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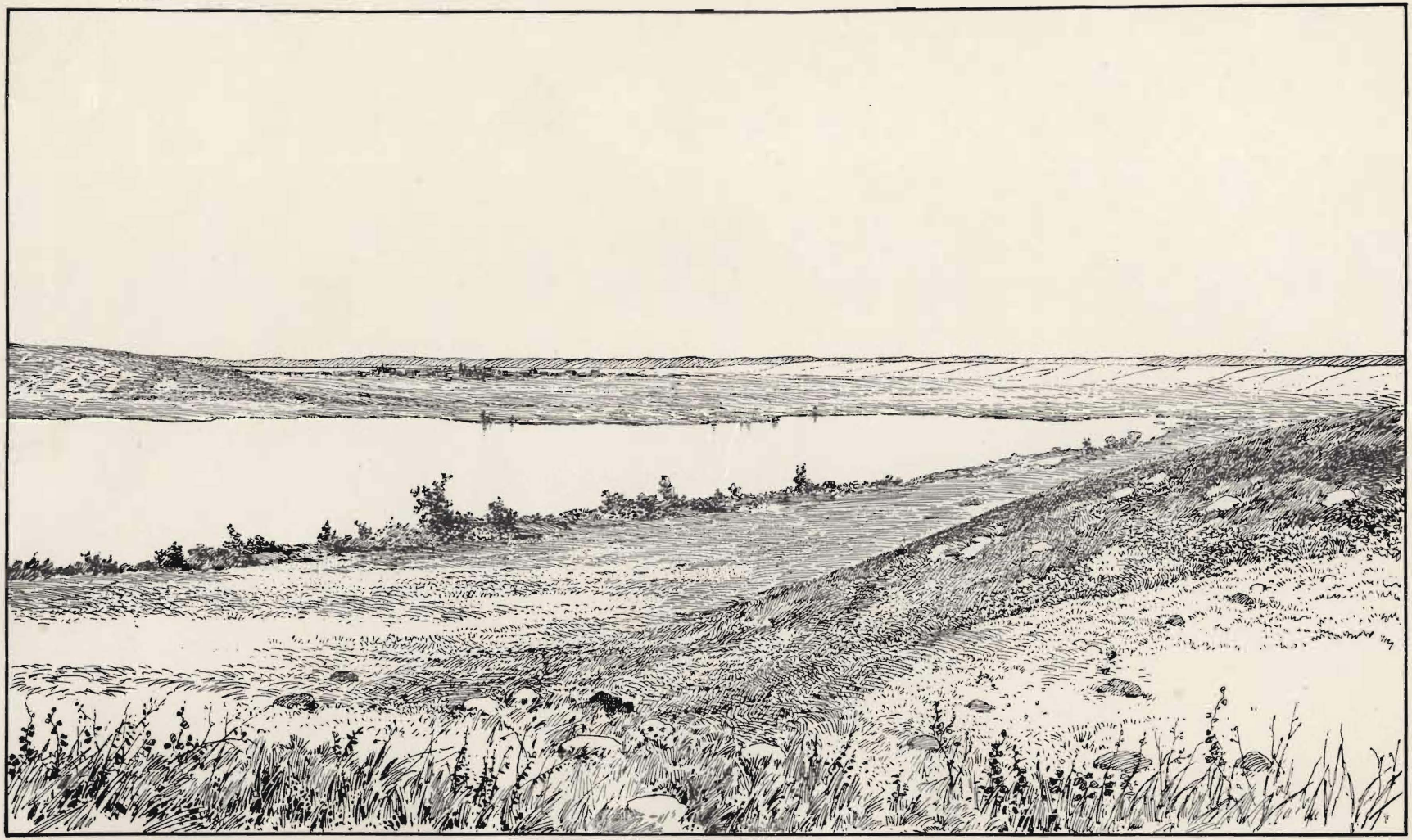

CHANNEL OF THE RIVER WARREN, THE OUTLET OF LAKE AGASSIZ.

Looking southeast, over the south end of Lake Traverse and the town of Browns Valley, to Big Stone Lake at a distance of 6 miles.

DEPARTMENT OF THE INTERIOR

MONOGRAPHS

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE GLACIAL LAKE AGASSIZ

BY

WARREN UPHAM 1850-

WASHINGTON
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1895

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UNIVERSITY OF CHICAGO,
Chicago, Ill., March 8, 1894.

SIR: I have the honor to transmit herewith, for publication as a monograph of the United States Geological Survey, the manuscript of a report on the Glacial Lake Agassiz, by Mr. Warren Upham. I am confident that it will be welcomed by the scientific world as a valuable contribution to the literature of North American glaciology.

Very respectfully,

T. C. CHAMBERLIN,
Geologist in Charge

To the DIRECTOR UNITED STATES GEOLOGICAL SURVEY.

PREFACE.

In my work for the Geological and Natural History Survey of Minnesota, from 1879 to 1885, under the direction of Prof. N. H. Winchell, State geologist, the highest shore-line of Lake Agassiz in that State was mapped through its prairie portion, extending about 175 miles from Lake Traverse eastward to Herman and thence northward to Maple Lake. During this survey Mr. Horace V. Winchell was my efficient assistant as rodman in leveling. The exploration showed that a very large lake occupied the Red River Valley in the closing stage of the Glacial period, when the ice-sheet was being melted away from this district. Terminal moraines of the ice-sheet, forming a series of eleven in consecutive order from south to north, were also explored and mapped in Minnesota; and it was seen that the glacial lake and moraines were intimately related as records of the recession of the ice and the transition from the Pleistocene to the Recent or present geologic period.

It became evident, however, that a satisfactory investigation of the extent and history of Lake Agassiz must comprise both sides of the Red River Valley. The United States Geological Survey therefore undertook the more extended examination of this lake area, which was assigned to me, as a member of the Glacial Division, under the direction of Prof. T. C. Chamberlin, for whose friendly counsel and constant interest in this work I have the pleasure of recording here my great indebtedness. Suggestions derived from the previous work for this Survey by Mr. G. K. Gilbert and Mr. I. C. Russell on other Pleistocene lakes also aided me much in both the field work and the study for preparing this report.

Again, when the shore-lines of Lake Agassiz had been mapped through North Dakota from Lake Traverse to the international boundary, it was found that a comprehensive monograph of this subject could not be presented while the exploration was restricted by a political limit. Hence it

was generously arranged by Director J. W. Powell, of this Survey, and Director A. R. C. Selwyn, of the Geological and Natural History Survey of Canada, that my work of mapping the Lake Agassiz shores, with determination of their heights by leveling, should be continued through the prairie region of southwestern Manitoba, which was done in the summer of 1887, the termination of my survey being near the southern end of Riding Mountain. Important observations of the part of Lake Agassiz adjoining the international boundary had been previously made by Dr. George M. Dawson; and during 1887 and subsequent years Mr. J. B. Tyrrell, of the Canadian Geological Survey, has added much to the explored extent of the shores of this glacial lake, tracing them northward along the east side of the Riding and Duck mountains, and noting them in isolated localities farther north to the Saskatchewan River. My work in Manitoba being thus supplemented, this monograph is enabled to include under its descriptions and discussion a continuous extent of nearly 700 miles of the ancient lake border.

The field work on Lake Agassiz for the United States Geological Survey occupied four summers; and during three of these, in 1885 and the two following years, I had the very satisfactory assistance of Mr. Robert H. Young as rodman. The fourth summer of exploration, in 1889, included no leveling, and was chiefly devoted to tracing the course of terminal moraines adjacent to the area of Lake Agassiz. With two summers which I had spent in exploration of this lake while engaged on the Minnesota Geological Survey, the work here reported comprises the field observations of six years.

Study, writing, and preparation of maps and illustrations for this report and three preliminary official publications relating to Lake Agassiz, which are noticed in Chapter I, have required considerably more time than was used in the collection of field notes. For so full opportunity to give to this subject long-continued investigation and to present it in this volume, my grateful thanks are due and are hereby respectfully tendered to the Director and to the Geologist in Charge of the glacial investigations of this Survey.

W. U.

ABSTRACT OF VOLUME.

CHAPTER I: INTRODUCTION.—Lake Agassiz occupied the basin of the Red River of the North and of Lake Winnipeg. Its northern barrier was the retreating ice-sheet of the Glacial period. That a great lake had existed here was recognized by Keating in 1823, and later by Owen, Palliser, Hind, Dawson, Warren, and N. H. Winchell.

It was named in 1879 to commemorate Louis Agassiz, who established the theory that the drift was due to glaciation. Its southward outlet was named the River Warren in 1883. The work here reported comprises explorations performed for the geological surveys of Minnesota, the United States, and Canada. Previous reports and papers relating to Lake Agassiz and its dependence on the waning ice-sheet are noted.

CHAPTER II: TOPOGRAPHY OF THE BASIN OF LAKE AGASSIZ.—The bed of this lake is the flat Red River Valley plain. Its channel of outlet by the River Warren is now occupied by lakes Traverse and Big Stone and the Minnesota River. The shore-lines of Lake Agassiz are commonly marked by beach ridges of gravel and sand a few feet high; less frequently by an eroded escarpment from 10 to 30 feet high. Several large deltas were formed contemporaneously with the highest shore-line. East of Lake Agassiz is a somewhat higher wooded country, on which are the Giants and Mesabi ranges and the morainic Leaf Hills. On the west are the Coteau des Prairies and the Manitoba escarpment, the latter comprising the Pembina, Riding, and Duck mountains and the Porcupine and Pasquia hills. Lake Agassiz is now represented by lakes Winnipeg, Manitoba, and Winnipegosis; while Rainy Lake, the Lake of the Woods, and Red Lake lie within its southeastern boundary. Its basin is drained by the Rainy, Winnipeg, Red, Assiniboine, and Saskatchewan rivers, and others of smaller size. For some time, also, Lake Agassiz probably received streams outflowing from glacial lakes in the basins of the Peace and Athabasca rivers. The area of Lake Agassiz was approximately 110,000 square miles, and the country tributary to it was 350,000 to 500,000 square miles. The length of the lake was nearly 700 miles; its maximum width in Manitoba was probably more than 250 miles; and its maximum depth, during its earliest and highest stage, was about 700 feet above the present level of Lake Winnipeg.

CHAPTER III: GEOLOGIC FORMATIONS UNDERLYING THE DRIFT.—The bed rocks of this lacustrine area comprise, in their order from east to west, Archean, Lower and Upper Silurian, Devonian, and Cretaceous formations. Sections of the Paleozoic rocks are known by borings for artesian wells at Humboldt, Minn., Grafton, N. Dak., and Rosenfeld and Morden, Manitoba. Cretaceous strata extend from Lake Agassiz westward across the plains to the Rocky Mountains. During the Tertiary era these strata had been greatly denuded, being generally worn down to an almost flat expanse. The vertical amount of the erosion was thousands of feet at the west and hundreds of feet at the east, as shown by mountains and hills that were spared. Later erosion, during an epeirogenic uplift closing the Tertiary and beginning the Quaternary era, removed the eastern part of the Cretaceous beds, and thus formed the broad trough of the Red River Valley and of the Manitoba lake region, which was the basin of Lake Agassiz.

CHAPTER IV: THE GLACIAL PERIOD AND ITS DRIFT DEPOSITS.—The continental ice-sheet attained an area of about 4,000,000 square miles, and had a maximum thickness, in its central portion, of probably 1 to 2 miles. It extended from the Atlantic to the Pacific and from the northern United States to the Arctic Sea, probably enveloping the Rocky Mountains in the region of the Peace River and northward. The closing stage of this glaciation was the time of existence of Lake Agassiz. On the greater part of the lacustrine area the drift is from 100 to 300 feet thick, consisting chiefly of till or bowlder-clay. A series of twelve terminal moraines is found in proceeding from south to north and northeast in Minnesota and North Dakota. The last six of these, named the Dovre, Fergus Falls, Leaf Hills, Itasca, Mesabi, and Vermilion moraines, were contemporaneous with Lake Agassiz, besides probably others to be traced farther north. Birds Hill, near Winnipeg, a remarkable esker, indicates that much drift was contained in the lower part of the ice-sheet. The deltas of Lake Agassiz were formed chiefly of modified drift, brought by streams from the receding ice. Very little transportation of bowlders and other drift was effected by icebergs or floes on this lake.

CHAPTER V: HISTORY OF LAKE AGASSIZ.—The records of glacial lakes are their outlets across present lines of watershed; eroded cliffs, beach ridges, and deltas at the levels of the former outlets; and lacustrine sediments in the basin inclosed by the old shores. Lake Agassiz grew from south to north as fast as the ice-sheet receded, forming its series of moraines. The outlet by the River Warren was eroded to a depth of about 90 feet. Afterwards lower outlets were opened toward the northeast. Probably the early northeastward outflow passed along the ice border and through the upper Laurentian lakes to the Mississippi, then to the Hudson River, and later to the much enlarged Gulf of St. Lawrence. Finally the outflow was tributary to Hudson Bay when the ice had melted so far as to admit the sea to that basin. With the uncovering of the course of the Nelson River, Lake Agassiz ceased to be held by the ice barrier, and became Lake Winnipeg. Epeirogenic uplifting of the area of Lake Agassiz, increasing in vertical extent from south to north, gave to its beaches a northward ascent, and caused the several shores of its southern part to become double or multiple as they are traced northward. The molluscan fauna of Lake Agassiz, so far as it has been discovered, consists of five fresh-water species. The amount of the shore erosion of Lake Agassiz and the volume of its beaches, compared with the postglacial erosion and beach deposits of the present Great Lakes, have a ratio approximately as one to ten. The duration of postglacial time is believed to have been from seven to ten thousand years; of Lake Agassiz, probably not more than one thousand years.

CHAPTER VI: BEACHES AND DELTAS OF THE HERMAN STAGES.—These shore deposits are described in detail. The earliest and highest beach, named from Herman, Minn., has been mapped, with determination of its height by leveling, through an extent of about 175 miles in Minnesota, from Lake Traverse east to Herman, and thence north to Maple Lake. In 140 miles, from south to north, this shore-line ascends from 1,050 feet to 1,170 feet, approximately, above the sea. Near Maple Lake four lower beaches, successively about 8, 15, 30, and 45 feet below the highest, were also formed during the time of accumulation of the single Herman beach at the south; and on the west side of the lake in Manitoba the Herman series of beaches is increased to seven. In North Dakota the uppermost Herman shore has a northward ascent of about 180 feet in the distance of 224 miles from Lake Traverse to the international boundary, where its height is 1,230 feet above the sea. At the latitude of Gladstone, in Manitoba, 84 miles farther north, the altitude of 1,315 feet is attained by the second of the Herman shores, which is the highest one extending so far. Six noteworthy deltas were brought into Lake Agassiz, contemporaneously with the formation of the Herman beaches, by streams which were exceptionally supplied with much modified drift by the melting ice-sheet. These are the Buffalo River and Sand Hill River deltas in

Minnesota, the Sheyenne, Elk Valley, and Pembina deltas in North Dakota, and the very large delta of the Assiniboine in Manitoba.

CHAPTER VII: LOWER BEACHES WITH SOUTHWARD OUTFLOW.—Below the Herman shore the southern part of Lake Agassiz has four shore-lines, which receive names from Norcross, Tintah, Campbell, and McCauleyville, in Minnesota. Portions of these shores have been traced with leveling and are here described. In the northern part of the area of my exploration the Norcross and Tintah beaches are double, and the Campbell and McCauleyville beaches are each represented by three. With the seven Herman shores recorded in Manitoba, Lake Agassiz had thus at the north seventeen stages marked by successive beaches during its time of southward discharge by the River Warren. The upper Norcross shore rises from about 1,030 feet above the sea at Lake Traverse to 1,215 feet on the latitude of Gladstone. In the same distance the upper Tintah shore rises from 1,015 to 1,150 feet; the upper Campbell shore, from 990 to 1,080 feet; and the upper and lower McCauleyville shores, respectively, from 970 to 1,035 feet, and from 960 to 1,012 feet, approximately, above the present sea-level.

CHAPTER VIII: BEACHES FORMED WHEN LAKE AGASSIZ OUTFLOWED NORTHEASTWARD.—Fourteen stages of Lake Agassiz are shown by beaches that were formed after the lake had fallen below its southern outlet. These comprise, in descending order, three successive Blanchard beaches, passing near Blanchard, N. Dak.; the Hillsboro beach, and two Emerado and two Ojata beaches, named likewise from towns in North Dakota; and the Gladstone, Burnside, Ossowa, Stonewall, and Niverville beaches, the last being double northward, named from places in Manitoba. These shore-lines are as definitely marked by beach ridges, and occasionally by low eroded escarpments, as the series belonging to the time of the River Warren. Their northward ascent is gradually diminished, until in the latest-formed Niverville beach it is only about 20 feet in the distance of more than 200 miles from near Winnipeg and the southern part of Lake Winnipeg northward to the mouth of the Saskatchewan.

CHAPTER IX: CHANGES IN THE LEVELS OF THE BEACHES.—The rate of northward ascent of the originally level highest beach, within the area of my leveling, varies from about 6 inches per mile near its southern end to about 1 foot per mile along the greater part of its extent to southern Manitoba. On the east side of the Red River Valley the old shores are higher than on its west side, the rate of ascent from west to east being about half as much as from south to north. The direction of maximum ascent of the planes of the former lake levels is therefore toward the north-northeast. Farther north several beaches of the series mapped by Tyrrell along the bases of the Riding and Duck mountains have a northward rise of 2 to 3 feet per mile. These changes of level were in progress and were nearly completed during the existence of Lake Agassiz, as is shown by the gradual diminution in the northward ascent of the successive lower beaches, until the latest and lowest differs only very slightly from perfect horizontality. Gravitation of Lake Agassiz toward the ice-sheet accounts for a small part of the present inclination of the beaches. Changes in the temperature of the earth's crust due to the Glacial period and its termination produced a still smaller effect, but this tended to give the opposite slope, or a descent toward the north. Upward epeirogenic movements, resulting from the unburdening of the land by the departure of the ice-sheet, were the chief element in the causes of the differential changes in the height of this basin. Flow of the plastic inner part of the earth's mass, restoring isostasy, uplifted first the southern half of the area of Lake Agassiz, from Lake Traverse to Gladstone; next it raised the northern half of the lake area, while the region at the south was almost at rest; and finally, during the Recent epoch, after the whole basin of Lake Agassiz was passed by this wave-like permanent uplift, it has been elevating the basin of Hudson Bay, where the movement still continues. Pleistocene oscillations of the land in many other parts

of the world have been independent of glaciation, or these have been combined with movements due to the accumulation of ice-sheets and to their removal; but the uplifting of the basins of Lake Agassiz and Hudson Bay is apparently attributable wholly to the departure of the ice-sheet.

CHAPTER X: ARTESIAN AND COMMON WELLS OF THE RED RIVER VALLEY.—Hundreds of artesian wells, from 40 to 300 feet deep, have been obtained in the drift formations of the Red River Valley plain, the axial lowest part of the Lake Agassiz basin. South of Crookston and Blanchard they yield fresh water; but northward, to the border of Manitoba, their water is usually saline and alkaline. The fresh water is derived from rainfall on the higher land adjoining this valley. The saline matter is brought mostly by water flowing through the Dakota sandstone and issuing into the drift of the Red River Valley upon tracts where this sandstone is the next underlying formation. The saline and alkaline wells in the drift of this district are thus supplied, like the deeper artesian wells penetrating the Cretaceous strata at Devils Lake and in the James River Valley, from rainfall on the flanks of the Black Hills and Rocky Mountains. Analyses and experience show that the saline and alkaline water is not suitable for use in irrigation. Sections of many artesian and common wells on the area of Lake Agassiz are reported, with notes of the characters of their water supply.

CHAPTER XI: AGRICULTURAL AND MATERIAL RESOURCES OF THE AREA OF LAKE AGASSIZ.—The fertility of the soil and the climatic conditions of the prairie portion of this area make agriculture its leading industry and source of wealth. Previous to its occupation by the present farming population the rich pasturage and countless herds of buffaloes betokened the value of the land for the cultivation of grain and for stock-raising. The annual wheat product of the six counties in Minnesota and six in North Dakota lying mainly within the Red River Valley is about 46,000,000 bushels, or on an average 285 bushels for each of the 161,049 people enumerated by the census of 1890 in these counties. Other crops which receive considerable attention are oats, barley, hay, potatoes, and flax. The tendency is toward diversified farming, with stock-raising and dairying. Magnesian limestones, which outcrop near Winnipeg, are used for building and the manufacture of lime. Clay of the best quality for brickmaking is found along all the Red River Valley, and this business is carried on in many places. The brines and natural gas occasionally supplied by wells, and the lignite occurring in very thin layers in Cretaceous formations of this region, and thence sparsely distributed in fragments through the drift, are not of economic importance. Many streams within the area of Lake Agassiz, especially in the northeastern wooded country, have valuable water powers, which are beginning to be utilized for mills and manufactures.