structures.

STOP 5 – THE FORKS IN DOWNTOWN WINNIPEG
Winnipeg's birthplace has a dynamic geological past.

The Forks, located at the confluence of the Red and Assiniboine rivers, represents the heart of modern Winnipeg (Fig. 10). Although the Canadian National Railway occupied the site during most of the 20th century, the establishment of the Forks Renewal Corporation in 1987 marked the beginning of a remarkable transformation. The Forks now serves as a year-round host to many community events and concerts and includes a eclectic variety of restaurants and specialty shops. Along with the walkway along the Red and Assiniboine rivers, which extends from the Provencher Bridge to the Provincial Legislative Buildings, these attractions have made the Forks into Winnipeg's most popular destination.

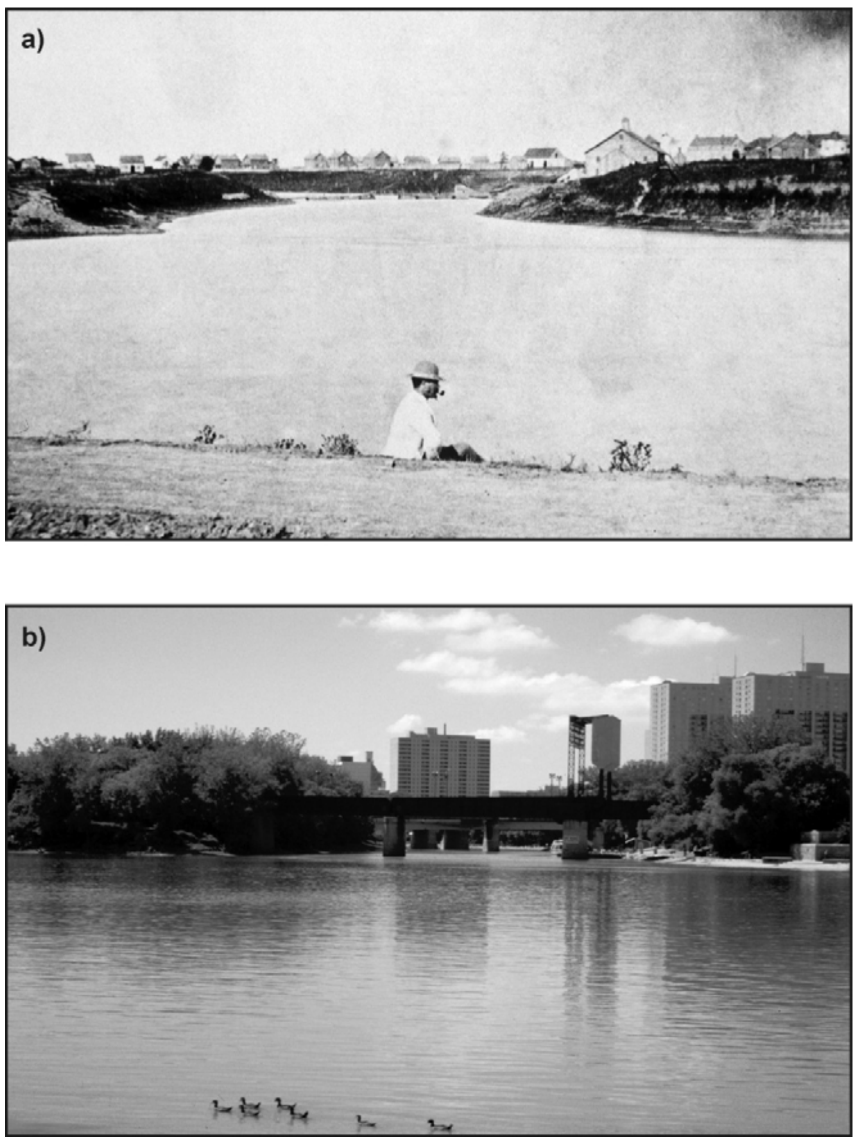


Figure 10: The Forks, looking westward toward the Assiniboine River in (a) 1875 and (b) 2001. The complete absence of riverbank trees in the earlier photograph reflects extensive deforestation caused by small river lot logging in the mid-19th century.

Radiocarbon dating of two campfires along the banks of the Assiniboine River suggest that aboriginal groups visited the Forks as early as 4000 BC. The area appears to have been used for several different purposes, serving as a provisioning site, a stop in seasonal migrations, and part of a transcontinental trade route that extended as far away as the Lake Superior region and northern Texas. Pierre Gaultier de Varennes, Sieur de la Vérendrye, was the first European to visit southern Manitoba and noted Assiniboine and Cree settlements at the Forks in 1737 and 1738, respectively. One of La Verendrye's compatriots in 1738 constructed Fort Rouge at the Forks in 1738 but the post was abandoned by 1749. Although the area continued to be used occasionally by fur-traders during the latter half of the 18th century, it was not re-occupied until the North West Company built Fort Gibraltar in 1810. The Red River Settlement, which would develop into modern Winnipeg, began with the arrival of the first agricultural settlers recruited by Lord Selkirk in 1812.

Although the Red and Assiniboine rivers may appear peaceful, their calm waters disguise a history of dramatic change since the last glaciation. Borehole data suggest that the Red River experienced rapid lateral migration between 8,000 and 6,000 yr. BP but has migrated very little over the last thousand years; since 1,000 yr. BP, lateral channel migration has averaged about 4 cm a year. In contrast, the Assiniboine River remained very active throughout much of the Holocene. The entry of the eastward-flowing Assiniboine River into glacial Lake Agassiz led to the formation of the extensive (6,400 km^2) Assiniboine Delta, which extends from Brandon to Portage la Prairie. Following the disappearance of Lake Agassiz, the Assiniboine River flowed across the Delta through a number of paleochannels originating at Portage (Fig. 11). Each of these channels were created and abandoned due to avulsion during floods or ice jams. Although the Assiniboine River occupied its current position by 7,490 ± 80 yr. BP (GSC-4839), the river switched course and drained into Lake Manitoba from approximately 7,000 BP to 4,500 BP (through the Willowbend and then Flee Island channels). The Assiniboine has flowed into the Red River since 4,500 BP but has followed several different routes, many of which did not terminate at the modern Forks. By about 3,000 BP, the Assiniboine River drained through the La Salle channel and joined the Red River 15 km south of Winnipeg. The river returned to the Forks some time before 2,450 ± 80 yr. BP (BGS-1635) and had established its entire modern channel sometime after 700 BP.

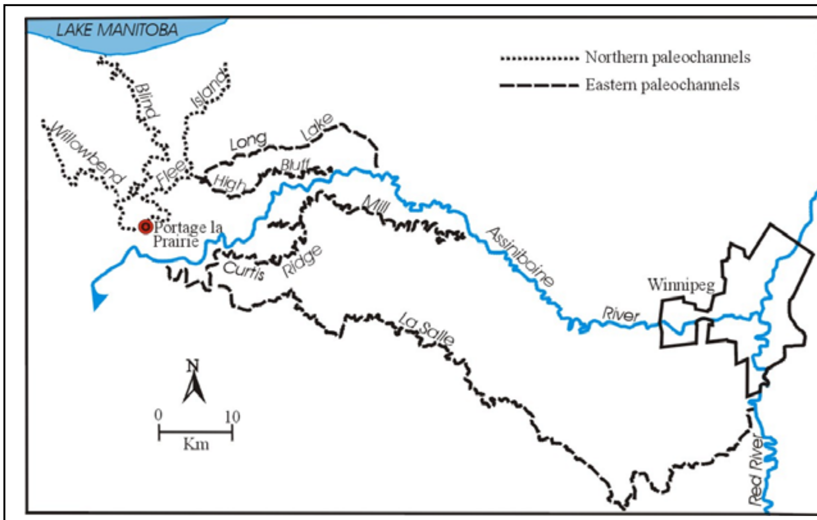


Figure 11: Assiniboine Delta and river paleochannels.

DINNER AT THE FORKS NATIONAL HISTORIC SITE

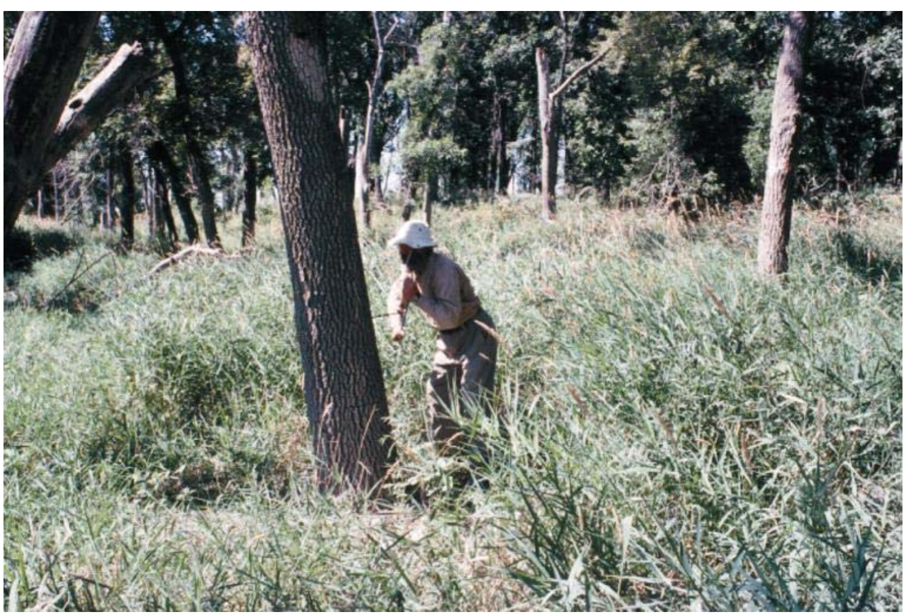
To end our day, the Manitoba Geological Survey is sponsoring dinner at the Forks National Historic Site.

A piece of Manitoba's environmental history

MGS and GSC staff have prepared several special tree-ring "cookies" personalised for each province and territory, so that each participant can take home a small piece of Manitoba. These pieces were cut from a long-dead eastern white cedar (*Thuja occidentalis* L.) that grew on the Pas Moraine near the northwestern end of Lake Winnipeg.

These cedars are an isolated relic population more than 300 kilometres removed from the nearest cedar forests in southeast Manitoba and northwestern Ontario. Over their lifetimes, many of these trees were distorted into their final twisted and gnarly forms by the cumulative effects of forest fires. This stand includes the oldest known trees in Manitoba, with some trees reaching an age of 500 years! While our cedars pale in comparison to those in Ontario and Quebec, (which can be over 1,000 years old!), these trees still represent the best example of true "old-growth forest" in our province.

Your cross sections were cut from a cedar that started growing in 1626 and lived for 359 years before its death in 1985. This tree was still in good condition lying on the surface as deadfall in July 2002. Because trees grow upwards as they get older, sections cut near the top of the tree will have fewer rings than those nearer the root. The smooth surface of the wood was produced using progressive finer grades of sandpaper and was finished off with extremely fine (600-grit) paper commonly used for autobody finishing. This preparation allows individual cells to be seen under a microscope and is critical for accurate tree-ring analysis. These sections have not been lacquered or varnished so please treat them with care – water or sticky fingers will definitely mar their smooth surfaces!



YOUR GUIDES

Erik Nielsen

After receiving his Ph.D. in 1976, Erik Nielsen has spent most of his career with the Manitoba Geological Survey working on glacial stratigraphy and geochemical exploration in northern Manitoba. More recently, he has studied modern geological processes on Lake Winnipeg and the evolution of the Manitoba landscape over the last 8000 years. In addition to his ongoing geochemical exploration work and other interests, he has pioneered tree-ring research in Manitoba over the last 9 years.

Scott St. George

After receiving degrees from the University of Winnipeg and the University of Western Ontario, Scott has been employed as a physical scientist with the Geological Survey of Canada (Terrain Sciences Division) since 1999. Most of his work with the GSC has focussed on past hydroclimatic change in southern Manitoba and its influence on flood risks in the Red River and Assiniboine valleys but he is also involved with projects related to forest ecology and marine archaeology in Nova Scotia. Scott is currently seconded to the Manitoba Geological Survey office in Winnipeg.

Greg Keller

Greg joined the Manitoba Geological Survey in 2000, having worked previously with the Geological Survey of Canada. He received his B.Sc. (4-year) in Physical Geography from the University of Winnipeg in 1998. Since joining the survey, Greg has been involved with 3D geological mapping and the 1:250 k digital compilation of the Surficial Geological Map of Manitoba. He specialises in database management, GIS and 3D geological modelling.

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