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The Ancient Mississippi River's Return

Current flooding along preglacial tributaries foreshadows broader changes as North America rebounds from the most recent ice age.

Roy Van Arsdale, Youngsang Kwon, Randel Cox, and David Lumsden

The Red River of the North, which flows northward from the United States into Canada across an ancient lake bed, is one of North America's most flood-prone rivers. Its gentle gradient, broad valley floor, and northward snowmelt pattern make spring flooding a perennial hazard. Ice jams and prolonged snowmelt routinely force the river over its banks, inundating farmland and urban areas.

Historical flood records extend back to the 18th century, and geological evidence reveals even older paleofloods far exceeding modern events in magnitude. Among documented floods, those in 1826 and 1897 set early benchmarks, and the mid-20th century saw some of the most consequential episodes. The 1950 flood devastated Winnipeg and much of the Red River Valley, prompting the construction of the Red River Floodway around the city. More recent decades have seen several notable high-water years. The 1997 flood broke records in Fargo–Moorhead and Grand Forks in North Dakota, overwhelming levees, displacing thousands from their homes, and causing billions of dollars in damage. Subsequent major spring floods occurred in 2001, 2009, 2011, and 2022.

Extreme and even near-record events are no longer rare aberrations. In the Fargo–Moorhead area, the river has exceeded flood stage in most years over recent decades; more than half of the highest crest events recorded there have occurred in the past few decades, a pattern that mirrors increasing precipitation extremes documented across the region.

Climate change surely plays a role in these floods, but so does geology. The geology of North America is still changing from the ice age that ended about 19,000 years ago, when a mountain of ice covered Canada and much of the upper Midwest. At its thickest, this ice sheet reached depths of three to five kilometers, its weight pressing down on the land underneath. Even today, the land is still slowly returning to its preglacial height. Current uplift rate is 11 millimeters per year along the southern shore of Hudson Bay and 2 millimeters per year in the city of Winnipeg, whereas immediately south of the Canadian border the land is sinking 2 millimeters per year. These incremental shifts slowly add up to big changes in where floods occur, because the Mississippi headwaters are returning to their watershed of 4 million years ago.

Through our work studying the ancient route of the Mississippi River, we realized that the Red River was once part of its watershed, stretching the waterway's length into the Arctic Circle. We collected the first clues to this story far downstream, on the bed of the Mississippi River of 3.6 million years ago, near what today is Memphis, Tennessee. Our analyses of the riverbed's geology suggest that the Mississippi headwaters once included a large portion of south-central Canada and that the watershed may be returning to its pre–ice-age state, which would exacerbate flooding in the region.

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The Pliocene Mississippi

While conducting research on the source and distribution of ancient Mississippi River sediments in 2001, one of us (Van Arsdale), uncovered a trove of

QUICK TAKE

North America is still rebounding from the most recent ice age. Today, the rising landscape is altering river gradients and drainage patterns, which influence flood risk.

Geological evidence suggests that rivers such as the Red River of the North once flowed south into the Mississippi River, forming a vast continental watershed.

As the rebound continues, ancient drainage patterns may reemerge. Within about 10,000 years, the Red River could reverse direction, causing increased flooding.

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Dan Harper Photo

During a flood of the Red River of the North in May 2022, the town of Morris, Manitoba, became an island. Geological research shows that this region is slowly shifting to the preglacial watershed of 3.6 million years ago, when runoff flowed southward into the Mississippi River rather than northward into Hudson Bay. This slow process, which will play out over thousands of years, will exacerbate flooding in an already flood-prone region.

data that could reveal the Mississippi River's ancient route before the most recent ice age—in a mining office in Texas. A friend, engineer Brian Waldron, had tipped him off about drill cores that a company had collected with a truck-mounted auger to explore for lignite in southeastern North America. These cores could also show where the sediment changed to sand and gravel, indicating the ancient Mississippi riverbed.

Most of the material that makes up asphalt and concrete is sand and gravel. The Pliocene Mississippi River's sand and gravel is the principal source of aggregate for asphalt and concrete for western Tennessee and surrounding regions. Thus, this ancient river deposit is finding renewed purpose as the principal source of building material upon which Memphis and the surrounding roads are built.

In the sediment cores, the layer that sits above this sand and gravel is silt, the Pleistocene windblown dust that buried river floodplains. Marine sediments made up of clays and fine-grained sands that contain the lignite are below the ancient river sediment. So the Pliocene Mississippi riverbed's layer of sand and gravel is like peanut butter between two pieces of bread. You can't miss it. Combining that dataset with the geological cores already collected by state and national geological surveys in portions of Illinois, Missouri, Kentucky, Arkansas, Tennessee, and Mississippi not only showed where the Pliocene riverbed was but also allowed us to calculate how much water flowed at that time through North America's largest river.

During the Pleistocene Epoch (the ice age from 2.5 million to 12,000 years ago), continental glaciers periodically covered most of Canada and extended into the North Central United States. As the glaciers overran the landscape and its rivers, they affected peripheral drainage patterns. We wanted to know how glaciation had changed the Mississippi from its preexisting drainage pattern.

Although post–ice-age rebound is well known, no one had quantified its effects on the ancient and modern Mississippi watershed. Our mapping of the ancient riverbed layers found in the drill cores revealed that during the Pliocene and possibly early Pleistocene, the Mississippi River floodplain near Memphis was very large. Its width was approximately the distance between Los Angeles and San Diego (200 kilometers)—40 percent wider than the modern Mississippi River floodplain at Memphis today. This ancient riverbed now sits at a higher elevation than the river today and is a sand and gravel deposit called the Upland Complex. Its base is 70 meters higher than the base of the adjacent modern Mississippi River floodplain. Pliocene river channel bends that were preserved in this

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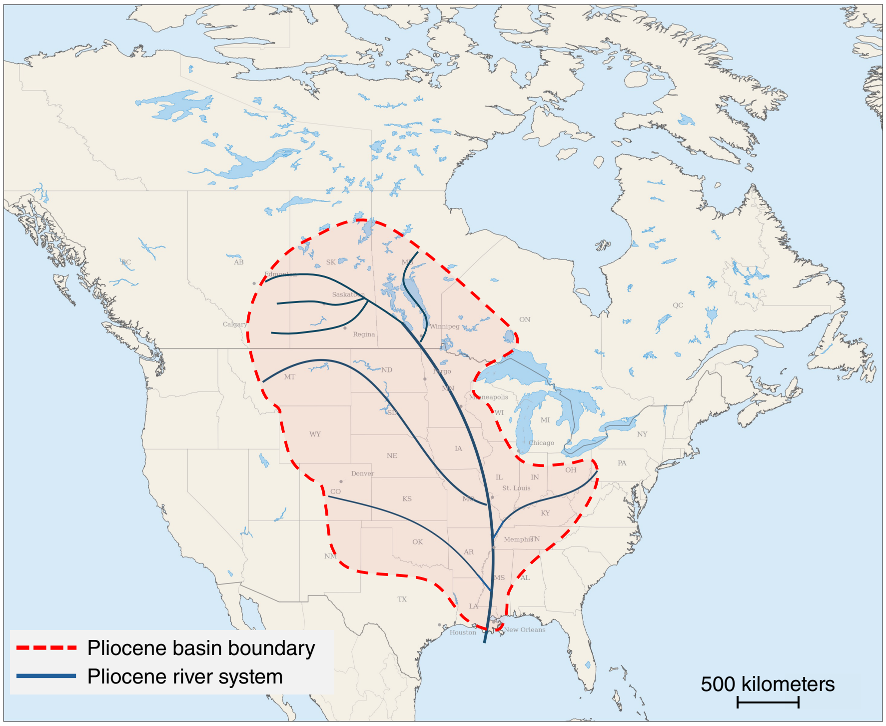
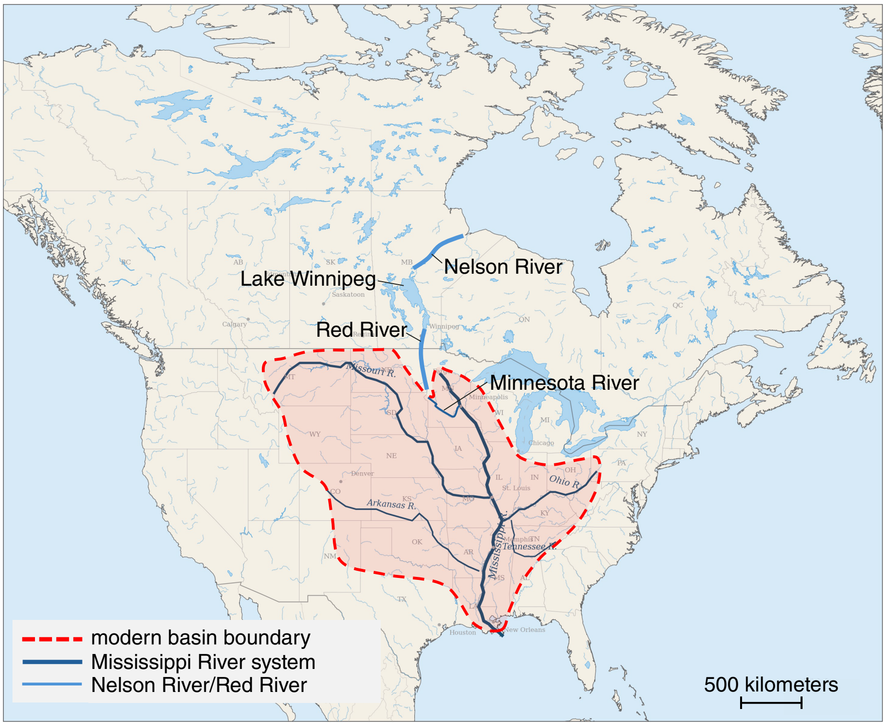
Pliocene, Preglacial



Present Day



Courtesy of the authors

During the Pliocene Epoch millions of years ago, the mighty Mississippi River was even longer than it is now and carried more water to the Gulf region. Back then, areas of today's Red River in North Dakota and Manitoba flowed southward into the Mississippi, discharging six to eight times more water and increasing this already massive watershed area by 50 percent (*top*). During the glacial cycles that followed, miles-thick Pleistocene ice sheets weighed down the land, switching the course of water in the region from south to north (*bottom*). As the land continues to rebound over thousands of years to its preglacial elevation, it will slope southward again, returning the Mississippi to its Pliocene might.

sediment deposit are much larger than those of the contemporary Mississippi River, indicating that six to eight times as much water flowed downstream millions of years ago.

To explain why the Pliocene Mississippi River was so much larger, either the rainfall or the lands that drain into the river must have been larger. Because there is no evidence of higher rainfall, we began to closely examine the alternative, that the area that drained into the Pliocene Mississippi River was much larger than the drainage basin today. We calculated that the Pliocene Mississippi River drainage basin was approximately 50 percent larger than the modern Mississippi River drainage basin (*see figure at left*). Since the Mississippi's drainage basin cannot be expanded east or west because of the Appalachian and Rocky Mountains, the only choice we had was to explore the possibility that the preglacial Pliocene Mississippi River's drainage basin extended well into south-central Canada.

The current south-flowing Mississippi River drains the central United States, with headwaters in the Rocky Mountains in the West, the Appalachian Mountains in the East, and along the Canada–United States border to the north. Most of the water in south-central Canada and portions of North Dakota and Minnesota flows north into the Red River, which in turn flows north into Lake Winnipeg. The northward flow continues from Lake Winnipeg to the Nelson River, which then flows into Hudson Bay. Thus, this watershed juncture near the border of the midwestern United States and Canada divides the northward and southward flow of water in central North America.

The Land's Postglacial Uplift

We hypothesized that prior to the Pleistocene glaciation, during the Pliocene Epoch (5.3 to 2.6 million years ago), much of the ancestral Red River–Lake Winnipeg–Nelson River drainage system flowed south into the Mississippi River. Growth of the Canadian continental ice sheet pushed down the Earth's crust at Hudson Bay and in south-central Canada, thereby causing the bedrock beneath the ice to slope north toward Hudson Bay where the ice had been thickest. As the ice sheet melted over the past 19,000 years, the landscape still held its depressed position, and the landscape

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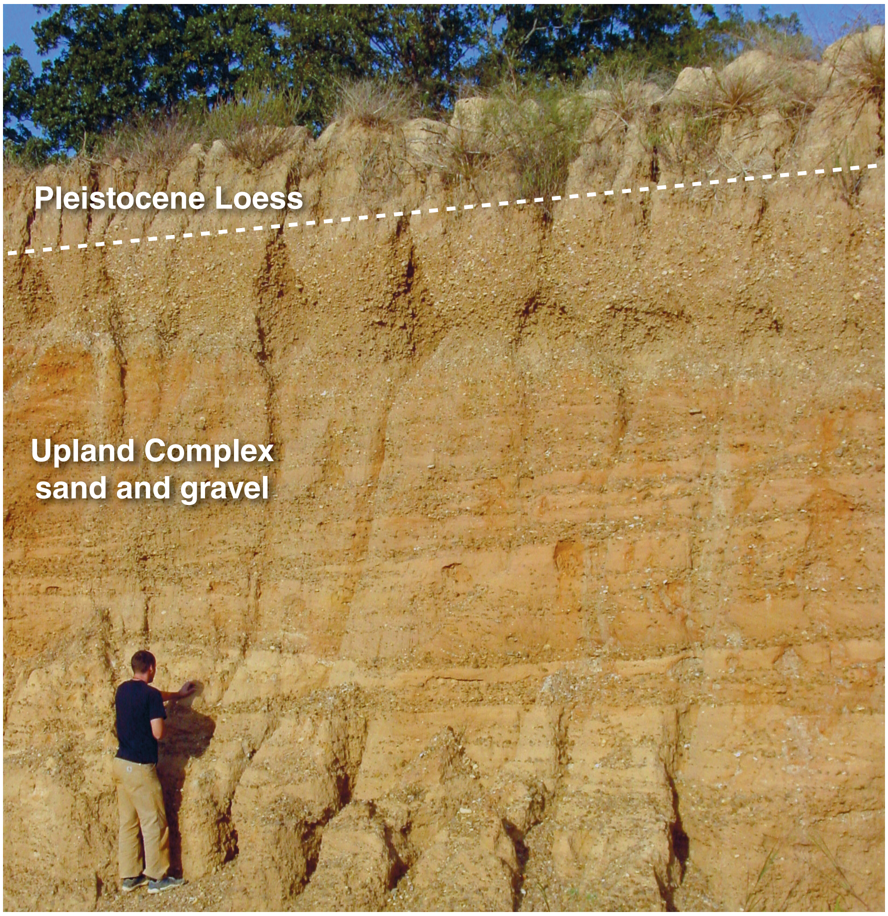


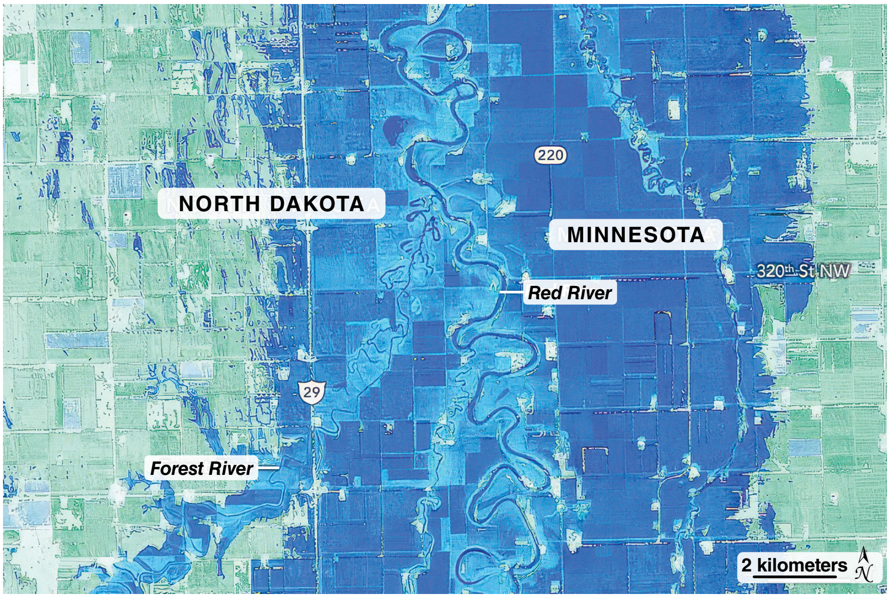
Courtesy of the authors

The Mississippi riverbed of the Pliocene Epoch 3.6 million years ago left a layer of sand and gravel sediment along its course bisecting North America. Above that layer is silt, the Pleistocene windblown dust that buried the entire river system. Below it is a layer of marine sediments made up of clays and fine sands. This photo (*right*) taken in a quarry in Arlington, Tennessee, (*above*) shows two layers. Mapping the sand and gravel sediment revealed the course of the ancient Mississippi and indicated how much more water was flowing through it during the Pliocene, prompting the authors to ask: Where did all that water come from?

of south-central Canada continued to slope northward toward Hudson Bay, because postglacial rebound was taking place more slowly than melting of the ice sheet. This rebound of Hudson Bay's floor and south-central Canada continues today. So, sometime in the future—probably thousands of years from now—south-central Canada's landscape will slope south again, and much of the Red River drainage system will reverse its flow to go south into the Mississippi River, as it once did during the Pliocene.

To test this hypothesis, we undertook a topographic analysis of south-central Canada. Underneath loose soil and sidewalks, the shape of the bedrock remains as it existed during the Pliocene, thus predating glaciation. We mapped the bedrock topography from the southern shore of the Hudson Bay into the North Central United States. Additionally, we mapped the bedrock topography along the floor of the Red River–Lake Winnipeg–Nelson River from the southern shore of Hudson Bay to North Dakota. We then used previous scientists' estimates of uplift in the region to examine the maximum height to which the landscape will ultimately rise along the southwestern margin of Hudson Bay. These remaining rebound values varied at the northern ends of the constructed bedrock profiles from 80 to 120 meters, or roughly the height of the Statue of Liberty.

Modern postglacial rebound in southern Canada and the northern United States reveals a zero line along which rebound is already complete and so no rebound is occurring—approximately at the United States–Canada border in the region we studied. Next, we recon-



NASA

A NASA map of the flooded areas of the Red River in April 2020 shows the flat landscape around the Red River on the border between North Dakota and Minnesota.

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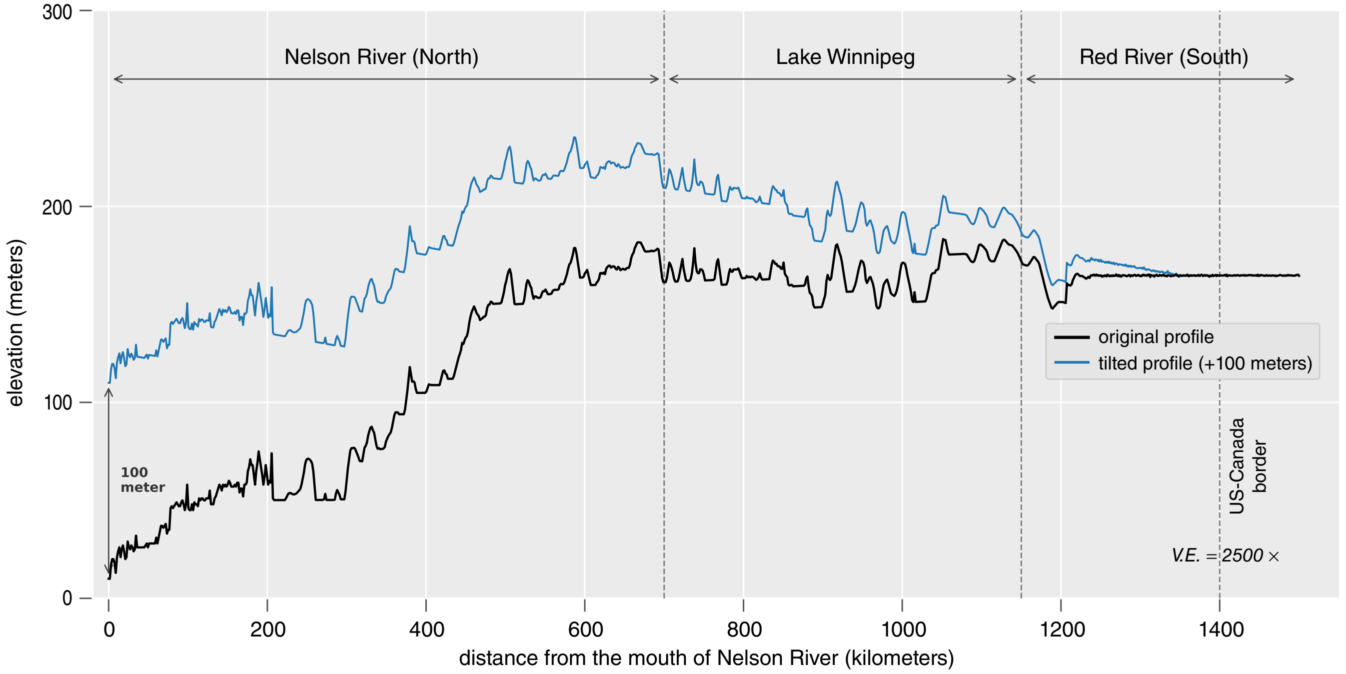

Courtesy of the authors

The authors mapped the buried bedrock beneath the Red River system from Hudson Bay to North Dakota to trace how the land is still rebounding after the most recent ice age. As the land rises—by as much as 80 to 120 meters—the river's northward slope is gradually flattening. Within 9,000 to 13,000 years, that tilt will ultimately reverse the direction of flow in the Red River, slowing the water, amplifying floods, and transforming the North Dakota–Minnesota basin into a vast lake akin to Lake Winnipeg. This lake's waters will then spill into the Minnesota River, which joins with the Mississippi River at St. Paul, Minnesota.

structured the preglacial landscape by mathematically raising the northern end of each bedrock profile by the amount of rebound still expected near Hudson Bay, while keeping the region about 1,500 kilometers to the south fixed where the rebound uplift is essentially complete. In effect, we modeled the land surface pivoting about this zero-rebound line, like a board slowly being lifted upward at one end. When the remaining postglacial rebound is finished, south-central Canada will once again slope southward.

We estimate that the Red River drainage system will reverse its flow 9,000 to 13,000 years from now, assuming continental glaciation does not return.

The reversal of slope we identified occurs 600 to 200 kilometers south of Hudson Bay. This line, which runs across northern Manitoba from the small community of Brochet to Island Lake, was locally the northern limit of the Pliocene Mississippi River drainage basin. Using shallow subsurface imaging techniques, André Pugin of the Geological Survey of Canada and his coauthors independently identified a part of the Mississippi's Pliocene drainage system, the Hatfield-Spiritwood River, which flowed east from southeastern Alberta, across southern Saskatchewan into southwestern Manitoba, and south into North Dakota. This river system aligns with our interpretation of an expanded Pliocene Mississippi River drainage basin, providing additional support for our hypothesis.

During the Pleistocene Epoch, Earth's orbital changes caused up to 18 glacial advances and melt retreats in Canada. During the early Pleistocene, glacial cycles lasted approximately 41,000 years; over the epoch's final 1 million years, glacial cycles lasted approximately 100,000 years. The 100,000-year glacial cycles consisted of 90,000 years of glacial growth and 10,000 years of glacial melting during interglacial periods. This history would imply that the reversal of flow on the Red River–Lake Winnipeg–Nelson River may have occurred during previous interglacial periods of the Pleistocene. There is no indication that this reversal has happened. Therefore, we believe the 10,000-year interglacial periods are too short for sufficient uplift to have occurred between Pleistocene glacial periods. So, the rate of uplift since the most recent ice sheet melted can be used to extrapolate the timeline for the complete rebound. We estimate that the Red River drainage system will reverse its flow 9,000 to 13,000 years from now, assuming continental glaciation does not return.

This ongoing reduction in the northward slope will thus reduce the Red River's flow rate and cause greater and more frequent flooding. We estimate that within approximately 9,000 years, the Red River basin will evolve into a lake basin like Lake Winnipeg is today. When the slope of the Red River becomes southward, we postulate that the Red River Lake will expand and overflow into the Minnesota River, which enters the Mississippi River at St. Paul, Minnesota. At that time, flow on the Mississippi River will regain

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drainage from south-central Canada and return to its Pliocene discharge.

The Key to the Future

If our Mississippi drainage evolution hypothesis is correct, then the Red River–Lake Winnipeg–southern Nelson River should currently be slowly tilting southward. That is indeed the case. The northern and southern shorelines of Lake Winnipeg are migrating south as the landscape tilts southward. Similarly, the northward gradient of the Red River is diminishing as the landscape tilts south. Because of this ongoing southward tilting, the Red River drainage system's northward gradient will continue to diminish and may ultimately reverse its flow. Whether or not flow reversal ultimately occurs, flood frequency and flood magnitude along the Red River and its tributaries will increase through time as the river's northward slope continues to diminish.

A fundamental principle of geology is that the present is the key to the past. Here we show that the reverse can also be true: The past is the key to the future. The 3.6-million-year-old ancestral Mississippi River of the Pliocene predicts the future state of the Mississippi River.

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