Examining the progression and termination of Lake Agassiz

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Abstract

This paper focuses on Lake Agassiz in north-central North America, which was a proglacial lake (formed during the retreat of a melting glacier) during the late Pleistocene and early Holocene. I will describe the formation of Lake Agassiz and its progression in central North America. The scale and drainage patterns of Lake Agassiz were spatially and temporally variable, with reconstructed outflow in the south through the Minnesota/Mississippi Rivers, in the north through the Clearwater/Athabasca Rivers and Hudson Bay, and in the east via the Ottawa River and Lake Superior during its 5,000 year history. Lake Agassiz reached a maximum area of 260,000 km^2 and a volume of about 22,700 km^3. During the early Holocene Lake Agassiz spanned a distance of over 3,000 kilometers from east to west along the retreating ice margin, with a north to south extent likely reaching 1,400 kilometers (Leverington et al., 2003). The size and position of Lake Agassiz was highly variable at times, covering parts of present day Saskatchewan, Manitoba, Ontario, Quebec, Minnesota, North Dakota, and South Dakota roughly between 13,500 y BP (11,700 ^{14}C y B.P.) and 8,500 y BP (7700 ^{14}C y B.P.) (Leverington et al., 2002). The dating of strandlines (abandoned shoreline positions), glaciolacustrine sediments, and the use of geographic information systems help identify the age and position of past shorelines and channels associated with Lake Agassiz. The present-day landscape is currently a flat plain with drainage networks oriented toward the north into Hudson Bay. This paper reviews the formation, progression, demise, and present day landscape of Lake Agassiz and provides insight on the features that were produced during its existence.

Introduction

Lake Agassiz was first hypothesized by American geologist William H. Keating in 1823 during an expedition in the Great Lakes region. It wasn't formally noticed by the scientific community until 1890, when geologist Warren Upham published, "The Glacial Lake Agassiz" (named after popular glaciologist Louis Agassiz). The discovery of Lake Agassiz has helped geologists, geographers, and others in the field understand the last continental glaciation and the glacial lakes associated with its retreat.

During the late Pleistocene and early Holocene (between 10 and 8 thousand years before present) many proglacial lakes formed along the ice margins of the Laurentide Ice Sheet (LIS). In the late Pleistocene, Lakes Maumee, Chicago, Saginaw, Algonquin, Iroquois, Minong, and Duluth formed in what is the present day Great Lakes region (Larson and Schaetzl, 2001). Several smaller proglacial lakes also formed in the Great Plains, New England, and Rocky Mountains during the same time period. The Great Lakes, Great Plains, New England, and Rocky Mountain proglacial lakes grew to be large (many larger than some of the present day Great Lakes) as meltwater accumulated. Lake Agassiz, which formed thousands of years later, originated in a different environment compared to the proglacial lakes mentioned prior. The glacial lakes of the late Pleistocene filled depressions created during the glacial advance with meltwater. These depressions filled and subsequently drained at low drainage routes (frequently to the south and east). Lake Agassiz formed in an environment where it was surrounded by generally higher topography (besides the glaciated north) for much of its existence. This caused the lake to get extremely large near the glacial margin and substantially deeper as the ice sheet retreated.

The chronology of Lake Agassiz can be divided into five main phases, the Lockhart (13,560-12,875 y BP), Moorhead (12,875-11,690 y BP), Emerson (11,690-10,630 y BP), Nipigon (10,630-9,160 y BP), and Ojibway (9,160- 8,480 y BP) (Figure 1; Fenton et al., 1983). These phases represent major events that shaped Lake Agassiz's appearance, drainage patterns, and demise in the early Holocene. The purpose of this paper is to interpret the multiple phases of Lake Agassiz, examine the features produced during its existence, and finally explain how its demise influenced the climate and today's landscape.

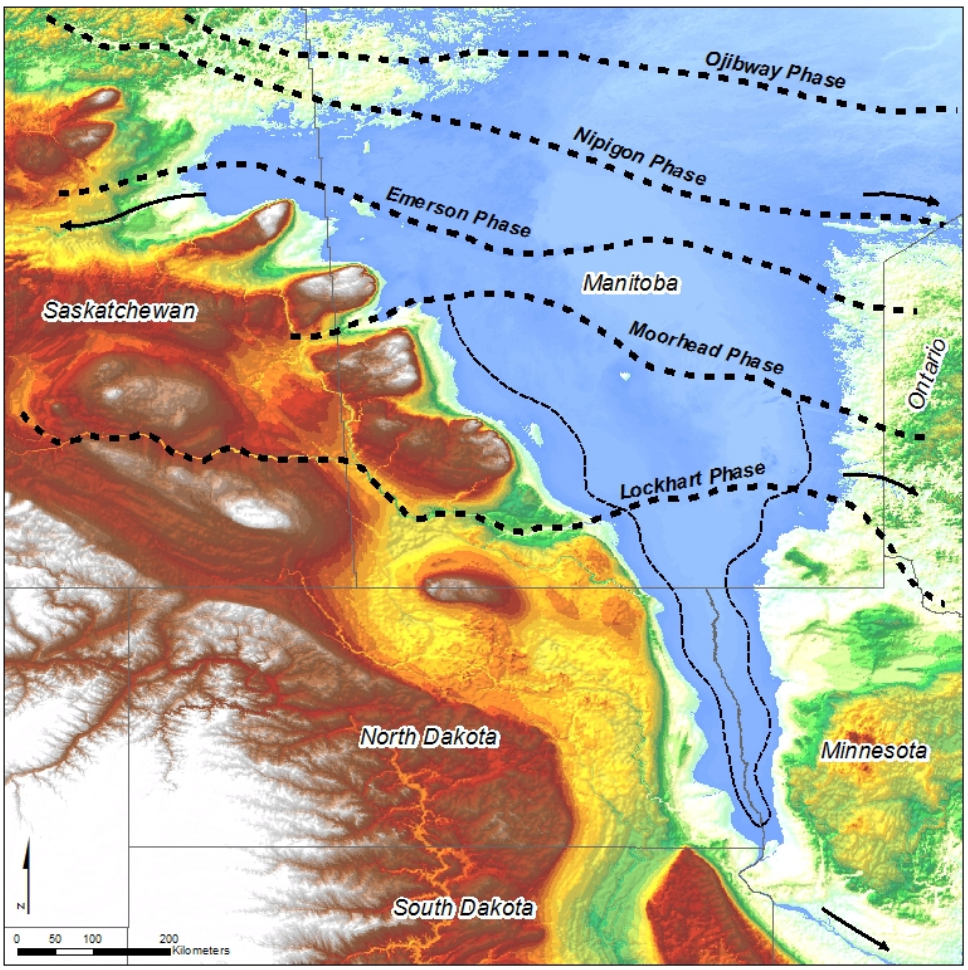

Figure 1. Lake Agassiz's five phases; Lockhart, Moorhead, Emerson, Nipigon, and Ojibway. Southerly drainage was dominant during the Lockhart Phase (13,560-12,875 y BP) and the Moorhead Phase (12,875-11,690 y BP). During the Moorhead Phase Lake Agassiz experienced a drop in lake level as the Kaministikwia route opened drainage east through Ontario. This drop in lake level is shown as the un-bolded dashed line during the Moorhead Phase. Several episodes of southerly and northwesterly drainage through present day Saskatchewan was initiated during the Emerson Phase (11,690-10,630 y BP). In the Holocene, Lake Agassiz found drainage to the east in multiple locations during the Nipigon (10,630-9,160 y BP) and Ojibway (9,160- 8,480 y BP) Phases. (Phase descriptions from Levertington et al., 2002) Dashed lines represent the glacial margin during the indicated lake stage. Arrows represent Lake Agassiz drainage routes taken during the lake stage (Figure produced by author).

Wisconsin Glaciation and Formation of Lake Agassiz

The Wisconsin Glaciation (between 10-100 thousand years before present) was the last glacial period on record. Cooler climates associated with changes in solar radiation, initiated the formation of large continental glaciers in high northern and southern latitudes. The accumulation of snow and a consistently cool climate produced glaciers, which soon advanced into lower latitudes. The formation and advance of the LIS helped set the stage for Lake Agassiz's creation in the late Quaternary.

A cooler climate initiated the formation of large continental glaciers in two main locations, the Keewatin and Labrador Ice Sheets in northern Canada (Figure 2). These two areas were sources for the Laurentide Ice Sheet. The ice sheets merged into one large ice sheet (Laurentide Ice Sheet) as they grew larger and spread across the landscape. Much of the surficial sediments of Canada and the northern United States were eroded as the glacier advanced over the landscape.

The sheer weight of glaciers in northern Canada caused the Hudson Bay region to subside. The heavily subsided northern craton and areas with soft sedimentary rock (northwestern Minnesota, North Dakota, southwestern Manitoba, and southern Saskatchewan) were easily eroded and soon filled with thick glacial ice. A combination of the subsided Hudson Bay region and the eroded Red River valley would help shape the future Lake Agassiz.

The LIS started to retreat from the northern United States around 20,000 y BP, filling the eroded crevasses that were carved during its advance with meltwater. When the ice margin reached the southern Lake Agassiz region (present day Red River valley) around 13,500 y BP, the filling of the eroded sedimentary platform began. The eroded sedimentary platform would be the heart of Lake Agassiz, dictating its shape and recording its deepest depths. The LIS retreated

into Canada shortly after 13,500 y BP. The next 5,000 years would shape Lake Agassiz and the North American continent alike.

Figure 2. The Keewatin and Labrador Ice Sheets (USGS, 2007).

The Lockhart Phase: 13,560-12,875 y BP

During the initial Lockhart Phase, meltwater started to accumulate in the present day Red River valley of North Dakota and Minnesota. Early Lake Agassiz functioned similarly to other proglacial lakes during the late Pleistocene, in that meltwater overflowed and drained southward

via an ancestral Minnesota and Mississippi River system into the Gulf of Mexico (Figure 3; Birks et al., 2007). During this time, the LIS was near the current United States-Canada border and rapidly melting northward. Early Lake Agassiz extended from southern Manitoba to the Land of Lakes region in northern Minnesota/Ontario, to well past Fargo, North Dakota along the Red River floodplain (Figure 3). The Lockhart phase is associated with the Herman lake stage (335 meters), which today is the highest shoreline (strandline) measured in southern Lake Agassiz. The Big Stone Moraine oriented horizontally across the southern drainage, obstructed the southerly advance of Agassiz lake levels (Figure 4). Lake Agassiz during the Lockhart Phase is estimated at being 231 meters on average (758 feet) in depth, with greater depths located near the glacial margin and shallower areas near the mouth of the ancestral Minnesota River (Leverington et al., 2002).

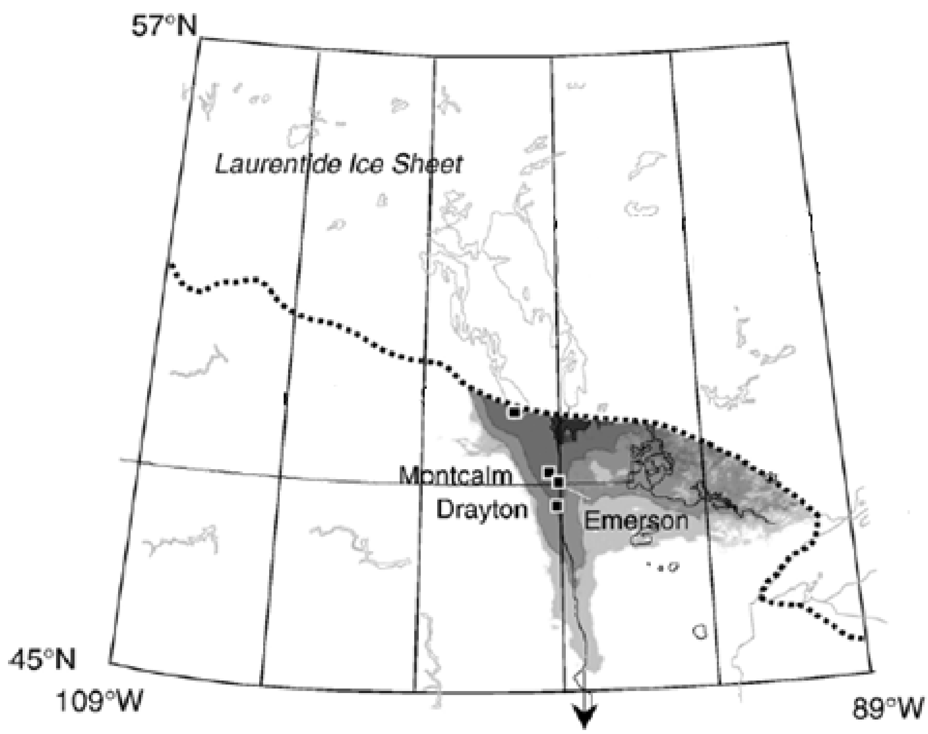

Figure 3. Lake Agassiz during the end of the Lockhart Phase, 13,000 y BP (Birks et al., 2007).

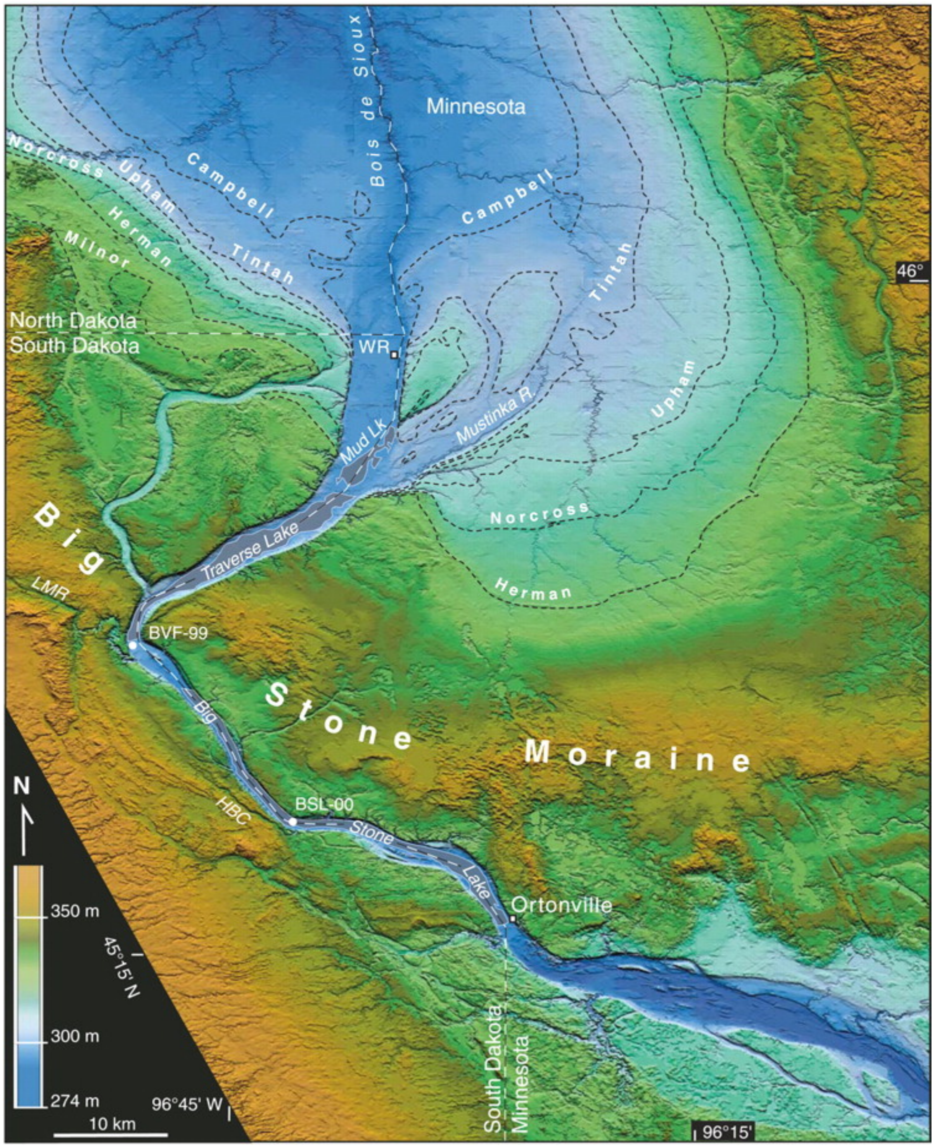

Figure 4. Lake Agassiz's southern drainage through an ancestral Minnesota and Mississippi River system. Notice the high Herman and Norcross lake levels/strandlines of the Lockhart and Moorhead Phases. This area is near the confluence of the present day states of Minnesota, South Dakota, and North Dakota (Fisher, 2005).

The Moorhead Phase: 12,875-11,690 y BP

As the LIS continued to retreat north into Canada, Lake Agassiz found alternative drainage. The Kaministikwia route near today's Minnesota-Ontario border offered a drainage route toward the east into Lake Duluth (western Lake Superior), which then drained southward via an ancestral St. Croix and Mississippi River system. As the Kaministikwia route continued to drain Lake Agassiz, lake levels quickly fell from the Herman lake stage. Isostatic rebound and

glacial readvances soon closed the Kaministikwia route and stabilized Lake Agassiz, raising lake levels to the Norcross lake stage (325 meters), never returning to the high Herman lake stage (Thorleifson, 1996).

These lake stages have been dated using Optically Stimulated Luminescence (OSL) and viewed using a Digital Elevation Model (DEM) by Lepper et al., (2002) in eastern North Dakota. Analysis indicated that highly elevated strandlines above the Herman lake stage were poorly developed and rare, indicating that Lake Agassiz was stable. Lake stages higher than 335 meters above sea level were short-lived. Lower strandlines are associated with the younger lake levels of the Norcross (325 meters) and Campbell (299 meters) lake stages (Table 1). A large alteration in the number of strandlines occurs between the 310 meter and 299 meter levels where transitional lake stages are not present, indicating a quick fluctuation in Lake Agassiz levels (Figure 5).The lower Norcross lake stage reshaped Lake Agassiz into a more slender appearance than noticed during the Herman lake stage. The average depth of Lake Agassiz during the late Moorhead Phase (258 meters) slightly increased as the glacial margin retreated northward exposing lower terrain. Drainage from Lake Agassiz still continued to flow southward out of the ancient Minnesota and Mississippi River systems into the Gulf of Mexico.

Sample	Strandline elevation (m)	Grain size[a]	N[b]	M/m[c]	υ[d]	Equivalent dose[e] (Gy)	Dose rate (Gy/ka)	Age (ka)		Uncertainty[f] (ka)
KG0505	299	VFS	96/96	1.02	0.19	16.329±0.324	1.585±0.156	10.3	±0.2	0.9
KG0505	299	FS	95/96	1.01	0.20	15.463±0.324	1.553±0.153	10.0	±0.2	0.9
KL1004	310	VFS	46/48	1.02	0.12	20.666±0.357	1.520±0.123	13.6	±0.2	1.1
KL1004	310	FS	92/94	1.01	0.14	19.982±0.397	1.492±0.121	13.4	±0.3	1.1
KG0501	*316*	*VFS*	*93/95*	*1.01*	*0.20*	*20.592±0.436*	*1.821±0.148*	*11.3*	±0.2	*1.0*
KG0501	*316*	*FS*	*45/48*	*1.01*	*0.16*	*21.659±0.528*	*1.787±0.145*	*12.1*	±*0.3*	*1.1*
KG0503	325	VFS	93/96	1.00	0.19	24.316±0.475	1.787±0.163	13.6	±0.3	1.3
KG0503	*325*	*FS*	*85/88*	*1.01*	*0.20*	*22.151±0.485*	*1.752±0.160*	*12.6*	±*0.3*	*1.2*
KG0504	335	VFS	93/95	1.00	0.16	25.132±0.421	1.761±0.162	14.3	±0.2	1.3
KG0504	335	FS	92/95	1.00	0.14	24.400±0.342	1.726±0.159	14.1	±0.2	1.3

Table 1. OSL dates on eastern North Dakota strandlines indicating that higher elevated strandlines are generally older than lower elevated strandlines, suggesting that Lake Agassiz was higher during initial formation in the late Pleistocene (Lepper et al., 2011).

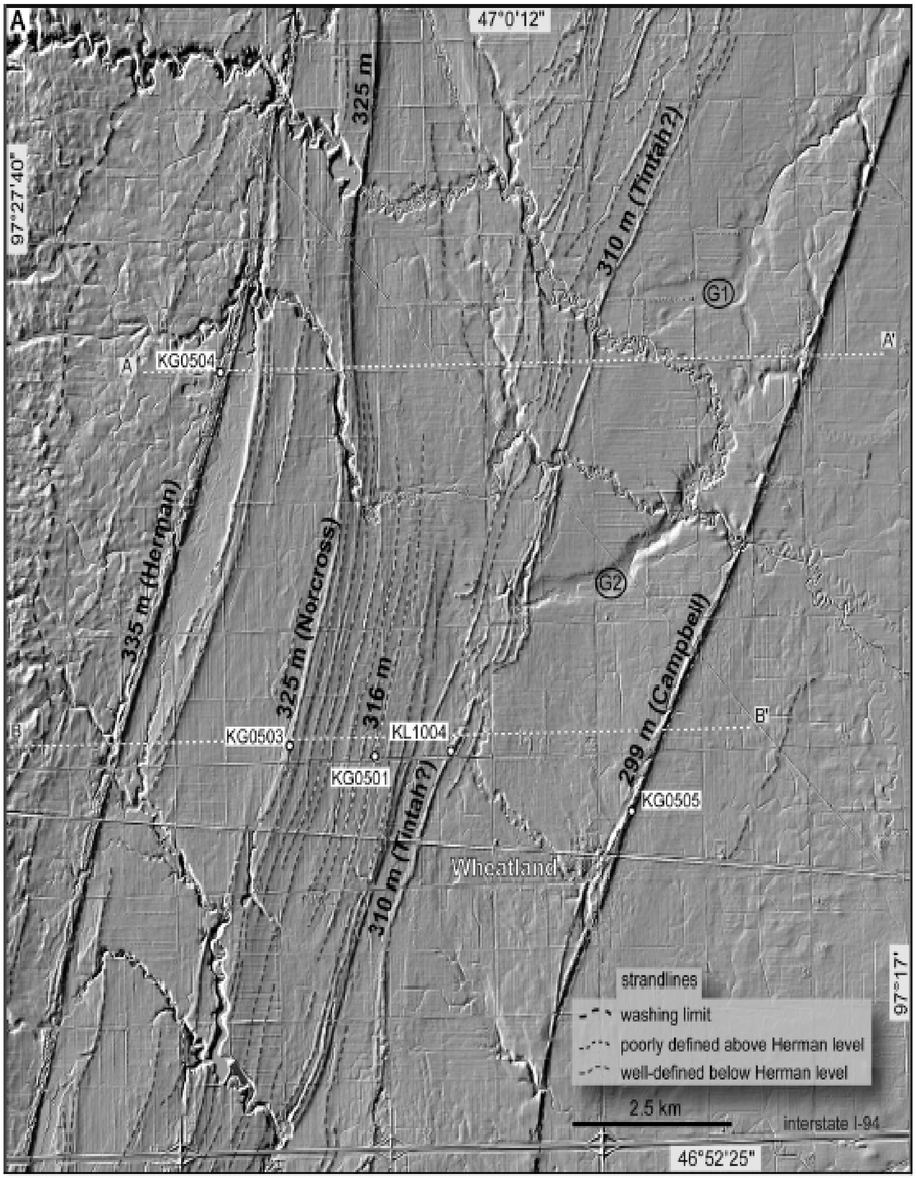

Figure 5. The Herman (335 meters), Norcross (325 meters) and Campbell (299 meters) strandlines are identified in present day eastern North Dakota. Notice the large alteration in strandlines between 310 and 299 meter levels, indicating quick fluctuations in Lake Agassiz lake levels (Lepper et al., 2011).

The Emerson Phase: 11,690-10,630 y BP

The Emerson Phase was a period in which Agassiz lake levels and drainage patterns continually fluctuated. A combination of isostatic rebound, meltwater from the retreating ice margin, and the closed Kaministikwia drainage route to the east, increased the size of northern Lake Agassiz. Lake Agassiz has been hypothesized as possibly being a terminal lake (balance of

surface inflows and evapotranspiration) during this time period (Fisher, 2013). The dating of glacial moraines indicates the ice margin covered drainage routes into the Clearwater and Athabasca River system and Lake Nipigon and Minong basin (Fisher, 2013). A terminal lake may be possible if the basin experienced less precipitation and meltwater input, coupled with large rates of evapotranspiration during the time period. Lake Agassiz would only have been terminal for a few hundred years if the theory is accurate, soon finding drainage to the northwest through the Clearwater and Athabasca River system (Figure 6). Short episodes of southerly overflow due to isostatic rebound and outlet erosion still occurred in the present day Red River valley (Leverington et al., 2002). The Norcross (325 meters), Tintah (310 meters), and Upper Campbell (299 meters) are the three strandlines associated with the Emerson Phase. The large fluctuations in lake levels during this time period are observable in the southern Lake Agassiz basin (Figure 7).

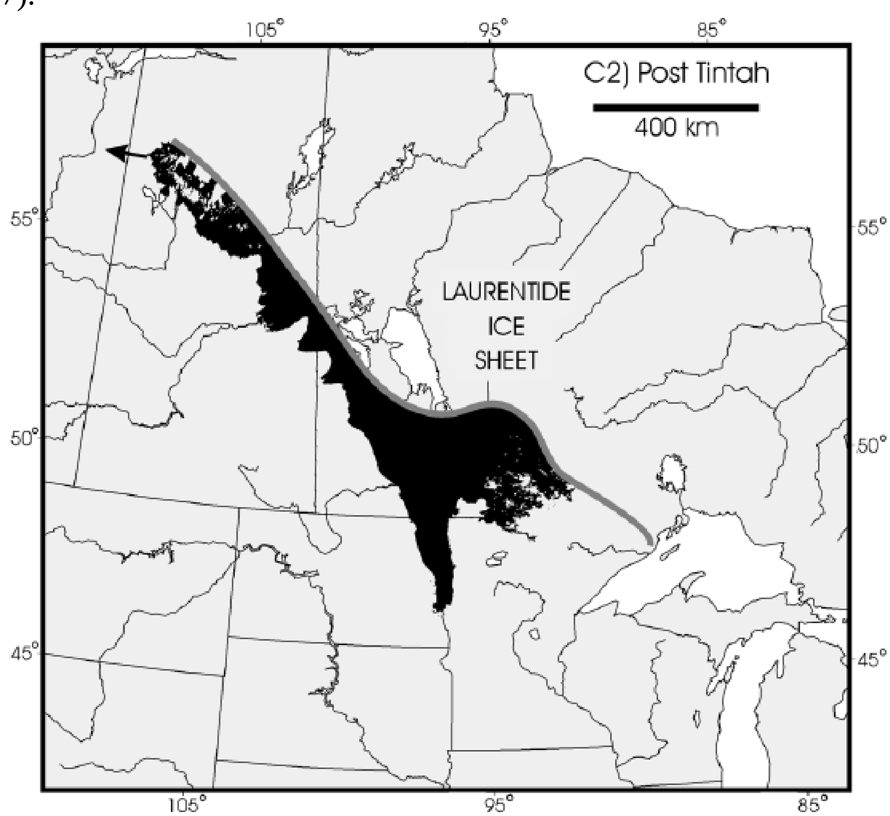

Figure 6. Lake Agassiz during the Emerson Phase (Teller and Leverington, 2004).

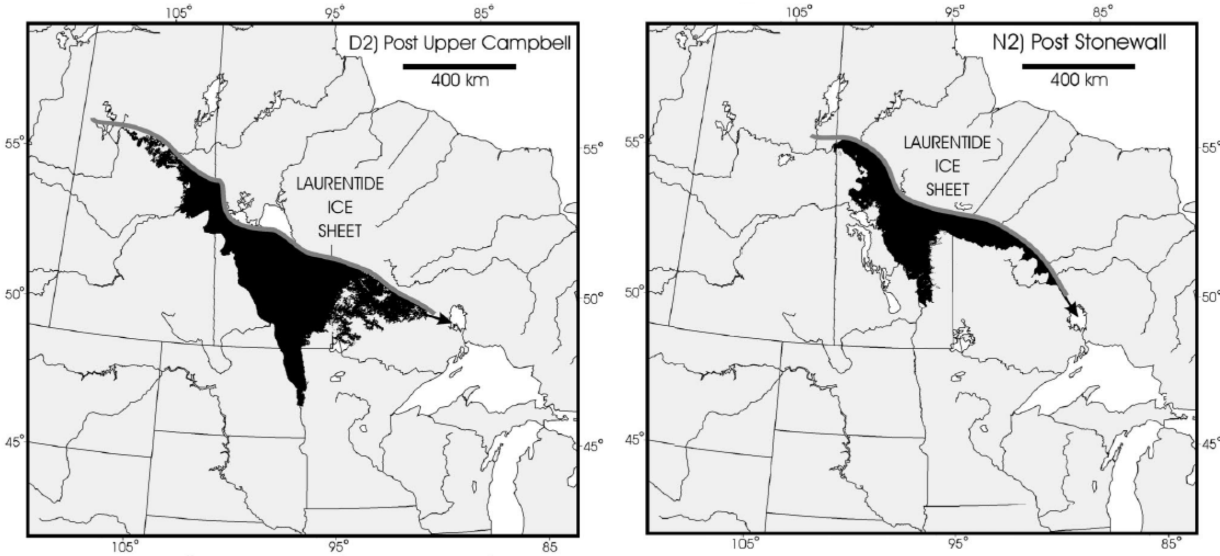

Figure 7. The Kaiashk outlet allowed over flow into the Lake Nipigon and Superior basins. The Kaiashk outlet dramtically reduced the size of Lake Agassiz between 10,630-9,160 y BP (Teller and Leverington, 2004).

The Nipigon Phase: 10,630-9,160 y BP

The Nipigon Phase was initiated by the deglaciation of the Kaministikwia drainage route in the eastern Lake Agassiz basin. This allowed drainage to enter the Lake Nipigon (hence the name of the phase) and Superior basins (Figure 7). Lower drainage and a readvancing glacial margin led to the abandonment of Lake Agassiz's northwestern (ancient Clearwater and Athabasca River system) and southern (ancestral Minnesota and Mississippi River system) drainages. Catastrophic amounts of outflow from Lake Agassiz filled the Lake Minong basin (Lake Superior) with the reestablishment of the Kaministikwia drainage route. Several low outlets allowed flow from Lake Agassiz into the Lake Minong basin. Outflow was interrupted during a readvance between 10.5 to 9.5 y BP, which blocked drainage routes in the northern Lake Nipigon basin (Teller and Thorleifson, 1983, 1987). It is possible that other previously established drainage routes opened for Lake Agassiz outflow during the Kaministikwia blockage. Subsequently, periodic catastrophic outbursts entered the Lake Minong basin as the Laurentide Ice Sheet retreated, once again opening Lake Agassiz drainage routes. These large inflows of water not only raised Lake Minong lake levels, Lake Algonquin in the Lake Michigan/Huron

basin also received significant additions (Drexler et al., 1983). Outbursts toward the end of the Nipigon Phase influenced the Great Lakes region dramatically. Lakes Chippewa (ancestral Lake Michigan) and Stanley (ancestral Lake Huron) were at extremely low levels due to isostatic rebound and the recent breach of North Bay (present day central-Ontario). These outbursts from Lake Minong temporarily flooded Lake Stanley, and then flowed through the North Bay drainage route, into the Champlain Sea (present day St. Lawrence lowland). With the retreat of the LIS, Lake Agassiz continued to shift to the north. Lake levels fluctuated as drainage channels in the Lake Nipigon and Superior basin opened, closed, and reopened due to erosion. The constant fluctuation of lake levels produced around a dozen strandlines during times of intermittent stability (Teller, 2001). New, lower strandlines were produced as lake levels continued to drop (Figure 8). During the end of the Nipising Phase, Lake Agassiz may have reached its largest geographical extent, as it joined with Lake Ojibway to the east (Figure 9).

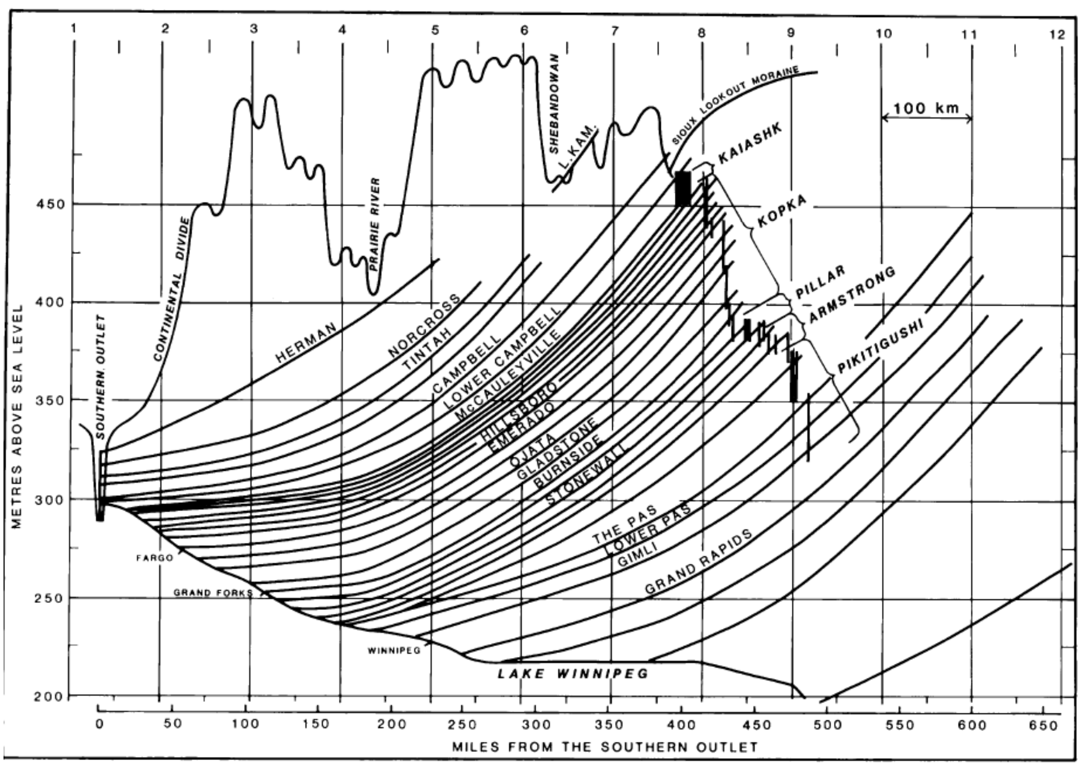

Figure 8. Notice the tremendous effect isostatic rebound has had on northern reaches (right) of the Agassiz lake plain. Dozens of strandlines formed during the Nipigon Phase, as Lake Agassiz progressively dropped and stabilized (Teller, 2001).

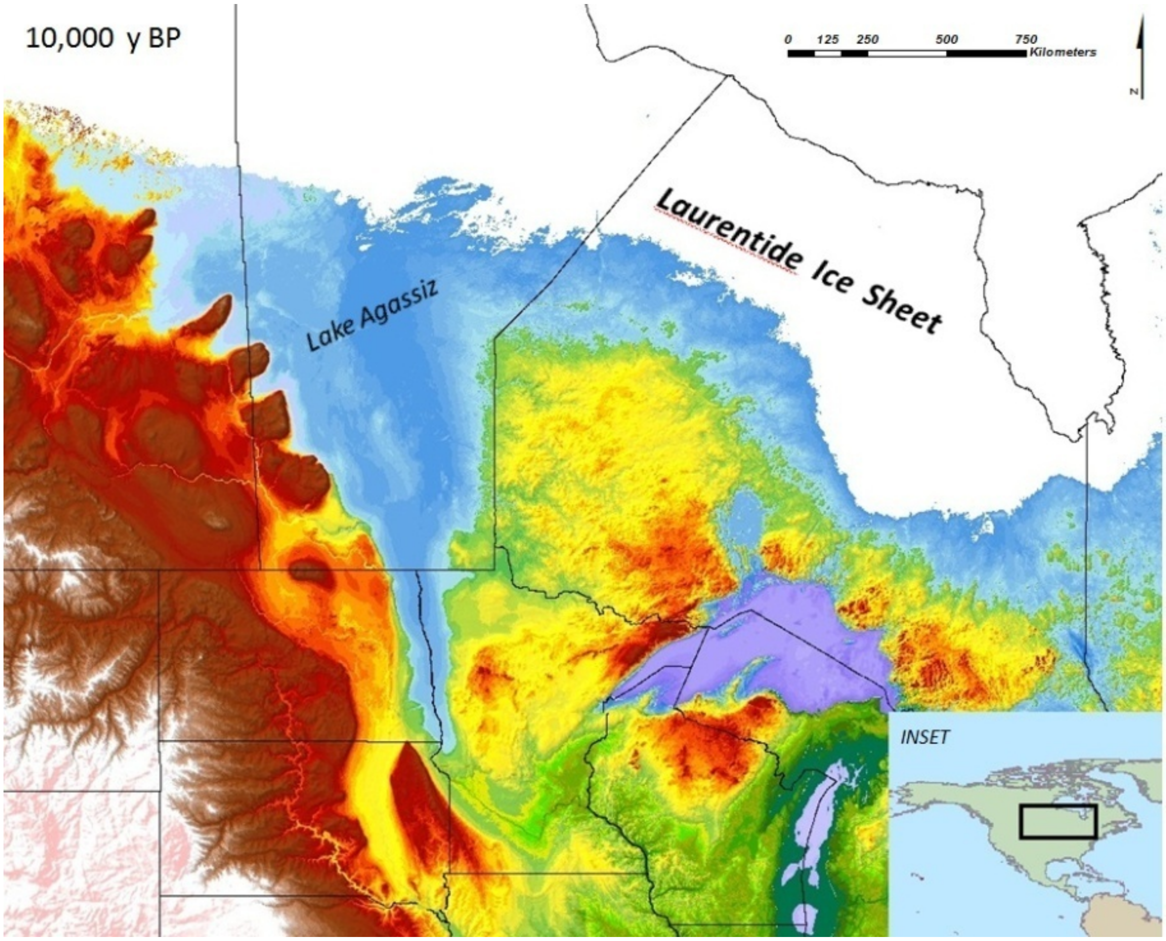

Figure 9. The extent of Lake Agassiz during the Nipigon Phase (Figure produced by author).

The Ojibway Phase: 9,160- 8,480 y BP

The Ojibway Phase started as Lake Ojibway (covering northeastern Ontario and central Quebec) merged with Lake Agassiz in present day northern Ontario. Meltwater additions and isostatic rebound of the previously glaciated lands in southern Canada gave Lake Agassiz-Ojibway a linear appearance along the LIS. Drainage now left the Agassiz basin to the east through the Kinojevis outlet into the Ottawa River valley (present day border of Ontario and Quebec). Large amounts of drainage entered the St. Lawrence lowland and the Atlantic Ocean at this time (Figure 10).

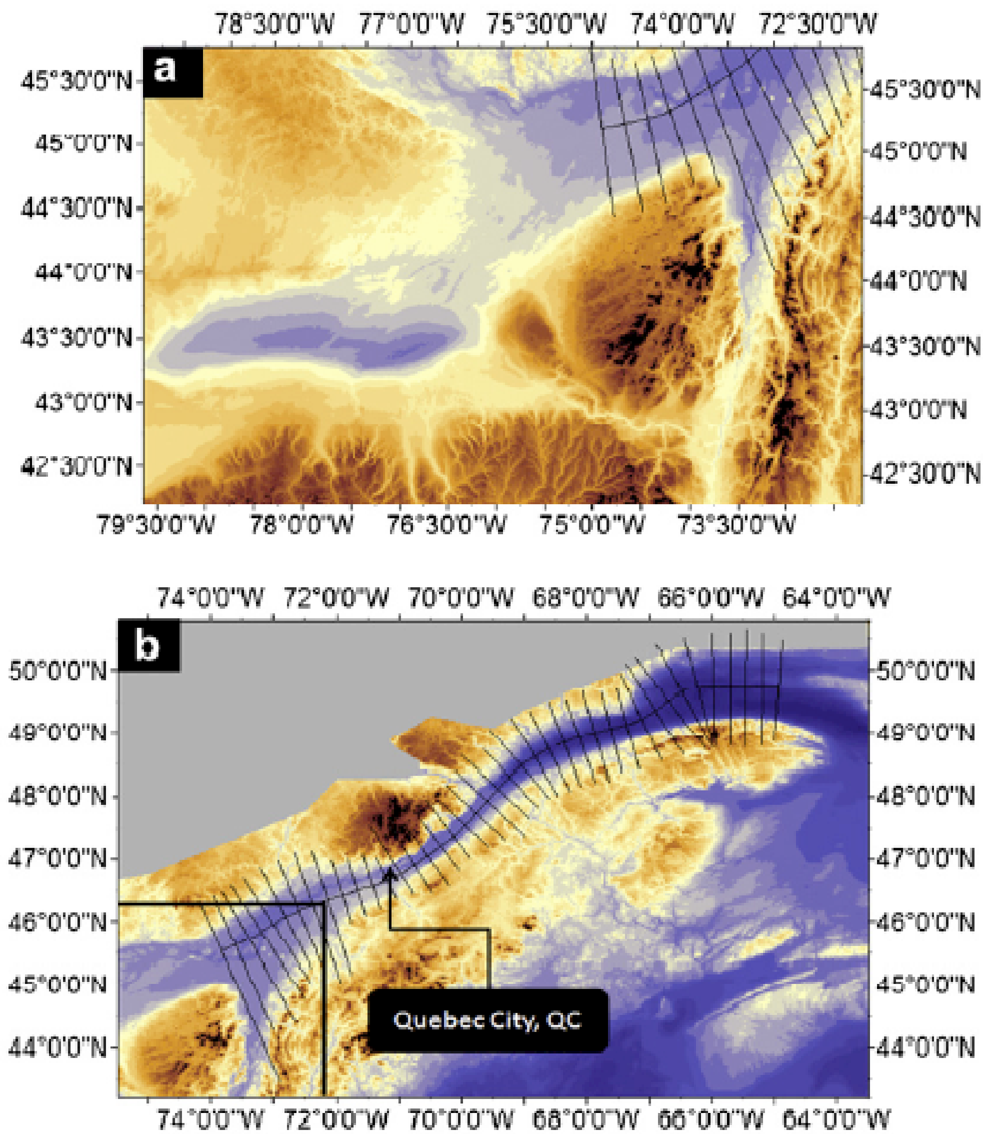

Figure 10. Lake Agassiz drainage flooding what is the present day (A) St. Lawrence lowland, and (B) St. Lawrence Seaway (Katz et al., 2011).

Lake Agassiz-Ojibway drainage raised sea level considerably, flooding low areas along the coast. An image of this profound sea level rise can be noticed in Nova Scotia, New Brunswick, and eastern Maine in Figure 10 B. Marine records from the North Atlantic have identified two separate episodes of surface ocean freshening and have been linked to northern hemisphere cooling events at 8,490 y BP and 8,180–8,340 y BP (Li et al., 2012). These events are possibly linked with the Ojibway Phase of Lake Agassiz and may indicate large amounts of drainage from the Ottawa River valley and the Tyrrell Sea (ancestral Hudson Bay).

The final Lake Agassiz-Ojibway drainage and an 8,200 y BP climatic event together comprise a rare and major climate change event that can be associated to a well-identified source of freshwater forcing (Li et al., 2012). This cooling is associated with alteration of the thermohaline circulation of the North Atlantic. Thermohaline circulation is driven by density currents of warm and cold water. Cold water sinks the ocean current, while warmer sea water allows the currents to rise toward the surface. When the excess cool freshwater enters the ocean, ocean current sinks in response, which in turn slows the overall oceanic current, causing the climate to cool. Ice core and marine records have suggested that Lake Agassiz played a profound role in decreasing the relative salinity and temperature of the North Atlantic, which, in turn, cooled the climate (Figure 11). Similar cooling events such as, the Younger Dryas (12,800 to 11,500 y BP) may also be related to above-average additions of freshwater into the ocean, thousands of year prior.

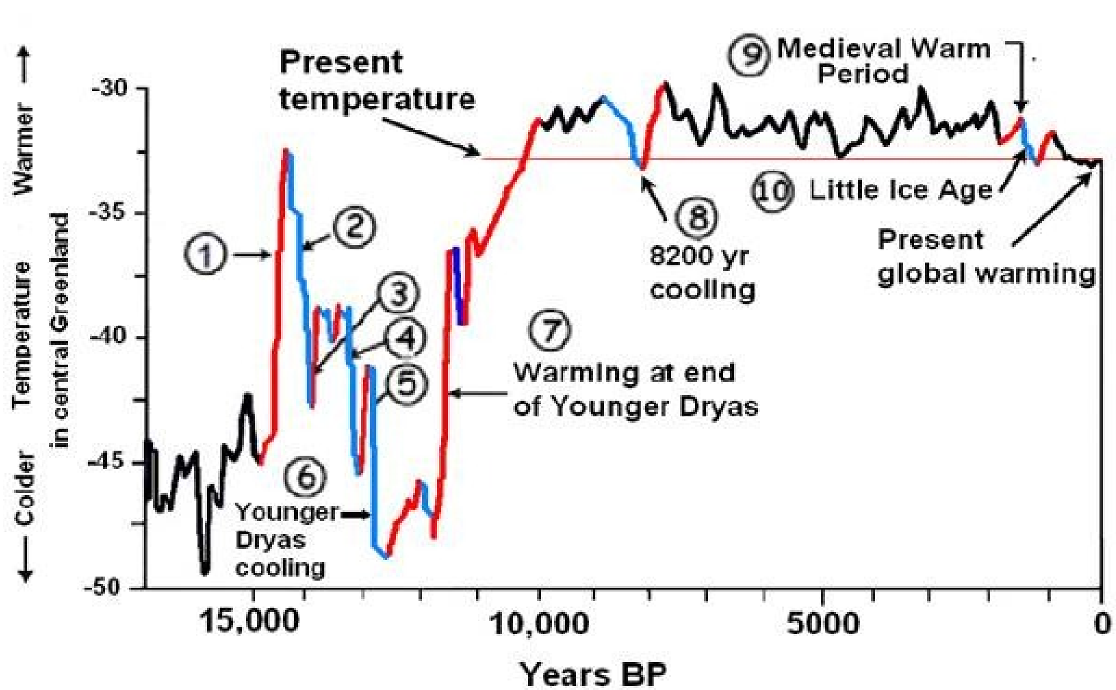

Figure 11. Climate fluctuations during the past 15 thousand years. Notice climate cooling event 8, which is thought to be caused by catastrophic Lake Agassiz drainage (Easterbrook, 2012).

As Lake Agassiz-Ojibway was draining through the Ottawa River valley, the Laurentide Ice Sheet continued to recede to the north (Figure 12). Continued warming of the climate drove the ice margin near present day Hudson Bay, where Lake Agassiz found a northward outflow through the Tyrrell Sea. The breach of the low-lying Tyrrell Sea allowed Lake Agassiz to quickly abandon its easterly drainage at the Kinojevis outlet. Catastrophic northward drainage into the Tyrrell Sea is believed to have followed the disintegration of the adjacent glacial front at about 8,480 y BP (Figure 13; Leverington et al., 2002). The breach of the Tyrrell Sea in the early Holocene, initiated the collapse of Lake Agassiz. The LIS continued to recede northward toward Baffin Island and the present day Greenland Ice Sheet and abandoned mainland North America around 5,000 y BP (Farrand, 1988). Late Holocene climates continued to warm and raise sea levels from those of the early Holocene.

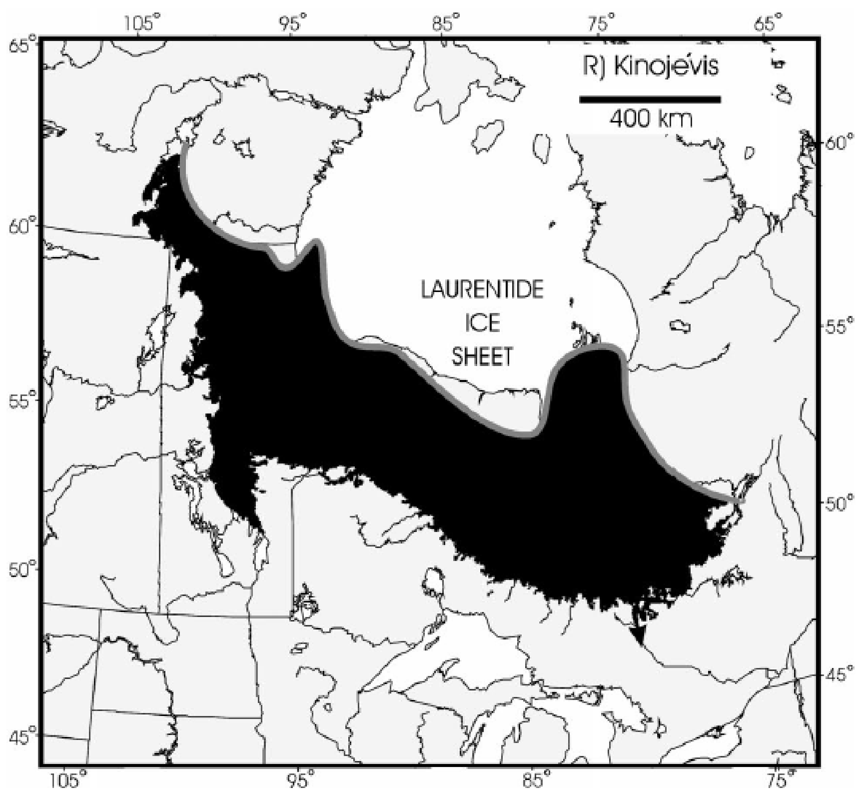

Figure 12. Lake Agassiz-Ojibway during the Ojibway Phase finding drainage through the Ottawa River valley. The Tyrrell Sea to the north will soon consume Lake Agassiz-Ojibway (Teller and Leverington, 2004).

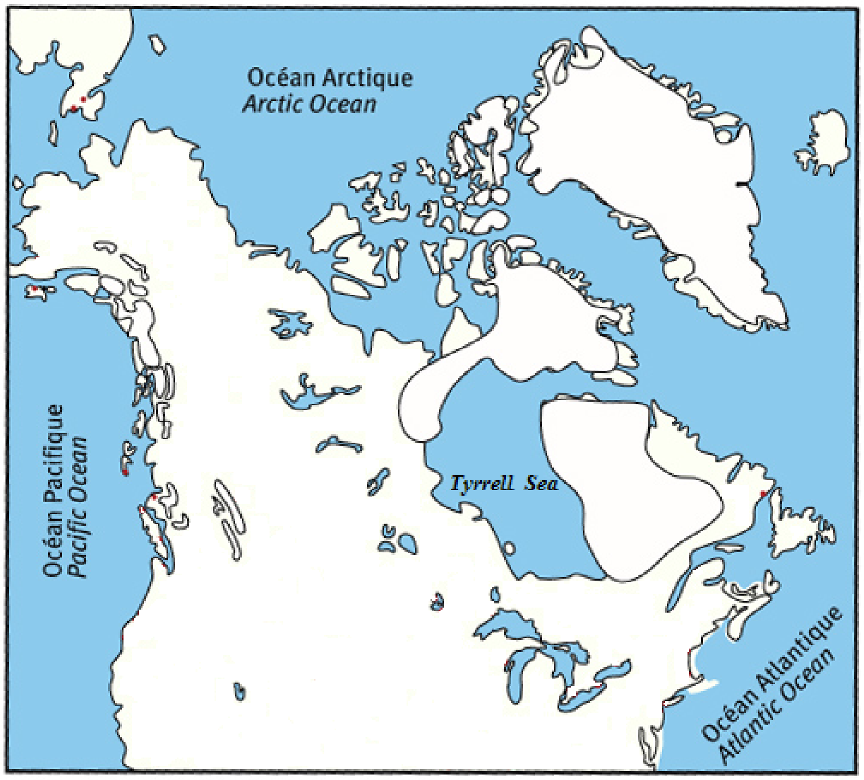

Figure 13. The Tyrrell Sea (present day Hudson Bay) allowed Lake Agassiz drainage to flow northerly into the Atlantic Ocean (Canadian Museum of Civilization, 2010).

The Lake Agassiz Lake Plain

Today, much of western Manitoba, Minnesota, eastern Saskatchewan, and North Dakota are noticeably flat (Figure 14). The fluctuation of lake levels allowed for constant erosive activity in the shallow reaches of the Lake Agassiz Lake Plain. The north-tilted landscape kept the deeper portions of Lake Agassiz near the glacial margin, while the shallow reaches of the lake plain tapered off slowly in the southern portions of the basin.

Thick accumulations of sediment in the lake plain can be analyzed today through varve (annual layers of sediment) and rhythmite (sediment deposited in regularity) samples in the basin. These sediments came into Lake Agassiz through glacial runoff and streams entering the basin. Deposited sediments coupled with erosive wave action in the shallow areas of Lake Agassiz, produced the flat topography noticed in the region today. This erosive wave action in shallow bodies of water is called shoaling. Waves entering shallow water decrease in speed and

wavelength, producing higher wave crests with the exchanged energy. When wave crests become too steep, the crest grows increasing unstable and curls in on itself. This causes the wave to break, often when the height of the wave becomes about the size of the waters depth. Energy from the waves transfer to the shoreline, which erodes and flattens the beach and surf-zone (Figure 15). The relatively shallow southern Lake Agassiz allowed this process to happen for thousands of years.

Figure 14. The Lake Agassiz lake plain in eastern North Dakota (Schwert, 2011).

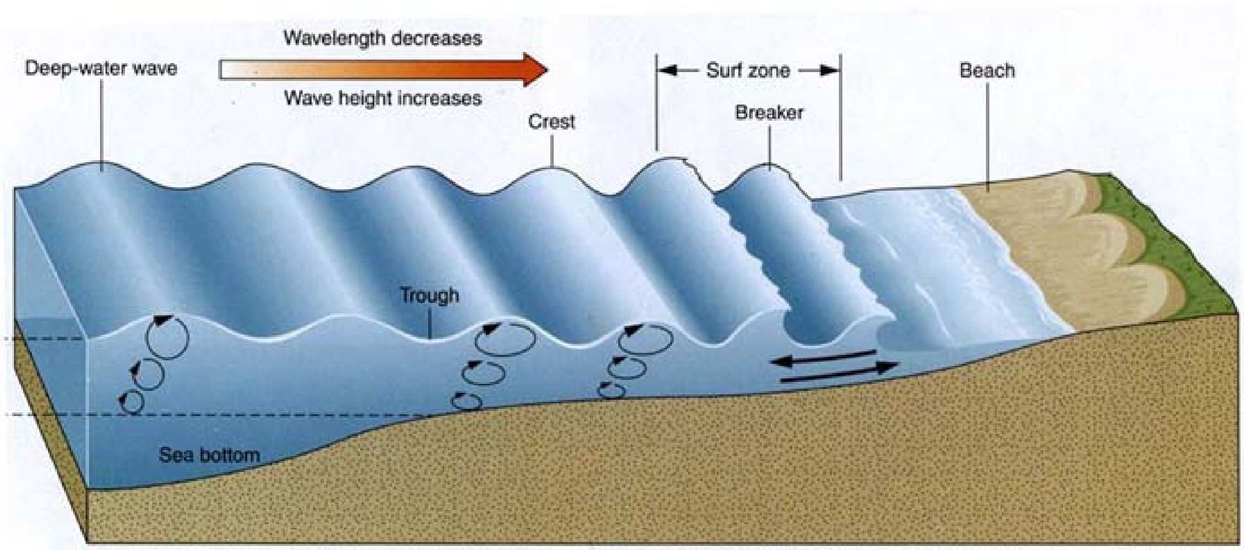

Figure 15. Shoaling: shallow portions of Lake Agassiz's lake bed were flattened, as oscillating wave action induced friction (Beiers, 2003).

As the lake levels of Lake Agassiz dropped the shoaling effect followed, flattening the landscape at each shore. This action was mostly at work in the southern portion of the basin where lake levels were relatively shallow. The northern portion of the basin also appears flat but borders the Canadian Shield, whose metamorphic and igneous ridges were relatively resistant to glaciations. Isostatic rebound has also produced a higher amount of uplift in the northern Lake Agassiz basin (Figures 8 and 16). Uplift in northern Canada has displaced Lake Agassiz shorelines/strandlines to substantially higher modern elevations.

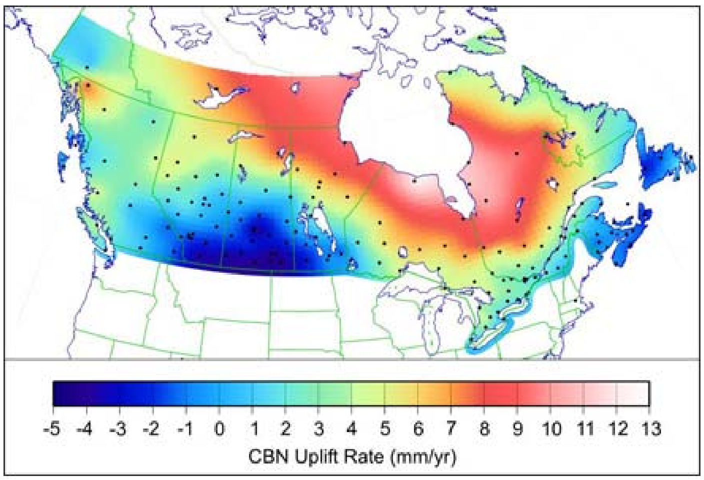

Figure 16. Map showing the rate of isostatic rebound, blue is low, red indicates high uplift (Wikipedia Commons, 2013).

Figure 17. Lake of the Woods, Winnipeg, Manitoba, Winnipegosis, Red, Lac La Ronge, Cedar, and many others are remnant lakes from Lake Agassiz (University of Minnesota, 2010).

Many of the lakes found in central Canada and northern Minnesota are remnants of Lake Agassiz. Some of these lakes include: Lake of the Woods, Lake Winnipeg, Lake Manitoba, Lake Winnipegosis, Lac La Ronge, Cedar Lake, Upper and Lower Red Lakes, and many other smaller lakes scattered throughout the region (Figure 17). These were deeper locations within Lake Agassiz and were highly glacially eroded by glaciations. Others may be kettle lakes, not associated with Agassiz. The heavily subsided region of northern Canada has had a lasting effect on the drainage characteristics of the Lake Agassiz Lake Plain. Elevations on the lake plain

gradually decrease toward Hudson Bay, just as they did when Lake Agassiz spanned central North America thousands of years ago. Today, drainage in the lake plain flows toward Hudson Bay as a result of the north-oriented landscape.

Effects of Agassiz on Modern Drainage

The Red River basin of Minnesota and North Dakota is the only region in the continental United States that drains to the Arctic Ocean. The Red River is 634 kilometers in length, beginning at the confluence of the Otter Trail (originating in central Minnesota) and the Bois de Sioux Rivers (originating in northeastern South Dakota) and empties into central Manitoba's Lake Winnipeg, which reaches base level at Hudson Bay. While the region is noticeably flat, an elevation difference is measurable. The Red River begins at an elevation of 287 meters above sea level and ends at 217 meters above sea level in Lake Winnipeg. Considering the length and elevation of the Red River, average channel slope of the stream only reaches 0.11 meters per kilometer. The incredibly low slope of the Red River is problematic during spring snow melts and heavy rain events. Floods commonly occur on the floodplain during times of high stream discharge. Some of the more notable floods in the historical record took place in 1826, 1897, 1950, 1997 (Figure 18), and 2009. Large paleofloods are also suggested to have occurred based on erosional landforms in the region (St George, and Nielsen, 2000).

The frequent large scale flooding of the Red River has caused many problems for large towns along the river's banks. The three largest towns on the Red River are Winnipeg (population 684,100), Fargo (population 107,349), and Grand Forks (population 52,631). Prominent flooding has occurred so often that the city of Winnipeg constructed a 47 kilometer long floodway channel (Red River Floodway) that diverts flood waters around the city in the event of a flood. Fargo and Grand Forks are also thinking of adding a floodway system to relieve

the potential flooding of urban areas. The geography of Lake Agassiz still has a strong link to present day processes and events that occur in the region.

Figure 18. Red River flood of 1997 in Grand Forks, North Dakota (Wikipedia Commons, 2011).

Conclusions

This paper analyzed the geomorphic history and features of proglacial Lake Agassiz that spanned north-central North America between 13,560 and 8,480 y BP. The advance of the Laurentide Ice Sheet scoured the landscape and caused the region around Hudson Bay to subside, which set the stage for the formation of Lake Agassiz as meltwater pooled near the receding ice margin. The position of the Lockhart, Moorhead, Emerson, Nipigon, and Ojibway Phases were reported to show the progression of Lake Agassiz. Lake Agassiz found drainage in multiple locations such as the Gulf of Mexico (via an ancient Minnesota/Mississippi River system), the North Atlantic (via Lake Superior and the St. Lawrence River), and the Arctic Ocean (via an ancient Clearwater/Athabasca River system and Hudson Bay) during its 5,000 year existence. The dating and interpretation of strandlines allows researchers to interpret the height and dates of Lake Agassiz lake level fluctuations. The catastrophic draining of Lake Agassiz raised the sea level, while also cooling much of the northern hemisphere. Isostatic

rebound is continually uplifting the Agassiz lake plain that once experienced glacial subsidence. Today, Lake Agassiz's lake plain is oriented toward Hudson Bay. The relatively low slopes of the Agassiz lake plain leads to ideal flood conditions in times of high discharge, like those on the Red River. Descriptions and interpretations made in this paper are made from related scientific literature to help better understand Lake Agassiz and its lake plain.

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