PROBLEMS IN LATE PLEISTOCENE

AND

RECENT HISTORY OF THE DEVILS LAKE REGION

NORTH DAKOTA

by

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A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

at the

UNIVERSITY OF WISCONSIN

1955

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PREFACE AND ACKNOWLEDGEMENTS

The following study is based on data collected by the writer, his colleagues, and assistants in the course of a ground-water and geologic investigation of the counties in the Devils Lake region, North Dakota for the Ground Water Branch, Water Resources Division, of the United States Geological Survey. The investigation covered parts of Benson, Eddy, Nelson and Ramsey Counties (see fig. 5).

For this investigation the writer mapped geologically two 15-minute quadrangles in detail (Grahams Island and Devils Lake quadrangles), two other 15-minute quadrangles and a 7 1/2-minute quadrangle in reconnaisance fashion (Hamar, Pekin and Crary quadrangles, respectively) and a contiguous area to the north covering about 100 square miles in a manner sufficient to delineate the end moraines (Maza-Churchs Ferry-Webster area). A portion of an area previously mapped by the writer and newly revised by him was also included in this study (Minnewaukan area). Two other 15-minute quadrangles (Tokio and Oberon quadrangles) and a portion of a third (Flora quadrangle), all previously mapped by the North Dakota Geological Survey, were revised by the writer on the basis of additional field work, air photointerpretation, and an examination of new detailed topographic maps. Of the 1400 square miles in the map area, about 950 square miles were mapped by the writer.

Work on the project, other than geologic mapping, included the drilling of over 150 test holes, collection of detailed well data for most of the area, collection of water samples for chemical analysis, and aquifer-performance tests.

Field work for the entire project took up all or part of every field season from 1948 through 1953.

The work was done under the general supervision of A.N. Sayre, chief, Ground Water Branch, Water Resources Division of the U.S. Geological Survey. The study was started under the supervision of P.E. Dennis, former district geologist, and concluded under the supervision of P.D. Akin, district engineer, who succeeded Mr. Dennis.

The writer's immediate colleagues, including the supervisors, in the Geological Survey office in Grand Forks, North Dakota either participated in the project or otherwise materially aided in the work. P.C. Benedict of the Quality of Water Branch in Lincoln, Nebraska supplied the writer with the manuscript and several illustrations from a Water Supply paper on the chemical quality of water from the Devils Lake region, by H.A. Swenson and B.R. Colby. H.M. Erskine of the Surface Water Branch in Bismarck, North Dakota gave the writer information on early lake levels of Devils Lake. Daniel Kennedy of the Topographic Division, Rolla, Missouri sent field sheets and advance copies of new topographic maps for the Devils Lake region. Reta Linebaugh of the Geologic Division and W.J. Drescher of the Ground Water Branch extended various courtesies to the writer during the preparation of the manuscript at the University of Wisconsin in Madison, Wisconsin.

On several field trips in western North Dakota, eastern Montana, South Dakota and southern Manitoba the writer benefited from discussions and later correspondence with many geologists. Among these are R.B. Colton, D.R. Crandell, R.W. Lemke and H.E. Simpson, Jr. of the Geologic Division of the U.S. Geological Survey and F.S. Jenson, formerly of the Geological Survey, and J.A. Elson of the Geological Survey of Canada.

Several members of the North Dakota Geological Survey and the Geology Department of the University of North Dakota, particularly Professor G.L. Bell made valuable suggestions to the writer both in the field and in the office.

Professors D.B. Lawrence and L.D. Potter of the University of Minnesota and North Dakota Agricultural College, respectively supplied the writer with information, bibliographic data and advice concerning the burr oak and botanical matters in general.

G.F. Will of Bismarck, North Dakota made available to the writer a photostat of a cross-section of a tree stump found near Stump Lake.

Professors F.T. Thwaites and Sheldon Judson of the Geology Department of the University of Wisconsin gave advice and encouragement in the course of preparation of the manuscript, and read and criticized it.

M. Della Torre and Norman Ward of Madison, Wisconsin also aided the writer by lettering several of the illustrations. Judith Aronow typed the lettering on many of the illustrations, as well as most of the text.

The writer gratefully acknowledges the aid received from these people, and from numerous others not mentioned. Responsibility for any of the opinions or the way in which they are expressed rests with the writer.

The three parts that make up this study have been written to stand more or less independently. The first part, the introduction provides a background of the regional hydrology and geology as well as an advance summary of the following parts. The second part is essentially a history of Devils Lake and Stump Lake, North Dakota, during late

Pleistocene time based upon the history of the major spillways of the region. In thus doing, the chapter covers many of the major glacial problems of the region. The third part is concerned with the evidence for the postglacial-prehistoric history of Devils Lake and Stump Lake and also contains a summary of the very recent events in the history of the lakes.

PART ONE—INTRODUCTION

Location, General Features, and Drainage System of the Devils Lake Region

The Devils Lake map area covers about 1400 square miles and includes what is locally referred to as the Devils Lake region. It lies in that part of the Central Lowland physiographic province (Fenneman, 1938, p. 559-588) that has been called the Drift Prairie by Simpson (1929, p. 7-10). The physiographic divisions of North Dakota and the location of the map area are shown on figure 1.

The age of the glacial drift in this region has generally been assumed to be Mankato or at least late Wisconsin in age. No positive correlations with the type area of the Mankato drift have been made.

All the bedrock underlying the glacial drift is believed to be Pierre shale of Cretaceous age (see Simpson, 1929, p. 38).

Devils Lake, from which the region gets its name, and Stump Lake form a southeast-east striking complex of lakes about 45 miles long. The Sheyenne River in the southern part of the region, parallels the main trend of the lakes. The river is at the present time flowing in a trench over half a mile wide and with a maximum depth of 75 feet. The lakes and the river are separated by a group of moraines, the principal one of which is the North Viking moraine (see fig. 6). Between the river and the moraines are a series of outwash and ground moraine plains. Several spillways, heading into ice-contact deposits in the moraine, or cutting through the moraine completely, traverse the outwash and ground moraine plains and trend toward the trench of the Sheyenne River.

North of the lakes is another group of moraines of which the Sweetwater moraine is most prominent. South of these moraines and north of the Lakes are ground moraine plains whose relief is enhanced by low morainal ridges, eskers, and kames. The morainal ridges generally strike northwest. The eskers in general strike northwest or north, i.e. transverse to the morainal ridges.

In the extreme northern part of the region is another, smaller, complex of lakes whose general strike parallels that of Devils Lake. The largest and most permanent of these lakes is Sweetwater Lake, the easternmost one.

All of the main features of the region give it a northwest-west--southeast-east "grain". This "grain" seems to be largely controlled by the configuration of the Pierre shale bedrock. The depression occupied by the Devils Lake-Stump Lake complex is probably the surface representation of the course of a stream, with numerous tributaries, cut into the bedrock or an earlier drift. Detailed drilling of the drift has indicated that the underlying bedrock topography is a "butte" type similar to that which has been developed in the parts of western North Dakota that were unglaciated or covered by older drift(s).

The Devils Lake map area lies within the Devils Lake interior drainage basin. This basin covers about 3,940 square miles (U.S. Geological Survey, 1953, p. 51), and is located between the drainage basin of the Red River of the North on the north, east and south, and the Souris River basin on the west (see fig. 2). The basin is conventionally considered a sub-division of the Red River of the North basin. Not all the area included in the Devils Lake basin drains into Devils Lake. Part of the basin is occupied by undrained depressions of various sizes which receive very local drainage. The number of square miles of area that can potentially supply runoff to Devils Lake and Stump Lake through integrated drainage is not known but the writer estimates that perhaps less than 3,100 square miles of area supplies runoff to the lakes.

At the present time Devils Lake and Stump Lake are not connected. Prehistorically they were once connected by means of a narrow channel known as the Jerusalem outlet. When the lake levels were high enough, water, discharged from Devils Lake into Stump Lake flowed into the Sheyenne River (which drains into the Red River) by the now unused Big Stony spillway (see figs. 3 and 6). Thus at one time the Devils Lake interior drainage basin was actually part of the Red River of the North drainage basin.

When lakes were high enough for water to be discharged into the Sheyenne River, the lakes occupied a high strandline whose elevation is about 1453 feet above sea level. Below this strandline are a number of others, prehistoric and recent. The "conventional" outlines of Devils Lake and Stump Lake shown on most maps is that of the years of the first land surveys of the region, 1881 to 1883. Devils Lake at that time had a surface elevation of about 1435 feet above sea level, and Stump Lake about 1423 feet above sea level (see fig. 3). Since that time the lakes, with minor resurgences, have been drying up. This lowering of lake level has caused the separation or disappearance of the various bays that made up the lakes.

The principal drainage into Devils Lake, and prehistorically into Stump Lake, is by way of Mauvais Coulee. This intermittant stream starts near the Canadian border and empties into Lac aux Mortes, one of the lakes of the smaller complex of lakes in the northern part of the region. This lake also receives drainage from Sweetwater Lake and Twin Lakes to the east. The Coulee, from a geographical point of view, discharges from Lac aux Mortes into Lake Irvine. It emerges from the south end of Lake Irvine, the westernmost lake of the smaller complex, and flows into

Devils Lake. Drainage is also received by Mauvais Coulee, by way of Little Coulee, from a group of lakes to the northwest which include Ibsen Lake and Silver Lake (see fig. 3).

Some surface runoff enters Devils Lake through integrated drainage at the western edge of West Bay. Stump Lake also receives a minor amount of run-off from contiguous areas.

Since the drying up of the lakes and the subsequent separation into more or less unconnected basins, parts of Devils Lake may no longer drain one into the other. Drainage will not enter Devils Lake or flow from one part of Devils Lake to another before the individual basins of the northern complex of lakes or the segmented basins of Devils Lake have been filled to their spillway elevations. This complex relationship has led to a lack of clear correlations among rainfall, runoff and lake level.

A Note on Topographic Maps of the Devils Lake Region

Two sets of maps are available for most of the Devils Lake region, a 15-minute series and a 7 1/2-minute series. The 15-minute series is on a scale of 1:62,500 and has a 20-foot contour interval; the maps in the 7 1/2-minute series are on a scale of 1:24,000 and have contour intervals of either 5 or 10 feet. The 15-minute series was prepared around 1927-1928 and the 7 1/2-minute series, 1948-1951. Because of a similarity of names between the new and old maps, the writer has noted in almost all places in the text where a given quadrangle is mentioned either the contour interval or the number of minutes covered. Figure 4 shows the relation between the new and old maps.

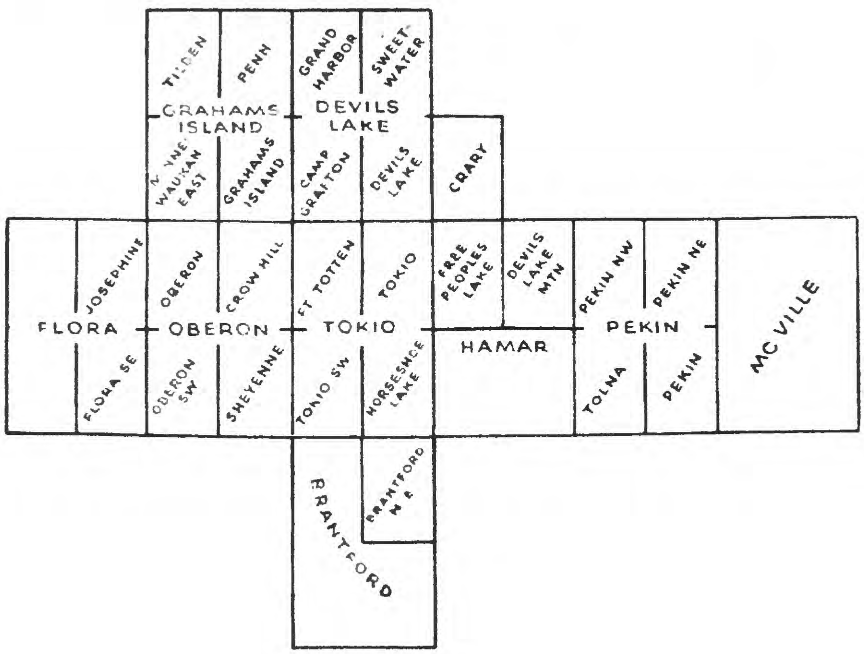


Figure 4.-- 7 1/2 and 15-minute quadrangles in the Devils Lake region to which reference is made.

Principal Previous Geologic Work in the Devils Lake Region

The first worker in the Devils Lake region was Warren Upham whose results were reported in his classic work on glacial Lake Agassiz (1896). He prepared a fairly detailed map of the end moraines on a scale of six miles to the inch (Plate XVIII). Descriptions of the moraines are scattered through chapter four of his work (p. 146, 156-158, 162, 169-171, and 175-176). Upham also studied and leveled some strandlines, spillways of the lakes and water levels (p. 170, 595-598). He also conjectured as to the age of the strandlines and spillways.

E.J. Babcock's report (1902) on the water resources of the Devils Lake region contains very little that is new concerning the geology or the lakes of the region. Most interesting, however, were some observations on the possibility of a former large lake around the chain of lakes north of Devils Lake.

H.E. Simpson (1912) prepared a long report on "The physiography of the Devils-Stump Lake region, North Dakota." This report contains no geologic map; the text supplies information on several spillways from the lakes to the Sheyenne River, and strandline elevations based on instrumental leveling. He also expanded on Upham's ideas concerning the relation of certain spillways to certain strandlines. The report contains Simpson's early views on the cause of the recent desiccation of the lakes as well as numerous items of historical interest and many photographs of the lakes before the desiccation became marked. Simpson's general work on the geology of North Dakota (1929) contains descriptive material on the geology of the region, well and ground water data, and his later views on the cause of the desiccation of the lakes (p. 71-76, 189-196).

The North Dakota Geological Survey has recently published reports and geologic maps of three 15-minute quadrangles in the Devils Lake region: Branch (1947) on the Flora quadrangle, Tetrick (1949) on the Oberon quadrangle, and Easker (1949) on the Tokio quadrangle (see fig. 5). Maps accompanying these reports are on a 1:62,500 scale and were used in the preparation of figure 8 of this report. Specific data and opinions of these workers will be considered in detail later in this study.

Suzanne L. Jones of the U.S. Geological Survey prepared a manuscript map in 1950 of an area centering around the city of Lakota in Nelson County (see fig. 5), a portion of which overlapped the northeastern part of the Pekin 15-minute quadrangle. The map shows the location of ice-tact deposits, 1/ morainal ridges, and spillways; it was used by the writer in the field while mapping the Pekin quadrangle and in the compilation of figure 8.

1/ This is used as a shortened form of the term "deposits of ice-contact stratified drift."

Aronow and others (1953) describe the lacustrine and drift features of an area which includes most of West Bay of Devils Lake, and contiguous drift areas to the south and west (see fig. 5). The report contains considerable subsurface data on West Bay as well as results of leveling of strandlines around West Bay.

Swenson and Colby (in preparation) cover the results of a study of the chemical quality of surface water by the U.S. Geological Survey in the Devils Lake region. Their report also contains an excellent summary of the hydrography of the Devils Lake region as well as an analysis of the available hydrologic data relative to the recent desiccation of the lakes. References to previous quality-of-water studies of the lakes, which have not been mentioned here, are also given.

Two other recent studies in areas contiguous to the Devils Lake region may be mentioned although they do not fall within the map area (see fig. 5). The first, by Aronow and others (1954-in press) covers an area around the city of Michigan in Nelson County. This reports on a ground water investigation and contains an inch-to-the-mile reconnaisance map of the glacial geology and includes much subsurface data on the drift, and bedrock topography. The second, by G.L. Bell of the North Dakota Geological Survey, is a detailed manuscript map on a 1:62,500 scale of the McVille 15-minute quadrangle.

Brief Resume of the Glacial History and Main Features of the Devils Lake Region

The purpose of this resume is to touch upon the major events in the glacial history of the region, and, in doing so, to mention the outstanding and prominent features of the region and the problems connected with them. In the course of the discussion reference will be made to figure 6, which shows the moraines, outwash deposits and spillways in somewhat diagrammatic form. This map also gives the names of many of the major features described. The major stands of the ice in the region are roughly indicated on figure 7. Details of the glacial geology may be found on the detailed 1: 62,500-map of the region, figure 8.

Upham (1896) assigned names to the end moraines in the Devils Lake region, and elsewhere in North Dakota, based on their presumed correlation with moraines in Minnesota. However, because (a) their status as interstate correlatives, in some places, has been revised (cf. Leverett, 1932, p. 67-68) and (b) Upham's morainal boundaries have been drastically changed in some places, new names have been given to the moraines. The sources of these new names is given in the discussion to follow.

No evidence for multiple glaciation has been found in the Devils Lake region. The drift immediately underlying the surface has been comparatively unleached and unweathered and hence is thought to be late Wisconsin in age. The glacier which deposited this surface drift mantle had previously advanced over the region in a more or less southerly direction. The major glacial features of the region are undoubtedly almost all the result of an essentially retreatal movement of the ice.

1. The first major stand of the ice in its retreat northward through the Devils Lake region is indicated by the Hillsdale moraine, named by

the writer after Hillsdale Township, and by a number of east-west trending patches of end moraine and ground moraine, now surrounded by the Heimdal outwash. Some of these patches contain east-west trending morainal ridges, clearly showing ice advance from the north. The "drumlinized" part of the Heimdal moraine (cf. below) south of the Sheyenne River may represent an over-ridden part of Hillsdale moraine. The discontinuous character of the elements marking this halt suggests very strongly that it was a definite halt rather than a readvance of the ice as most of the other moraines in the region seem to indicate (cf. Thwaites, 1946, p. 41).

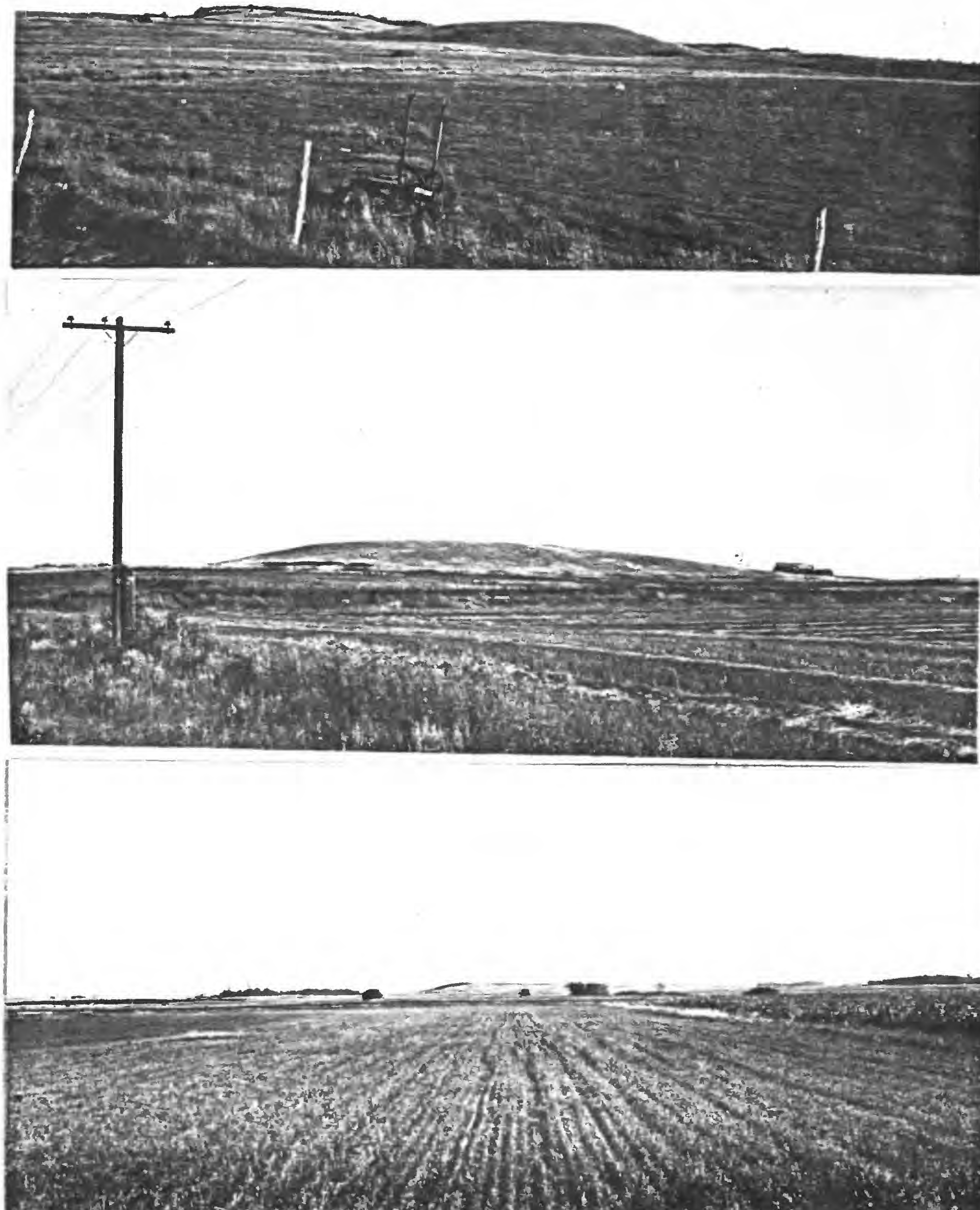
2. The Heimdal moraine was named by Branch (1947, p. 6). It was the site of the second major stand of the ice in the map area.

The moraine apparently owes its bell-shaped ground plan to the presence of a number of bedrock "highs", the most prominent of which underlies Sullys Hill at the "apex" of the moraine 2/ (see fig. 8). The

2/ Pierre shale bedrock is exposed in several places along the southern shore of Main Bay of Devils Lake in cuts on the south side of State Highway 57 (see fig. 8). Another "high" was found by test drilling in the re-entrant of the Warwick outwash between the Heimdal and North Viking moraines.

Tokio and Heimdal outwash deposits were probably continuous and drained southward into the glacial James River. Later, upon the opening of a lower outlet for drainage, probably when the ice left the site of the eastern flank of the moraine, the Tokio outwash drained to the east through the site of the Sheyenne trench.

Two interesting features of this moraine are (a) the drumlins and drumlinized drift of the eastern flank (see fig. 8 and pl. 1), (b) the numerous morainal ridges of the western flank south of the Sheyenne



A

B

C

Plate 1.—Drumlins and drumlinized end moraine. Steep sides of hills face northeast, direction from which ice advanced. A. Drumlin seen from north in SW 1/4 sec. 13, T. 151 N., R. 64 W. B. Drumlinized end moraine hill surrounded by Warwick outwash, in NW 1/4 sec. 18, T. 151 N., R. 63 W. Hill strikes northwest, view parallel to long axis of hill. C. Drumlinized end moraine hill surrounded by Warwick outwash, in S 1/2 sec. 32, T. 151 N., R. 63 W. Seen from north.

River.

(a) The strike of drumlins and drumlinized drift is roughly perpendicular to the general strike of the eastern flank of the moraine. In many places they form isolated hills, surrounded by the Warwick outwash. Test drilling and exposures of bedrock (see fig. 8) in this area show that they have been localized by bedrock "highs" in at least some places.

(b) The morainal ridges of the western flank show an interesting lobate pattern of very small radius 3/ as well as the variety of movements of the ice during the deposition of the moraine.

3/ The curious arcuate pattern of the moraine between the Tokio outwash and the Sheyenne trench was probably made by a lobe of similar dimensions.

3. The ice halted for the third time and readvanced at the site of the North Viking moraine named by Branch (1947, p. 6). This moraine is the most complex in topography (see pl. 2) and areal pattern in the whole region. 4/ Part of this complexity results from the influence of the

4/ Upham (1896, p. 146, 156-157, 162, 169-170) early recognized the complex character of this morainal tract. Five of the twelve moraines which he and others mapped through South Dakota, North Dakota and Minnesota merge, at least in part, in this morainal tract.

underlying bedrock on many parts of the moraine. Among the most spectacular examples of this is merging of this moraine with the "apex" of the Heimdal moraine (cf. Tetrick, 1949, p. 18-19). The bedrock core of Sully's Hill apparently acted as a kind of bastion around which the ice moved during the deposition of the Heimdal moraine. Later, during the deposition of the North Viking moraine, it continued to function as an impediment to ice advance. Other examples are the two large, northeast-striking, butte-like drift-covered hills between East Devils Lake and

Plate 2.—Highest part of the North Viking moraine located along the southern shore of Main Bay of Devils Lake. Seen from the northwest. Sullys Hill is on the left. The cleft just to the right of the bare stretch extending to the top of Sullys Hill is a re-entrant of the high 1453-foot strandline. The body of water in the foreground lies in a similar re-entrant. These re-entrants are more or less collinear with Seven Mile Coulee, a large south-striking spillway in the Tokio outwash. The general form and location of the hills and re-entrants is believed to be determined by "highs" in the Pierre shale bedrock.

West Bay of Stump Lake, Devils Lake Mountain and Blue Mountain (see fig. 8 and pls. 3 and 4). Bedrock control of Devils Lake Mountain has been definitely established by test drilling. The Devils Heart, a large conical hill about 100 feet high, in the moraine east of the northern part of the Tokio outwash (see fig. 8 and pl. 5) is thought by Easker (1949, p. 25-26) to be made up of till and likewise to be related to a bedrock "high". 5/

5/ Upham (1896, p. 157) describes this hill as the "largest and most remarkable kame that has come under my observation..." Clearly, this argument over fact will not be settled until some subsurface data becomes available.

South of most of the re-entrants of the high 1453-foot strandline into the moraine are through channels, kettle chains or ice-contact deposits. All of these lead into, or are collinear with, spillways cutting through the Oberon, Tokio, Warwick (see pl. 6) and Pekin outwash deposits, respectively, south of the moraine. The very striking alignment of these elements is likewise thought to be the result of bedrock control of drift deposition.

Northeast of Crow Hill, in that part of the moraine south of West Bay of Devils Lake (see fig. 8) is an imposing group of eskers. This group of northeast-striking anastomosing ridges which in places have over 90 feet of relief show in many places steep-sided ice contact faces. According to Tetrick (1949, p. 14): "Some of the ridges appear to consist entirely of till, whereas the other consist entirely of vaguely stratified material..." 6/

6/ Tetrick (1949, p. 13-15) has a discussion of the origin of these eskers to which the writer appends the suggestion that they may have been formed when the ice front stood at the location of the Heimdal moraine. Later, the eskers may have been overriden and partly buried in till during

Plate 3.—Devils Lake Mountain seen from the north. This high place in the North Viking moraine, just east of East Devils Lake, has been demonstrated by drilling to be underlain by bedrock at a shallow depth.

Plate 4.--Blue Mountain seen from the southeast. This rugged part of the North Viking moraine is located just west of West Bay of Stump Lake. It probably owes much of its relief to a bedrock "high." The 1453-foot strandline lies at the base of the rise (an esker) from which the picture was taken, continues to the left (west) and circles back and re-crosses the road at the break in slope at the upper right (east).

Plate 5.--The Devils Heart seen from the south. This prominent hill in the North Viking moraine is either a kame or a rock-cored hill covered with drift. It is located in the NW 1/4 sec. 4, T. 153 N., R. 64 W. This hill can be seen from a distance of over ten miles from U.S. Highway 2 east of the City of Devils Lake.

Plate 6.—The Warwick outwash seen from the northwest at the foot of the North Viking moraine in the NW 1/4 sec. 18, T. 151 N., R. 62 W. The crop is flax.

the deposition of the North Viking moraine. This would explain the rather anomalous orientation of the eskers in relation to the main axis of the North Viking moraine.

Also noteworthy is the somewhat discontinuous character of the morainic topography: the isolated morainic mass with the lobate pattern of morainal ridges at the extreme east end of the moraine and the patches of ground moraine within the moraine west of East Devils Lake.

4. The retreat of the ice northeastward from the North Viking moraine was slow and oscillatory with no important readvance until the ice was well north of Devils Lake and Stump Lake. This mode of retreat is well shown by the numerous northwest-striking morainal ridges in northern and western part of the North Viking moraine, as well as in the ground moraine north of it and by the patchy end moraine areas south of the Sweetwater moraine (see figs. 6 and 8). Two halts, but not readvances of the ice are shown (stands IVa and IVb) on figure 7 as indicated by rough alignments of end moraine patches. 7/ These patches are too scattered and lacking in clear alignment to be named as a definite moraine.

7/ These two "stands" do not conform to the actual direction of ice retreat as shown by the morainal ridges; they are approximately correct considering the scale of the map. Also see Aronow and others (1953, p. 33-34 and fig. 6) for details of morainic patch at west end of stand IVa.

The most significant features produced during this retreat are (a) the lobate pattern of the morainal ridges bounded by north-striking arms of Devils Lake (b) the trend of the eskers and other ice contact deposits crossing perpendicular to general strike of the morainal ridges and (c) large masses of ice-contact lacustrine deposits in the vicinity of West Bay, Devils Lake.

(a) Good examples of this lobate pattern can be seen in figure 8 west of Sixmile Bay of Devils Lake, between Creel Bay and Sixmile Bay, and north of East Devils Lake. Apparently these arms of Devils Lake functioned drainageways in the re-entrant angles between the lobes. 8/

8/ The analogy to the Kettle Moraine of Wisconsin is not perfect (see Thwaites, 1946, p. 42). In the origin of the Kettle moraine, the persistant re-entrant angle between the lobes led to the deposition of a nearly continuous train of ice-contact deposits. Only the interlobate re-entrant north of East Devils Lake shows any large deposits. Of course, some deposits in the other re-entrant angles may have been flushed out during the draining of the ice from the site of the Sweetwater moraine (cf. below).

(b) The eskers crossing the morainal ridges probably originated by gradual distal accretion rather than by more or less contemporaneous deposition from proximal to distal ends. Otherwise they probably would not have been preserved in these areas where ice movement was frequent.

(c) The masses of laminated ice-contact lacustrine silt and very fine sand seem to have been laid down in ponds on surface of the ice and later lowered onto the underlying drift as the ice melted forming a blanket over the surface (see pl. 7).

The close association of the morainal patches, morainal ridges and ice-contact deposits with the high 1453-foot strandline around Devils Lake (especially north of Main Bay) certainly suggests thay many of these features must have been deposited in standing water (see fig. 8). The level of the standing water must have been somewhat higher than the elevation of this strandline.

5. The Sweetwater moraine, named by the writer after Sweetwater Lake, was deposited during the last major halt and re-advance of the ice in the map area. The moraine actually seems to have been formed by the merging of the drift left by two stands of the ice (stands Va and Vb--- see fig. 7). The limits of the two stands become indistinct toward the

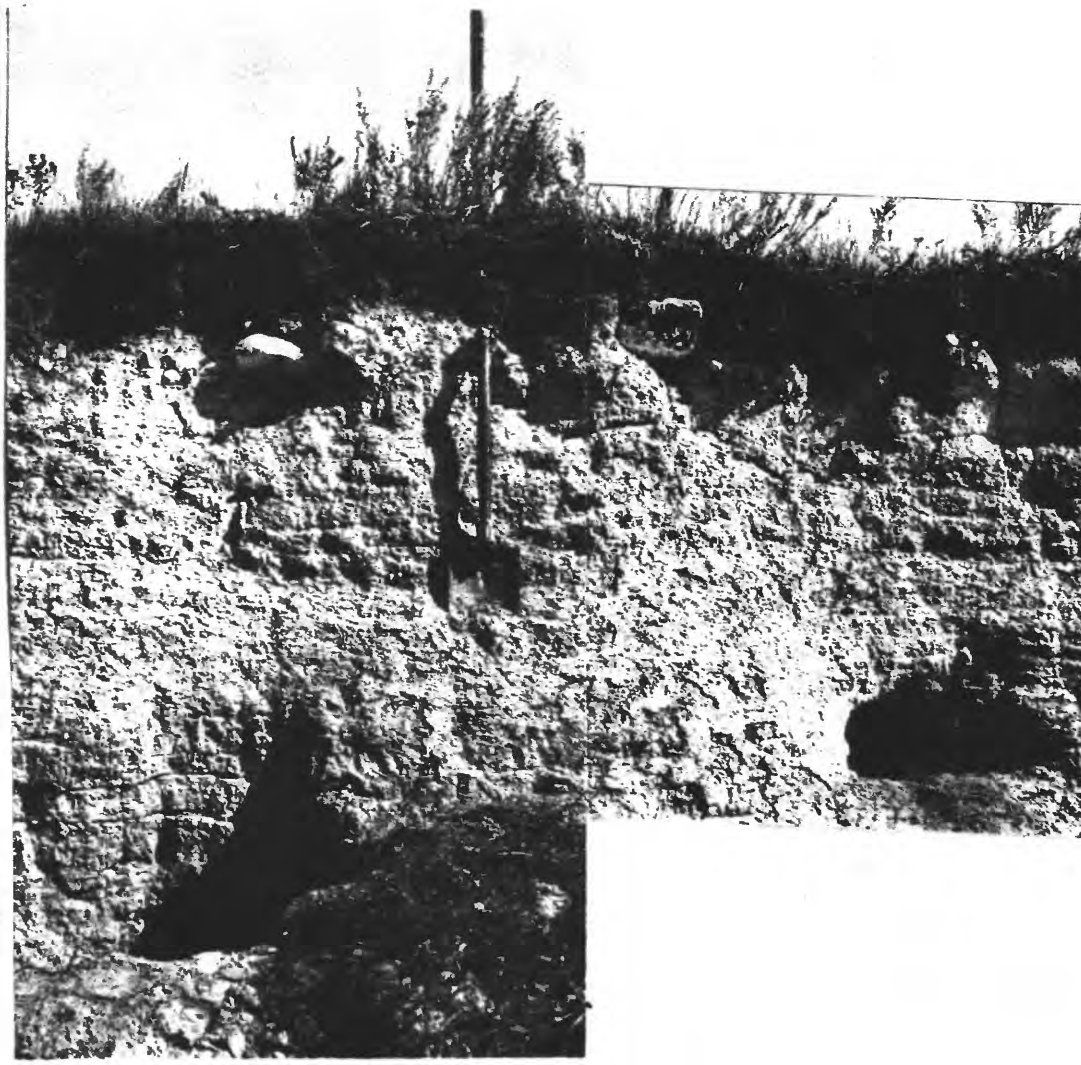


Plate 7.--Laminated ice-contact lacustrine very fine sand and silt exposed in road cut in NW 1/4 sec. 12, T. 152 N., R. 66 W. These deposits were probably laid down in small ponds on the surface of the ice and lowered down onto the underlying drift as the ice melted. The boulders at and near the surface were probably released into the pond as the surrounding ice-walls of the pond melted. These deposits cover several square miles in the vicinity of West Bay of Devils Lake. Openings at the base of the exposure are animal burrows.

southeast and there is little point in assigning separate morainal names to them.

The prominent features of this moraine, like those of the North Viking moraine, seem to have been determined by bedrock "highs". Subsurface data indicates that the three highest places in the moraine are underlain by bedrock at higher elevations than that underlying the other parts of the moraine. 9/

9/ These high places are (1) around the Devils Knuckles, (2) north-south hill in secs. 4 and 9, T. 154 N., R. 64 W., and (3) a prominent round hill at the southwest end of Dry Lake.

The northwestern parts of the moraine, the bifurcated portion around Dry Lake and Twin Lakes, do not have a great deal of absolute relief nor, in places, do they necessarily stand above the level of the associated lakes and surrounding ground moraine. This portion is actually a group of kettle-chain extensions of the higher parts of the moraine to the southeast.

The part of the moraine with best knob-and-kettle topography, located east of Dry Lake and south of Sweetwater Lake, contains many kames and short eskers. The Devils Knuckles, one of the landmarks in the region, are a group of five small kames topping one of the highest parts of the moraine (see pl. 8).

An outwash apron in front of the Sweetwater moraine is distinctly lakking; the reason for its absence is by no means clear. Meltwater was possibly disposed of through the lakes in the northwestern part of the moraine, through the long north-striking arms of Devils Lake in the other parts, and by unchanneled flow across ground moraine areas, although there is little evidence to support this last.

Plate 8.--Devils Knuckles seen from the northwest. The "knuckles" are a group of five kames located on a high part of the Sweetwater moraine, northeast of the City of Devils Lake. The uncropped kames are contrasted with the cultivated lower portions of the moraine.

Plate 9.--Seven Mile Spillway, looking north from an east-west road between secs. 2 and 11, T. 151 N., R. 65 W. The terrace-like areas on the east and west are the surfaces of the Tokio outwash, into which the Spillway is cut. The Spillway carried meltwater from ice at the site of the Heimdal and North Viking moraines.

During the deposition of the Sweetwater moraine as well as during the period that the ice retreated from the North Viking moraine, melt-water released into the lakes was passed into the glacial Sheyenne River by two spillways (Warwick and Big Stony) crossing the North Viking moraine. This water was discharged into the glacial Sheyenne River in quantities large enough to erode away parts of the Warwick and Pekin outwash deposits.

6. After the ice retreated northeastward from the region, glacial melt-water was undoubtedly in more or less continual transit through the region to the glacial Sheyenne River. Water entered Devils Lake and Stump Lake through the individual drainage nets of the lakes in the northwest part of the region, through Mauvais Coulee from the north and west, and through a system of spillways entering Stump Lake. As the volume of water diminished, only Big Stony spillway the one with lower threshold, was used. The water carried away by the Sheyenne River emptied into glacial Lake Agassiz (see Upham, 1896, p. 315-317).

7. In postglacial time only Big Stony spillway has been used to discharge water from the lakes. Water last passed through this spillway, however, in prehistoric time. The threshold of Big Stony spillway controlled the level of the highest well-defined strandline around Devils Lake and Stump Lake. This strandline has an elevation of about 1453 feet above sea level, which is considerably higher than any recorded in local historic time. This strandline was definitely last occupied in postglacial time. The evidence for this rests upon the discovery of soil zones buried in sand and gravel deposits associated with this strandline. Evidence that the lakes were, at least once at a low level prior to that of the present one is provided by tree stumps uncovered in place as the level of Stump Lake went down at the end of the last century. In very recent time water levels in both Devils Lake and Stump Lake, with minor recoveries, have

been going down. The probable reason for this decline is a slight increase in the evaporation rate coupled with the "sensitive" relation between the levels of the lakes emptying into Devils Lake and the threshold elevations of their outlet channels.

During a postglacial dry period the finer-grained material in the Warwick outwash was blown into extensive tracts of dunes which cover most of the Warwick outwash south of the Warwick spillway (see fig. 8). The forms of the dunes are poorly defined and no dominant wind direction could be determined from a study of aerial photographs. These dunes were partly reactivated during the drought of the 1930's. During the period of the writer's investigation (1948-1953) local blowouts were common, especially where grass cover was destroyed by cattle or where excessively sandy soils were cultivated.

PART TWO—GLACIAL SPILLWAYS TO SHEYENNE RIVER SOUTH OF DEVILS LAKE AND STUMP LAKE

Introduction

The southern shores of Devils Lake and Stump Lake, recent and prehistoric, are almost everywhere bounded by the eastward-striking North Viking moraine (see fig. 6). This moraine is the chief barrier between the lakes and the Sheyenne River. In at least eight places, the moraine is clearly breached, or traversed by southward-striking ice-contact deposits 1/ and kettle chains, all of which indicate glacial drainage of varying amounts into the Sheyenne River. Almost all of the spillways head toward the several bays of Devils Lake and Stump Lake which indent the northern part of the moraine. In fact, almost all of these indentations in the moraine made by the bays are marked by some form of drainageway striking south across the moraine. This repeated arrangement points to a similar origin for these features.

The modes of drainage, their efficacy and timing have interested the earlier workers in this region as well as the former writer. They form an interesting chapter in the glacial history of the region and point up some of the difficulties encountered by the writer in interpreting glacial history relative to proposed theories of ice retreat. In addition, the relation of the spillways to the end moraines, outwash deposits, and terraces along the Sheyenne River provide convenient links in summarizing the early phase of the late Pleistocene history of the region.

For the purposes of discussion all the possible drainageways, from east to west, found by earlier workers and the writer are listed as follows:

1/ This is used as a shortened form of the term "deposits of ice-contact stratified drift."

1. Long Lake spillway
2. Crow Hill spillway
3. Seven Mile spillway
4. Warwick spillway
5. Minco spillway
6. Big Stony spillway
7. Osago spillway
8. Harrisburg spillway

In addition, a ninth feature, the Jerusalem outlet formerly connecting Devils Lake and Stump Lake will also be discussed here, though, strictly speaking it is not a spillway in the same sense as the others. They are shown in diagrammatic form in figure 6, and on a larger scale on figure 8. Details of Crow Hill, Big Stony and Osago spillways are shown on figures 14, 15 and 16, respectively.

For those using Simpson's (1912) report, a few remarks on the nomenclature of the spillways are in order. Simpson, following local usage, designated some of these spillways as "coulees." Locally the term "coulee" is applied to channels, usually abandoned glacial spillways which carry water only in the spring or after a heavy rain. To avoid confusion in the literature the writer has followed Simpson's names (for Crow Hill, Seven Mile, Big Stony and Harrisburg spillways). The term "coulee" was dropped and "spillway" adopted. This done for the sake of uniformity, and because three of Simpson's "coulees" have been renamed on the new 7 1/2-minute quadrangles. Big Stony Coulee, Seven Mile Coulee and Harrisburg Coulee have been redesignated Tolna Coulee, Big Coulee and Silver Creek, respectively.

The spillways found by the writer (Warwick, Minco, and Osago spillways) were named after local townships.

Branch's name, Stony Lake spillway, (1947, p. 24) has been changed to Long Lake spillway in this study. Long Lake is a larger lake and is more centrally located in the spillway.

The term "spillway", is used by the writer to include in addition to channels in the outwash, any kettle chains and ice-contact deposits in the North Viking moraine into which these channels may head.

The portions of the spillways, including collinear ice-contact deposits and kettle chains within the North Viking moraine, are referred to as the proximal parts; the portions in the outwash south of the moraine, as the distal parts.

The spillways can be conveniently grouped on the basis of similarities of proximal parts:

Group I—No clear-cut channel for proximal part; few, if any, ice-contact deposits associated with proximal part.

Long Lake spillway

Seven Mile spillway

Minco spillway

Group II--Many prominent ice-contact deposits associated with proximal part.

Crow Hill spillway

Big Stony spillway (early phase of activity)

Osago spillway

Group III--Clear-cut channel for proximal part

Warwick spillway

Big Stony spillway (later phase of activity)

Harrisburg spillway

Previous Work

Upham (1896, p. 170, 595-598), the earliest worker in the Devils Lake region, reported on only one of the spillways, Big Stony spillway. The high strandline around the lakes was maintained, he believed, by glacial meltwater flowing out of the spillway, "but there is no proof that any time since the departure of the ice has been so humid as to raise the lake to this channel." Further, the Jerusalem outlet between Devils Lake and Stump Lake controlled the height of what the writer calls the intermediate strandline 2/ around Devils Lake: any excess water from Devils Lake flowed through the outlet into Stump Lake, thus maintaining this strandline. Reversal of flow did not take place because of the combination of high evaporation in the region and less inflow into Stump Lake.

2/ This strandline is not shown in figure 8. It is a strandline represented by cut cliffs and beaches which encircles Devils Lake at an elevation of about 1445 feet above sea level. This and the high strandline (elevation about 1453 feet above sea level) for the two most prominent prehistoric strandlines around Devils Lake.

Simpson (1912, p. 139-142) thought that at first, Seven Mile, Crow Hills, Big Stony and Harrisburg spillways carried meltwater from the ice on the site of the moraine. Later, as the ice front retreated north, the spillways drained marginal lakes formed between the moraine and the ice front to the north. As the ice front continued to retreat north the marginal lakes merged and formed two large lakes connected by the Jerusalem outlet. However, "these 'big coulees' are...considered important... not as outlets of Devils Lake, but as glacial spillways cut by the great floods of water passing from the front of the ice when it lay immediately to the south of Devils Lake." Simpson considered the high strandline to have encircled his glacial Lakes Minnewaukan (for Devils Lake) and Wamduska 3/

3/ Simpson (1912, p. 146) believed these lakes, encircled by the high 1453-foot strandline to be glacial in age. The writer (cf. below, part three) has concluded that the last occupation of this strandline was definitely in postglacial time and hence has abandoned Simpson's terms for these ancient lakes.

(for Stump Lake). Like Upham he believed the high and the intermediate strandlines around Devils Lake to have been maintained by Big Stony spillway and the Jerusalem outlet, respectively.

Branch (1947, p. 24), who mapped the Flora quadrangle in which the Long Lake spillway terminates, does not specifically state that it drained a glacial Devils Lake. He considers it one among several such spillways in the Flora quadrangle

> through which outwash material was carried after the ice had retreated a considerable distance to the north...probably flowing at a time somewhat later than that during which the main deposits in their respective terminal outwash belts were laid down.

Tetrick (1949, p. 11-15), who mapped the Oberon quadrangle, believes that the Crow Hills spillway did not carry "much, if any" water from a glacial Devils Lake because the ice-contact deposits were not eroded away and because no strandline was formed at the elevation of the threshold. The stream or streams, however, which deposited the ice-contact materials also cut the channel in the outwash forming the distal part of the spillway.

Easker (1949, p. 33) thinks that the Seven Mile spillway in the Tokio quadrangle also did not drain a glacial Devils Lake because "the lake was never high enough to cross the divide between the old spillway and the glacial lake."

Aronow and others (1953, p. 50-55) contains a detailed discussion of the origin of the Long Lake spillway.

The Sheyenne River and Associated Features

Because the activity and timing of some of the spillways is related to the glacial ancestor(s) of the Sheyenne River, it is apropos to include here some remarks about the river, its trench, and terraces.

The Sheyenne River

The Sheyenne River, within the map area, is, during most of the year, a small stream less than 200 feet wide.

Stream flow data is available from two gauging stations within the map area: one, at the city of Sheyenne, and the other, due south of the village of Warwick. The one south of the village of Warwick is the farther downstream of the two stations and will suffice to give a good idea of the size and regimen of the stream. This station was established in October 1949; published records are available through September, 1951 (U.S. Geological Survey, 1953, p. 50). The maximum recorded discharge has been 3,800 cfs, in April 1950; the maximum during 1951, in April, 1,240 cfs. Minimum recorded discharge occurred during August 1951 when the flow was about 1 cfs.

The important geologic fact about the Sheyenne River is its underfit character. Almost nowhere within the map area is it cutting laterally and widening the trench in which it flows. The only two places where it has distinctly undercut the wall of the trench are (1) in the SW 1/4 sec. 28, T. 150 N., R. 60 W. and (2) where the stream enters the map area, at the western edge. Comparisons among topographic maps made in the late 1920's, aerial photographs taken during the period from about 1941 to 1944, and new topographic maps made between 1948 and 1951 show only negligible differences in the meander patterns. An examination of the aerial photographs and the new topographic maps reveals no meander cut-offs of larger radii of curvature than the present meanders.

The surface of the alluvial fill of the trench, which can also be considered as the floodplain of the river, according to Branch (1947, p. 27-28) and Easker, (1949, p. 31-32) is underlain, in general, by gray, well-sorted, very fine sand and silt. The upper part of the fill has been considerably darkened by organic material. The stream channel itself contains, in addition to sand-sized material, gravel, cobbles and boulders. The coarser material, if it moves at all, probably does so only during the spring floods. Its origin is undoubtedly largely residual derived from glacial till and previous coarse alluvial fills.

The trench

The trench of the Sheyenne River (see fig. 9) in places, is over half a mile wide and over 75 feet deep. The part of the trench in the map area is about 61 miles long. The stream (the lowest part of the trench) enters the map area at an elevation of about 1420 feet above sea level and leaves the map area at an elevation of about 1340 feet above sea level, a drop of about 80 feet. The average gradient of the trench then is about 1.3 feet per mile. By contrast, the stream channels which is about 85 miles long within the map area, has a gradient of approximately .9 feet per mile.

The trench is cut largely in glacial till which veneers the Pierre shale bedrock. Bedrock is exposed in many places in the trench. The trench seems to follow a drift-filled "sag" or valley in the bedrock or older drift topography. The writer believes the fact that more Pierre shale is not exposed is more of a result of the efficacy of mass-wasting processes than of the thickness of the drift fill in the "sag".

Near where the trench leaves the area to the east, it becomes rather complex and anastomosing in form (see fig. 9). Here, two bedrock "buttes" seem to have been resurrected from under the drift cover. A similar "butte" bifurcates the trench at the meridian between the Tokio and Hamar 15-minute quadrangles but no bedrock is exposed.

The trench was probably excavated, at least in the gross aspects of its present form, during the release of large volumes of water from Lake Souris, a glacial lake in northwestern North Dakota (see Upham, 1896, p. 315-317). The spillway connecting this lake with the Sheyenne River found by Upham is shown in figure 1.

Since the period of major excavation of the trench, the Sheyenne River had done very little to modify it. Most modifications and changes seem to have been the result of mass-wasting processes. Slumping along the walls of the trench is common. The slumped material tends to simulate morainal topography in appearance and composition (the walls of the trench are largely till). It can be recognized by the anomalous position of such topography in the trench.4/

4/ Cf. maps and photographs of landslide topography along the Missouri River near Pierre, South Dakota in Crandell (1952, p. 548-568; especially p. 557 and 559).

The terraces

The terraces along the Sheyenne River are shown areally in figure 9 and in profile in figure 10. Figure 9 also shows some general elevations for the outwash plains near the trench; the mouths of the principal spillways are also shown in the profile, figure 10.

The terraces in the areas mapped by the writer (Pekin and Hamar 15-minute quadrangles) were sketched on aerial photogra hs in the field; more precise limits were determined by use of the photographs in conjunction with a preliminary sheet of the 15-minute Hamar quadrangle which contained more spot elevations than the published sheet, and with the Tolna and Pekin 7 1/2-minute quadrangles. Terraces shown on Branch's, Tetrick's, and Easker's maps (the 15-minute Flora, Oberon and Tokio quadrangles, respectively) were identified on 7 1/2-minute quadrangles and their limits, in some places, revised. A few other terrace remnants in these quadrangles were found in the field and by office study of the 7 1/2-minute quadrangle and were checked on aerial photographs.

In the construction of the profile, the midpoints of the trench, starting at the western edge of the area, were plotted on the available quadrangle maps at half-mile intervals. These midpoints were connected by line segments. This sequence of line segments followed the curves of the trench with considerable fidelity. The succession of midpoints is shown at the bottom of the profile. Perpendiculars were dropped from the northern and southern limits of each terrace remnant to the line segments and thus shown on the profile.

Most of the terrace remnants as found on the detailed contour maps seem to have no systematic decrease in elevation downstream; after some experimenting, the writer decided that the representation of each remnant by a single horizontal line was the simplest and most objective way of presenting the data. These horizontal lines were drawn at the average elevation of a given terrace remnant as determined by inspection. The vertical range of each remnant is also indicated on the profile.

The profile of the bottom of the trench was drawn on the basis of stream-surface elevations. The stream, of course, in all places, flows in the lowest part of the trench. Stream surface elevations were shown on the available maps as spot elevations, dam-spillway elevations, and where contours crossed the stream.

In some terrace plots that have appeared in the geologic literature, the base line (in this plot, the floor of the trench), has been shown as a horizontal line and the terrace elevations plotted by their relative vertical distances above the base line. This was not done here, for it is obvious, that with a given terrace remnant shown everywhere by the same elevation, the terrace remnants would then be seen as sloping upstream--something which the writer considers a rather disturbing illusion.

Some detailed information on the terrace materials is given in Branch (1947, p. 25-27), Tatrick (1949, p. 24-25) and Easker (1949, p. 31). Some terraces have been cut in till which is thinly veneered with alluvial sand and gravel or a residuum of boulders and cobbles, and others underlain by alluvial sand and gravel of varying thicknesses over till and Pierre shale. The writer noted that in the area included in the Hamar 15-minute quadrangle some terraces were covered with wind-blown sand and silt, and slopewash material. Because of the variety of origins and materials constituting the terrace remnants, and the lack of data concerning their distribution, the writer has not differentiated so-called alluvial terraces from those which are essentially scoured surfaces.

The known exposures of Pierre shale shown in figure 9 indicate that many of the terrace remnants are rock defended and non-paired. These were probably formed as glacial meltwater eroded an original sag in the drift surface. The meltwater channels probably shifted from one side of the sag to the other depending on an inherent tendency to meander and the erodability of the underlying material.

Some of the terraces seem to be paired, that is, represent an original channel surface that has been bisected. However, many of these remnants, if paired, represent a channel which was distinctly asymmetrical and "hyperbolic" in cross-section. Among those that may be paired are nos. 1 and 4; 3, 5 and 12; 22,24 and 26, 13, 15 and 17 (see figs. 9 and 10). Most of the terraces in the Hamar 15-minute quadrangle seem to be paired but detailed elevation data is not available.

The major fact that the profile demonstrates is the "break" or discontinuity in the terrace levels at the mouth of Seven Mile spillway. Downstream from the mouth of the spillway are a group of high level terrace remnants. Upstream from the spillway, the remnants start at much lower elevations and rise progressively upstream. Only near the western edge of the map area do they attain elevations equal to those downstream from the spillway. The best explanation for this discontinuity was the presence of an ice and/ or drift dam just upstream from the spillway mouth. During t.e existance of this dam some meltwater was discharged both through the present site of the trench as well as through a spillway called Robinson Coulee which is shown on the Brantford 7 1/2-minute quadrangle (see fig.5 for location of this quadrangle).

Both major groups of terrace levels, upstream and downstream from the spillway mouth, apparently merge in the group of remnants in the Hamar 15-minute quadrangle. Many of the "overflow" channels that rise to higher elevations than the bulk of the terrace surfaces may have carried water or been filled with standing water during the existance of the dam upstream from Seven Mile spillway.

The "butte" surfaces and terraces at the eastern end of the profile, in the Tolna and Pekin 7 1/2-minute quadrangles cannot be clearly related to the terraces upstream until the data on the terraces in the Hamar 15-minute quadrangle becomes available. However, it is fairly probable that the terrace bounded by the terrace bounded by the Big Stony spillway scarp (no. 37) and the terraced part of the eastern "butte" (no. 42) were made during the formation of the terraces in the Hamar 15-minute quadrangle. The lower terrace remnants in this part of the profile are probably related to events occuring during the draining of the Warwick, Big Stony and Harrisburg spillways, and the excavation of the present trench.

Group I

The spillways in group I are characterized by having a kettled or tortuous channel for their proximal parts and few if any associated ice-contact deposits.

Long Lake spillway

The proximal part of Long Lake spillway, the westernmost one, is essentially a kettle chain whose long axis strikes transverse to the main trend of the North Viking moraine. A few ice-contact deposits, kame and kame terrace in origin, are near the north end. This proximal portion was partly occupied by a narrow arm of prehistoric Devils Lake (see fig. 6).

The distal part of the spillway is a shallow, poorly defined channel in the Oberon outwash.

Inconclusive subsurface data suggests that the proximal part of the spillway is underlain by a bedrock "low". This data is summarized in figure 11. Test drilling in the Oberon outwash south of the proximal part failed to disclose another low place in the bedrock (see Aronow and others, 1953, p. 52).

That this spillway drained a glacial Devils Lake was believed by Aronow and others (1953, p. 50-55). A reconsideration 5/ of the problem

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5/ This suggestion was made to explain the covering of the coarser outwash material with a blanket of finer material. Enlarging on Branch's idea (cf. above) it was believed that this finer material was deposited by water from a glacial Devils Lake. Coarser material presumably was dropped in the Lake and only the finer material carried through the spillway. Branch's idea was to have the coarser material trapped in the spillway when the ice was still at the site of the moraine. Branch's idea, of the two, now seems more reasonable. However, the writer believes that Thwaites's generalization (1948, p. 46): "The present extraordinary smoothness of *many* [outwash] plains is due to later deposits of sand and silt mainly laid down by wind since cessation of glacial drainage." offers the correct explanation for the finergrained blanket over the surface.

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shows that this was unlikely. The threshold of the spillway, located in

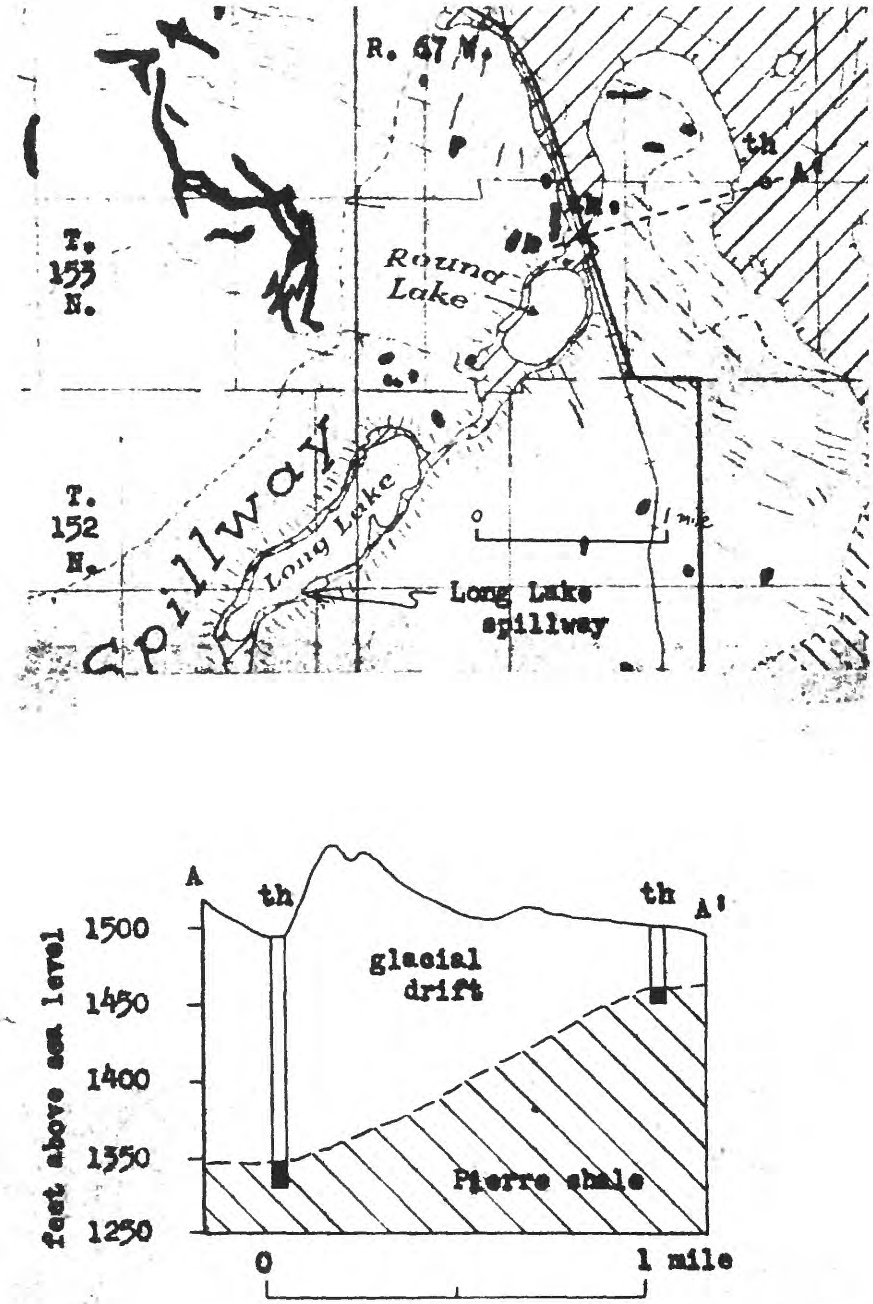

Figure 11.—Subsurface data on Long Lake spillway. th = USGS test hole (see Aronow and others, 1953, for details).

the Oberon outwash just south of the moraine, has an elevation of between 1545 and 1550 feet above sea level. An examination of the Josephine 7 1/2-minute quadrangle shows that, unless much of the moraine was protected by stagnant ice, water flowing at the threshold level would have invaded many parts of the North Viking moraine. Evidence for such an invasion is lacking. The most likely time for this spillway to have carried water was early in the retreat of the ice northward across the North Viking moraine. The shallowness of the channel in the Oberon outwash testifies to the small volume of water discharged through the spillway.

A large group of eskers and esker-like ice-contact deposits, about four miles long and striking south past the city of Minnewaukan (see fig. 8) trends toward the proximal part of the spillway. The water that laid down these deposits probably drained, at least in part, into a large lake that undoubtedly occupied most of the proximal part of the spillway at that time.

Seven Mile spillway

Description and Relation to Bedrock

Seven Mile spillway, cut into the Tokio outwash south of Main Bay of Devils Lake (see fig. 6), is, in its distal part the largest of the spillways heading into the North Viking moraine (see pl. 9). In places it is as much as three-fourths of a mile wide and as much as 50 feet deep. The spillway becomes progressively narrower and more contorted until, through a maze of morainic hills and clefts, it connects with or overhangs two prominent re-entrants of the southern strand of Main Bay in the vicinity of Sullys Hill (see fig. 8). The threshold of the spillway is located in the S 1/2 sec. 22, T. 152 N., R. 65 W.; its elevation is between 1570 and 1580 feet above sea level. In the northern part of the distal portion are many tributary channels graded to the bottom of the spillway. Their gully-like form is probably not the result of postglacial erosion except in minor details. 6/ The extreme southern end

6/ Among the reasons for this belief are: (1) Many channels head into and are graded to shallow ramifying channels in the outwash. (2) At least one channel (in NW 1/4 sec. 1, T. 151 N., R. 65 W.) contains a closed depression. The channel probably drained an ice block in the outwash. (3) No alluvial fans could be detected at the mouths of the channels either on the 10-foot contour interval, 7 1/2-minute Fort Totten quadrangle or on aerial photographs on the floor of the spillway.

of the spillway has an elevation of about 1500 feet and is sharply truncated by the trench of the Sheyenne River.

Surface exposures of the Pierre shale bedrock indicates that the surface of the bedrock sags under the spillway. The available data are summarized in figure 12.

Tokio Outwash

The genesis of this spillway is closely connected with the history of the Tokio outwash 7/ in which it lies, and with that of the Heimdal and North Viking moraines. For this reason the relationships among the Tokio outwash and the moraines will be explored.

7/ See Easker (1949; p. 27-29) for a detailed description of the topography and materials of the Tokio and Heimdal outwash; see p. 33 of his report for his views on the history of these outwash deposits. The writer has drawn freely upon Easker's data and views.

The chief problem concerning these moraines and the Tokio outwash is the actual existance of a distinct and major stage in the history of the region at the site of the morainic deposits called the Heimdal moraine, as approximately depicted in figure 7. In other words, was the bulk of the Tokio outwash deposited when the large loop in the Heimdal moraine was occupied completely and contemporaneously by ice?

Figure 13a shows, diagrammatically, the successive stands of the ice as taken from figure 7. Figures 13b and 13c show respectively two other possible major stands during which most of the Tokio outwash may have been deposited. There is very little in the gross configuration of the moraines or in the geometry of the morainal ridges and ice-contact deposits which would indicate which of the three versions or gradations between versions, is most nearly correct. An examination of the character and arrangement of the outwash deposits, the spillways, and terraces along the Sheyenne River seems to provide the answers.

The following considerations concerning the Tokio outwash have made the writer believe that the version shown in figure 13a is most likely to be the correct one:

(1) An inspection of the Tokio SW and Fort Totten 7 1/2-minute quadrangles shows that the Tokio outwash is graded to and was once continuous with the Heimdal outwash. During their deposition they must have drained into the

glacial James River to the south.

(2) The Tokio and Heimdal outwash deposits occur at higher elevations where they border on the Sheyenne River than either the Oberon outwash to the west or the Warwick outwash to the east. Also the Heimdal and Tokio deposits are obviously not graded to either of the outwash deposits to the east and west. Thus during their deposition the Tokio and Heimdal deposits were physically confined to the area in which we now find them; the drainage exits to the east and west now available through the trench of the Sheyenne River did not then exist. Drift dams, now broken through, and/ or ice dams, must have blocked this channel. However, it is clear that no morainal dam could be breached while active ice was present at the site of the moraine.

(3) A number of topographic facts concerning the outwash and moraines are also significant to the timing. Among these are:

a) Much of the Tokio outwash is pitted; the most conspicuous non-pitted area is along the major axis of the outwash. Most of the peripheral part of the outwash is pitted. In the northern part expecially, the kettles occupy swales between well-formed crevasse fillings. 8/ Here, and in many other places the moraines merges topographically with the outwash.

8/ As used originally by Flint (1928, p. 414): "Closely associated with recessional moraines and pitted outwash plains , but lie beyond the former and incorporated within the latter...For any given stand of the ice, they are found below and beyond the zone of eskers."

b) In some places the outwash surface is higher than the surface of the moraine contiguous to it.

c) An inspection of the topographic maps also shows no systematic slope in the surface of the outwash to the east or west.

The pitted character of the periphery of the outwash, the lower morainal topography indicates that when the Tokio outwash was laid down, the contact between the moraine and outwash was along a zone of stagnant ice. The lack of systematic slope of any great magnitude shows that there was neither preponderance of outwash from one or the other sides of the moraine nor was there later superposition of outwash from either side. If the latter did occur, it was before the masses of stagnant ice along the contact melted, or else there would have been clear topographic control of the height of the outwash in relation to that of the moraine.

In general, there seems to be no strong evidence for either of the two possibilities shown in figures 13b and 13c.

Relation of Terraces to Seven Mile Spillway

The mouth of Seven Mile spillway hangs above the trench just downstream from where the trench has cut through the Heimdal moraine. Opposite the mouth of the spillway on the south side of the river is a high terrace remnant. Remnants at successively lower elevations can be traced downstream. These terrace remnants where they first appear are higher than any upstream except near the western edge of the map area.

The most plausible explanation for these high terrace remnants is the damming, either by drift or by ice or by both of the future site of the trench just upstream from the place where the high terraces first appear. A lower outlet also had to be opened down stream to divert meltwater from its course across the Heimdal outwash to the glacial James River to a course now represented by the high terrace remnants.

Where the trench now cuts through the eastern limb of the Heimdal moraine, west of the Hillsdale moraine, is the most likely place in the map area for such an outlet to be opened. 9/ This indicates that the

9/ On the Brantford NE 7 1/2-minute quadrangle (see fig. 4 for location) can be seen a shallow, poorly defined glacial spillway called on the map Robinson Coulee. This channel starts at the large bend at the extreme southern edge of the Tokio quadrangle and strikes south and east; on the aerial photo index sheets of Eddy County it can be seen to join drainage leading into the James River. It seems to be graded to the high terraces (see fig. 10) and was probably a partially effective drainageway for water flowing at the level of the high terrace, which functioned until another, lower outlet was opened sufficiently to divert all of the water. Little is known of the geology in this area and no reasons can be advanced at this time for the opening of this channel. The writer's tentative hypothesis may thus stand until more can be learned about the geology south of the Tokio quadrangle.

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ice left the eastern limb of the Heimdal moraine earlier than the western. However, this does not vitiate the idea that the bulk of the Tokio outwash was laid down with the ice front essentially in position "a" of figure 13.

It is believed that during the opening of this lower outlet Seven Mile spillway was first established. The lower base level allowed meltwater to erode out the spillway rather than deposit outwash material. This meltwater probably once flowed out of the spillway at levels high enough to be confined in the channel(s) now represented by the high terraces (see fig. 10).

The Oberon outwash immediately upstream from the spillway has elevations similar to those of both the mouth of the spillway and parts of the high terraces (see fig. 9). Thus it may be concluded that for a short time after the removal of the dam, Oberon outwash was deposited contemporaneously with water flowing out of the spillway. By this time the ice had retreated to the site of the North Viking moraine.

At present, the mouth of the spillway is below the level of the highest parts of the terraces downstream from it and also slightly below the level of the Oberon outwash just upstream. Meltwater from ice at the site of the North Viking moraine must have continued to drain through the spillway, cutting it down to the present level. Probably most of the meltwater from ice at the site of the North Viking moraine contiguous to the Tokio outwash drained through the spillway.

The removal of the dam upstream from the spillway and the deposition of the outwash from the ice at the site of the North Viking moraine caused the regrading of the entire system, the forming of new channels at lower levels, and the truncating of Seven Mile spillway.

Proglacial Lake Drainage

The threshold of Seven Mile spillway is in the northern part of the proximal portion in the S 1/2 sec. 22, T. 152 N., R. 65 W. Its elevation has been 1570 to 1580 feet above sea level. The presence of ice in the channel would, of course, have raised this threshold.

The writer, with Easker (1949, p. 33), believes that the spillway did not drain a glacial Devils Lake or a proglacial lake. The reason for this belief lie mainly in the fact that such a lake, like that in the vicinity of Long Lake spillway, would have had rather extensive dimensions, the evidence for which is lacking. More precisely, the ice retreated from the site of the North Viking moraine in the area northwest of the spillway in a northern and eastern direction, as shown by the morainal ridges (see fig. 8). Any proglacial lake that may have been drained by the spillway would have occupied at least an area now covered by the southwestern part of Main Bay. It would have had a water surface at least equal in height to that of the spillway threshold. An examination of the Fort Totten and Crow Hill 7 1/2-minute quadrangles shows that such a lake would have unundated much of the then ice-free parts of the North Viking moraine to the west. However, there is no evidence that such an inundation ever took place.

In cuts along State Highway 57 on the south side of Main Bay several large masses of ice-contact lacustrine very fine sand and silt, interbedded with till, are exposed. These were probably deposited in or on masses of stagnant ice. The possibility of the drainage of stagnant ice masses through the spillway, however, must meet the same objection as that raised against the proglacial lake hypothesis.

The Minco spillway

The Minco spillway (see fig. 6) at the south end of East Devils Lake, has little, if any distal part cut in the outwash. A small kettle in the proximal part causes it to slope north, towards the lake. This spillway was cut during, or at least participated in the main deposition of the Warwick outwash as indicated by the lack of any clear-cut distal part. However, the kettle in the proximal part may signify that it may not have been cut, in the usual sense of the word, but appeared and was modified slightly after the melting of a mass of ice. At any rate, drainage activity if any from a proglacial lake or ice mass in the lake basin, was slight. This spillway can be considered of minor importance in the history of the region, other than as an indicator of a possible bedrock "low".

Group II

The spillways in group II are characterized by the association of their proximal part with large ice-contact deposits.

Crow Hill spillway

The Crow Hill spillway south of West Bay of Devils Lake (see fig. 14) has as its proximal part one of the most impressive assemblages of ice-contact deposits in the whole Devils Lake region. It is a complex mass of eskers, kames and kame terraces; the eskers and kames are mostly in the northern portion and the kame terraces in the southern (see fig. 14). The kame terraces border elongate kettle lakes and the kames and eskers weave in and around prominent kettles (see pls. 10 and 11). 10/

10/ Exposures of the ice-contact deposits may be seen, for example, in road cuts where crossed by State Highway 57 and in a gravel pit on the south side of an east-west section line road in the NW 1/4 sec. 10, T. 151 N., R. 66 W. (see pl. 12)

Tetrick (1949, p. 11-12) describes a difference between the materials in the kame terraces and in the eskers and kames. The material in the eskers is poorly sorted and has a high detrital shale content. The kame terrace material has a smaller proportion of detrital shale. Tetrick believes the difference due to the derivation of the kame terrace material from the upper part of the ice and the esker, from the bottom and "...the gouging out of the Pierre shale bedrock to form the basin of Devils Lake would have contributed more shale to the lower than to the upper part of the ice sheet."

The writer believes that the difference in material is the result of greater reworking of the materials in the kame terraces than in the eskers. The eskers date from an earlier period in the thinning of the ice, kame terraces from a later. Hence it may be expected that these materials have

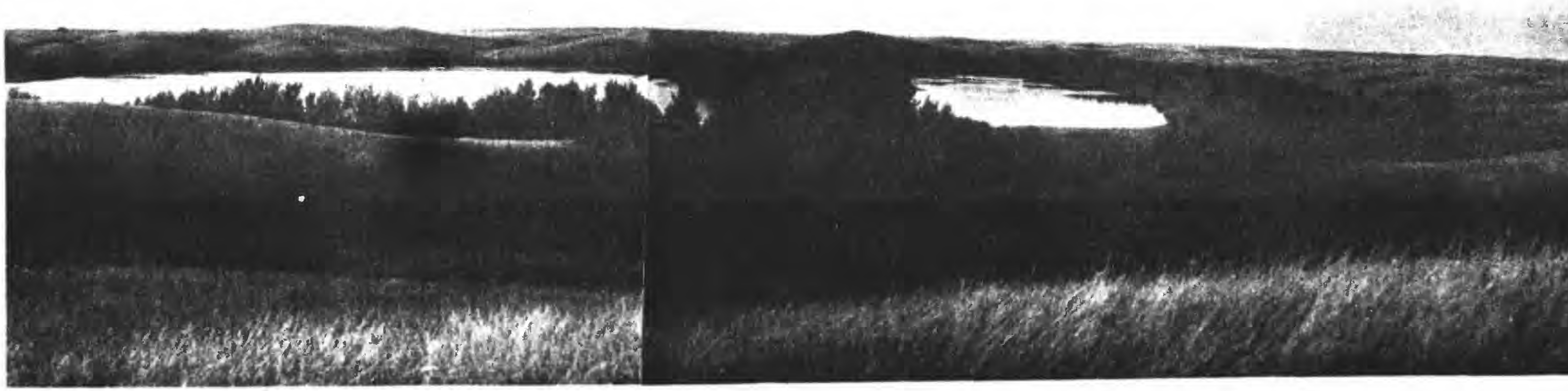


Plate 10.—Kettle lake and hills of ice-contact deposits in proximal part of Crow Hill Spillway. Picture taken from winding east-west road in S 1/2 sec. 28, T. 152 N., R. 66 W., looking due north. Lake is in center of sec. 28.

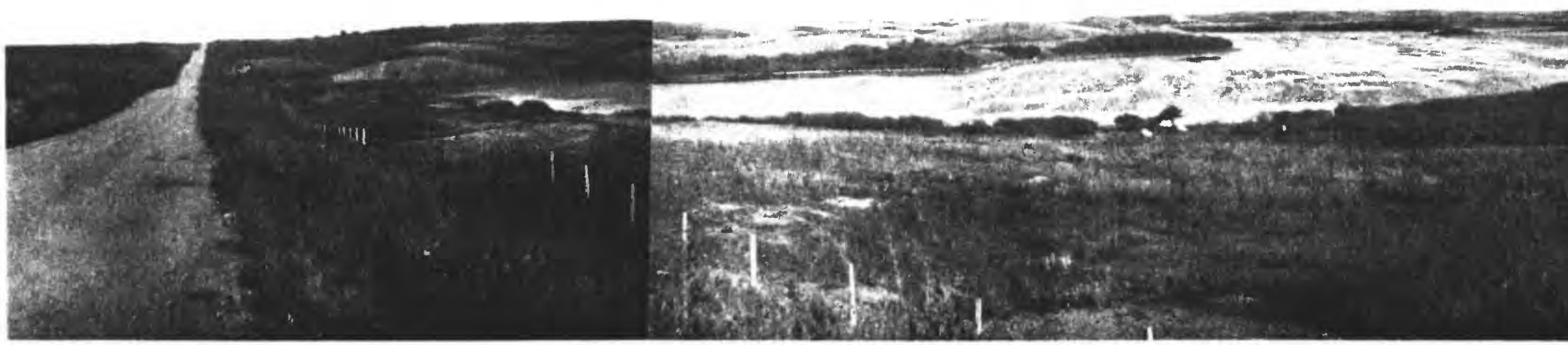


Plate 11.--Looking east across proximal part of Crow Hill Spillway in NW 1/4 sec. 10, T. 151 N., R. 66 W. Kames in view on far side of lake. Arrow indicates location of pit in which plate 12 was taken.

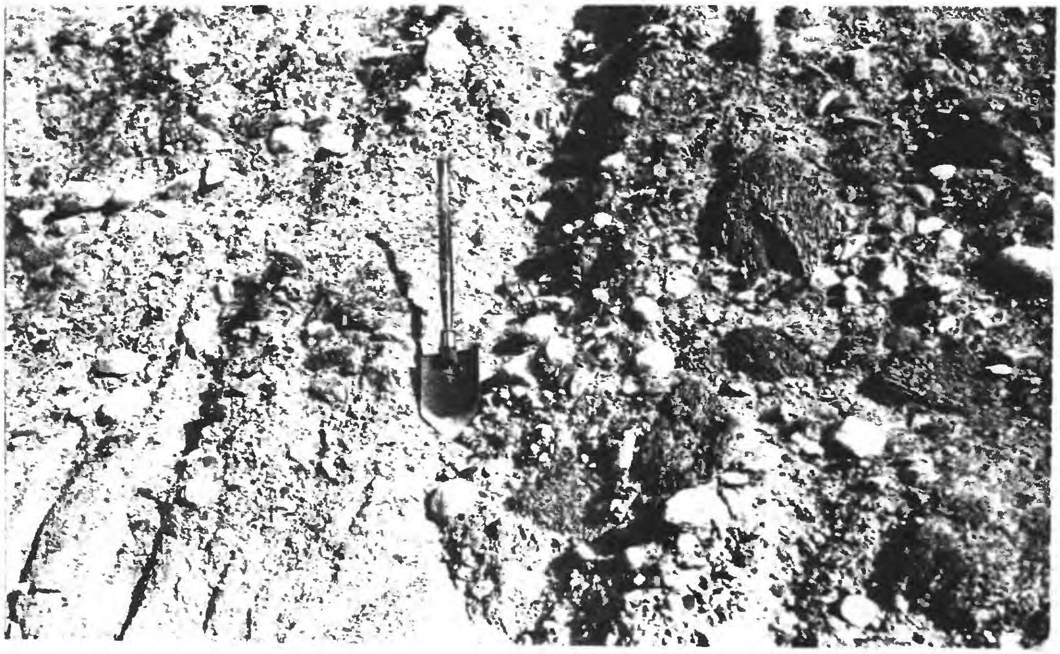


Plate 12.--Poorly sorted and bedded cobbly and bouldery ice-contact deposit in proximal part of Crow Hill Spillway. Note disintegrating boulders of Pierre shale. Exposure in pit on south side of east-west section-line road in NW 1/4 sec. 10, T. 151 N., R. 66 W.

Plate 13.--Eskers north of Big Stony Spillway, at west end of West Bay of Stump Lake. Looking northeast. These eskers were deposited by water which first established the course of Big Stony Spillway.

undergone more reworking and attrition and that the fragile detrital shale fragments were broken down into clay or otherwise comminuted.

The distal part of the spillway is a well-defined channel in the Oberon outwash; it broadens towards the trench of the Sheyenne River. Its elevation where it hangs above the trench of the Sheyenne River is about 1480 feet above sea level (see fig. 9).

Big Stony spillway (early phase)

Big Stony spillway seems to have had two phases in its history; the evidence for the first is introduced here. North of the continuous cut channel of the spillway at its exit from Stump Lake are a group of braided, southwest-striking eskers with a trend subparallel to that of the spillway (see fig. 15 and pl. 13). The deposits range in size from silt and sand to coarse cobbly gravel and boulders. Bedding and sorting range from poor to excellent. 11/ The materials seem to have been laid down, in general with considerable reworking by running water insofar as shown by sorting and bedding.

11/ Exposures may be seen in a pit at the extreme eastern end of eskers, in the NE 1/4 sec. 17, T. 151 N., R. 61 W., and in cuts along an east-west sectionline road between secs. 17 and 20, T. 151 N., R. 61 W.

Plate 14.--Coarse, bouldery and unbedded ice-contact deposit in proximal part of Osago spillway. Exposure on north side of winding east-west road in NE 1/4 sec. 5, T. 150 N., R. 60 W. These deposits were probably "dumped" from the ice with little reworking by running water other than to remove most of the clay fines.

Plate 15.--Threshold area of Big Stony Spillway, looking west from extreme west end of West Bay of Stump Lake. End moraine on the left (south) and end moraine and eskers on right (north). This threshold area controlled the level of the 1453-foot strandline around Devils Lake and Stump Lake.

The Osago spillway

The Osago spillway's proximal part is a group of ill-defined kames and esker-like forms with intervening kettles which strike south from East Bay of Stump Lake (see fig. 16). They are partly flanked on the northeast by a re-entrant of the high 1453-foot strandline. East and west the ice-contact deposits merge into the North Viking moraine.

Exposures of the deposits were found only in the northern part. 12/

12/ Exposures occur where crossed by a winding east-west road and in a pit in the NE 1/4 sec. 5, T. 150 N., R. 60 W.

In contrast to those of the Big Stony spillway these deposits are exceedingly bouldery and cobbly with very little bedding and sorting (see pl. 14). In some places the clay content was rather high and suggested that the material was little removed in character from till. There was obviously comparatively little reworking by running water.

A definite but shallow channel leads away from the proximal part through the Pekin outwash. The channel ends where it is sharply truncated by a prominent scarp at or near the edge of the Pekin outwash (see fig. 8).

Origin of spillways

General Statement

Any explanation of sequence of events common to these spillways must take into account the areal juxtaposition of three elements in each of them:

(1) the prominent indentation of the high 1453-foot strand into the North Viking moraine

(2) the ice-contact deposits transverse to the North Viking moraine forming the proximal part,

(3) the continuous channel in the outwash deposits south of the moraine, forming the distal part.

The writer's original working hypothesis to explain this juxtaposition was rather simple: Stagnant ice persisted on the site of the moraine for some time after the retreat of the ice to the north. Proglacial lakes or large, stagnant masses of ice drained through the re-entrants in the lake shore. The re-entrants were probably cut by the water or at least modified by it. The ice-contact deposits were laid down by these meltwaters passing through the stagnant ice and debouching into the outwash plains south of the moraine. This hypothesis, as applied to Crow Hills spillway, disagrees with the sequence of events outlined by Tetrick (cf. above).

A more careful review of the ice-contact deposits and their relation to other features in the area caused the writer to modify his views. Flint's critical discussion of the evidence for ice stagnation (1942, p. 124-131) also had a dampening effect on the writer's enthusiasm for such large-scale stagnation and wholesale explanations.

Of the seven features cited by Flint (p. 125) as having been used to substantiate the presence of stagnant ice, the following are relevant here: (1) kettles, (2) complexes of small knolls, ridges, and closed depressions, (3) kame terraces and (4) eskers. 13/ Only the first two

13/ The other features are (5) potholes on interfluves, (6) lake deposits lacking distal closure and (7) absence of end moraines.

are thought by Flint to demonstrate stagnant ice. Concerning kame terraces he says (p. 130-131) that they are of only local significance and "do not prove a general stagnant condition for the entire cross-section of the glacier." Eskers may, in some places be clearly produced in stagnant ice. "But until new facts are available we can scarcely regard eskers, although suggestive of feeble movement, as proving that the terminal zones of the related glaciers were wholly stagnant." 14/

14/ At least some of the eskers in the Devils Lake region must have been built up by distal accretion rather than by contemporaneous deposition from proximal to distal ends. These eskers strike transverse to the trend of morainal ridges flanking them (see fig. 8).

Simply the occurrance of the principal types of ice-contact deposits then does not in itself "prove" the presence of stagnant ice. Some alternative, plausible and potentially verifiable hypothesis, other than the fortuitous drainage through stagnant ice was needed.

In the search for the cause of the aligning of the three elements which make up these particular spillways, as well as the traversing of the moraine by the other spillways, the writer has had to fall back upon the hypothesis of control by bedrock configuration. Subsurface data for the areas around these spillways is almost completely lacking or inconclusive. However, it is certainly the most plausible cause of this alignment. This view has been advanced by Tetrick (1949, p. 12-13), and others working in the Devils Lake region. In detail, the view is that the spillways were localized by preglacial valleys, or valleys cut in an earlier drift, which were tributary to the major valley which determined the general strike of the Devils Lake-Stump Lake complex.

Assuming that the configuration of the underlying bedrock or previous drift is the cause of the localization of the three elements in these spillways, the problem arises concerning the manner in which they influenced the laying down of the ice-contact deposits. The writer suggest two possibilities:

(1) Differential movement in the ice may have been initiated by the "lows." This may have been significant in thinning ice where more rapid movement may have taken place in areas of thicker ice. Shearing would develop crevasses which might have influenced the drainage of meltwater and thus deposition of ice-contact deposits.

Tarr (1908, p. 97) in his study of "Some phenomena of the glacial margins in the Yakutat Bay region, Alaska" says that:

> It is doubtful whether eskers are ever developed under glaciers that are really active, first because, if formed, they would be destroyed during the recession; and secondly, because even a moderate ice motion will tend to displace the stream course from season to season.

The writer agrees that eskers of any great size and length could not be deposited and preserved under active or feebly moving ice. However, the eskers associated with the proximal parts of Crow Hill and Osago spillways are short and discontinuous. Probably the presence of the "low", and concomitantly, of thicker ice, caused the re-establishment of a new system of "feeding" crevasses or meltwater channels in the ice for each new generation of ice-contact deposits laid down with each oscillation of the ice front (cf. below). These features then represent essentially the deposits of a series of displaced stream courses which have been localized above the hypothetical "low".

(2) The "low" may have provided places where the ice could persist to greater thicknesses during uniform surface thinning of the ice and thus supply the necessary supporting walls, or tunnels for the deposition of ice-contact deposits.

Under the general assumption of bedrock control, some local histories have been worked out.

History of Crow Hill Spillway

A possible sequence of events for the development of the Crow Hills spillway is suggested by a consideration of the following features (see fig. 14) in and near the proximal part of the spillway:

(1) the more esker-like forms in the northern part and the kame terrace forms in the southern.

(2) the group of southeast striking morainal ridges (in secs. 31 and 32, T. 152 N., R. 66 W.).

(3) the southeast-west striking Crow Hills eskers--a group of overridden eskers and/or morainal ridges (see Tetrick, 1949, pp. 13-15).

(4) the morainal ridges north of the Crow Hills eskers whose strike gradually changes from that of the eskers to almost due south.

(5) the somewhat reticulating pattern of ice-contact deposits in the extreme northern part.

(6) the large area, over 4 square miles, of ice-contact lacustrine deposits (thin bedded very fine sand and silt) between the high 1453-foot strandline and the North Viking moraine northwest, of the re-entrant into the spillway. At least two other ex-

posures of this material were also found in road cuts north of the main deposits of the spillway.

Nos. (5) and (6), it may be noted, can be considered as falling into Flint's category of "complexes of small knolls, ridges and closed depressions."

On the basis of these features, the following sequence of events for Crow Hills spillway has been worked out:

(a) As the ice gradually uncovered the North Viking moraine, small masses of ice were left in low places in the moraine--particularly in a depression above a pre-glacial valley or a valley eroded in earlier drift.

(b) At the place indicated by the morainal ridges west of the spillway, the ice seems to have halted or briefly maintained an oscillatory front. Drainage from the ice was funneled into the partly ice-filled depression, laying down the kame terraces and few eskers in the southern part.

(c) The ice continued to retreat haltingly toward the north and northeast as shown by the strikes of Crow Hills "eskers" and the morainal ridges. During this time, water issuing from ice above the site of the old preglacial valley continued to pass through the kame terrace area and into the channel in the Oberon outwash. Most likely the depression in the moraine, and the slow retreat of the ice tended to preserve or constantly re-establish the system of tunnels and crevasses in which the eskers and kames of the northern part were deposited. The general strike of the mass of deposits is oblique to the direction of ice retreat.

The volume of water released from the ice at any one time during this retreat must have been small and its erosive power dissipated by channel friction as it spread out among the masses of ice, ice-contact deposits and kettles downstream from the ice front. No doubt this is the principal reason why most of these deposits have been preserved rather than destroyed during the continual discharge of water from the retreating ice front.

(d) The somewhat reticulating pattern of the deposits in the extreme northern part and the small deposits of ice-contact lacustrine material probably indicates a small area of stagnant ice left as the ice retreated from the area to the northeast.

(e) The masses of stagnant ice, in and on which the ice-contact lacustrine deposits were laid down just northwest of the re-entrant may have drained as they melted into the re-entrant and partly flooded at least the northern part of the ice-contact deposits in the spillway.

In so far as the record of flow through the distal part is concerned, the elevation of its mouth is lower than the terrace remnants downstream but higher than the remnants upstream (see fig. 10). Probably the spillway was graded, when active, to the dam just upstream from the mouth of Seven Mile spillway when it was partly eroded away and hence lowered. Drainage of water through Crow Hill spillway apparently ceased by the time the terraces upstream from it were formed.

A careful examination of the spillway as depicted on the Crow Hill 7 1/2-minute quadrangle shows that water flowing at an elevation of about 1500 feet above sea level could pass through both the proximal and distal parts of the spillway. The course of such flow through the proximal part would be tortuous and irregular. Any large volume of water, such as from the drainage of a proglacial lake, or from subglacial drainage from a stationary ice front would have certainly eroded away many of the ice-contact deposits and carved a more uniform channel.

In view of the lack of positive evidence of stagnant ice for most of the proximal part of the spillway, the lack of an uninterrupted sequence of kame terraces and eskers from north to south end, the evidence of ice movement offered by the morainal ridges, and the absence of a broad uniform channel, the writer agrees with Tetrick (cf. above) that large amounts of drainage from the site of Devils Lake did not pass through the whole length of the spillway.

Histories of Osago and Big Stony Spillways

The other two spillways in Group II, Big Stony and Osago spillways were also undoubtedly controlled by a trough-like depression in the underlying older drift or bedrock.

The coarse, unsorted material found in the proximal part of the Osago spillway can best be explained as having been deposited or "dumped" from the front of a retreating ice-sheet with little reworking by running water. Certainly there is no indication here of through drainage from the site of Stump Lake into the outwash south of the moraine.

On the other hand, the braided eskers of Big Stony spillway were probably laid down contemporaneously from one end to the other as "conventional" eskers. The evidence for this is not conclusive but highly suggestive: (a) the lack of morainal ridges or other evidence of ice movement, (b) the comparative "reworking" of the deposits as contrasted to those of Crow Hill and Osago spillways and (c) the more or less continuous morphology of the deposits as opposed to that of the "intermittant" and discontinuous deposits of the two other spillways.

However, in light of what is known of the other spillways, it is probable that the distal part of the now continuous channel of Big Stony spillway was at least started during the deposition of the eskers. Later it was probably established as a through channel when the ice in the area melted and opened a lower channel across the moraine for the disposal of meltwater. There is no proof that the possibly "conventional" eskers ever drained a proglacial lake or a detached mass of ice.

The evidence available offers no clear-cut proof that any large volume of water ever passed through both the proximal and distal portions of each of these three spillways contemporaneously. The areal relations of other glacial features, the forms and materials of the ice-contact deposits themselves, and the lack of evidence of stagnant ice in the "right" places makes the writer accept the conclusions of Tetrick and others.

Group III

The three spillways in Group III, Warwick, Big Stony and Harrisburg spillways, have continuous channels through the North Viking moraine and into the outwash.

Warwick spillway and Big Stony spillway (later phase)

Descriptions

The Warwick spillway drained East Devils Lake near its south end (see fig. 6). The threshold lies between 1462 and 1465 feet above sea level. The actual location of the threshold is not clear but at present it is definitely located in the distal part of the spillway in the Warwick outwash. The extreme proximal end of the spillway has been postglacially notched; this may have cut down the original threshold.

Water flowing in this spillway cut a series of anastomosing channels in the outwash, taking advantages of low places such as the kettle in sec. 33, T. 151 N., R. 62 W. Water from this spillway was disposed into the glacial Sheyenne River of by two routes:

(1) indirectly, by flow into Big Stony spillway in sec. 5, T. 150 N., R. 61 W., where the junction of the two drainages is accordant and

(2) by a direct route into the glacial Sheyenne River. The middle segment of this second, direct route has been all but obliterated under an extensive cover of wind blown sand (see fig. 8), leaving a"decapitated" portion leading into the trench of the Sheyenne River. The junction of this direct route with the trench of the Sheyenne River is not accordant; the lip of the main spillway channel is about 30 feet above the edge of the present floor of the trench.

South of the junction of the two spillways, a large shallow channel seems to end blindly. It probably furnished sources of unchanneled flow into the Sheyenne River; it has been partly obliterated by wind-blown sand.

Big Stony spillway upon emerging from the west end of West Bay of Stump Lake has a meandering course before reaching the trench of the Sheyenne River. A small almost obliterated terrace remnant at the mouth of the spillway (see fig. 10--higher spillway mouth) is about 20 feet above the edge of the floor of the trench. The major portion of the mouth of the spillway is accordant with the floor of the trench (see fig. 10). 15/

15/ The writer believes that although some judgment is involved, statements here and elsewhere concerning the accordance or lack of accordance of channel junctions are approximately correct. The interested reader may examine most of these junctions on the Tolna and Pekin 7 1/2-minute quadrangles.

The threshold (see fig. 15 and pl. 15) of Big Stony spillway is the lower of the two and undoubtedly was the one that controlled the level of the postglacial 1453-foot strandline around the lakes. The threshold elevation is about 1459 feet 16/ above sea level, about 6 feet higher than the elevation of the strandline.

16/ The elevation of the threshold was taken from a spot elevation on the field sheet of the Devils Lake Mountain 7 1/2-minute quadrangle. The reasons for this difference in elevation are discussed later in part three.

Histories of Warwick and Big Stony Spillways

The earliest events in the history of these spillways were probably the draining of proglacial East Devils Lake and proglacial West Bay of Stump Lake during the time that the ice front was south of the Jerusalem outlet. The cutting of the channels through the outwash deposits must have begun during this period. However, the writer believes that the major channel cutting and eroding of the outwash deposits and till surface described below did not start until the Jerusalem outlet opened and the ice occupied a broad front in large proglacial ancestors of Devils Lake and Stump Lake; for only then would large quantities of meltwater become available.

During the early period, and during a later period when the Jerusalem outlet was free of ice, the spillways seem to have been the deepest channels and places of greatest velocity for water released from the lakes. They probably had the same relation to the areas they traverse as a stream channel to a broad flood plain. The evidence adduced for this is as follows:

(1) Several cut scarps subparallel the spillway channels and continue beyond them. These scarps (see fig. 8) are for example, in sec. 24, T. 151 N., R. 62 W., in the section just west of sec. 24, and in the vicinity of the junction of the two spillways. The most prominent of these scarps begins where Big Stony spillway emerges from Stump Lake, and continues, paralleling north of the spillway, roughly to where the spillway enters the Sheyenne River trench. The scarp has been eroded away, or was indistinctly cut, from here to the village of Pekin; it reappears southeast of the village and extends almost to the eastern edge of the map area before it is obscured by the postglacially notched portion of the Harrisburg spillway. Elevations of the base of the scarp are given in figure 9. According to the available shale exposures, this terrace remnant seems to be underlain by a flat-lying "shelf" of Pierre shale bedrock (see fig. 8)

The scarp south and east of the village of Pekin can be properly considered as the northern edge of a Sheyenne River terrace. Incidentally this terrace remnant (no. 37—see fig. 10) and "butte" surfaces (cf. below), and the group of terrace remnants immediately downstream from Seven Mile spillway (cf. above) are the only ones that are clearly related to major events within the map area.

(2) The more distal parts of both Warwick and Big Stony spillways traverse an area that is underlain by thin patchy outwash deposits and glacial till. The edges of the outwash deposits in many places are near or coincide with the base of the scarps. The till surface, where exposed, has been generally eroded and "planed off". This has left a surface residuum of boulders, cobbles and coarse gravel (see pl. 17). 17/

17/ The western edge of this map unit on figure 8 was mapped mainly on the basis of boulders found on the surface. The area is largely covered with thick deposits of wind-blown sand, which, as far as data collected during the well inventory of the area was concerned, could not be distinguished from sand-sized outwash material. It was assumed, with some justification, that boulders in fields and shallow road cuts, which are absent from the northern part of the outwash were not carried there by running water or by ice in streams (cf. Flint, 1947, p. 135). This area may, of course, include some areas of uneroded ground moraine, also buried by wind-blown material.

These eroded and "planed-off" till surfaces continue south of the trench in the Hamar and Pekin 15-minute quadrangles. These surfaces were probably cut partly during (a) the existance of the dam upstream from Seven Mile spillway, (b) the laying down of the Pekin and Warwick outwash deposits and (c) during the later erosion of these outwash deposits. Elevation and geologic data are not exact enough at this time to distinguish among these events. The lower, channelled, parts, expecially in the Hamar 15-minute quadrangle are continuous with and seem to be graded to terrace remnants immediately contiguous to the trench. At least the lower portions of these channels probably were filled with water overflowing from the channel now represented by the terrace remnants. Undoubtedly these channels were originally cut at the same time as the "planed-off" till surfaces.

(3) Big Stony spillway has a channel whose width, depth, and the radii of whose meanders indicate a larger volume of water than is likely in postglacial time. In some places the channel has cut into the Pierre shale bedrock beneath the till, which indicates considerable erosive power (see fig. 8 and pl. 16). There is the possibility that this

Plate 16.--Exposure of Pierre shale in the north side spillway of dam across Big Stony Spillway in the SW 1/4 sec. 18, T. 150 N., R. 61 W.

Plate 17.--Rubbly residuum on eroded till surface above north bank of "decapitated" portion of Warwick spillway, looking southeast. Exposure on east side of north-south section-line road in SW 1/4 sec. 23, T. 150 N., R. 61 W. Deep channel in upper right, Warwick spillway; trees in upper left in trench of Sheyenne River. Note shovel in center for scale.

channel is part of a re-excavated preglacial channel. The channel was probably "roughed out" during the time when both spillways were active contemporaneously as shown by terraces remnants (see pl. 18) along the sides of the now unused bifurcated parts of the trench (nos. 35 and 40-- see fig. 10). These remnants are higher than the mouths of the two spillways.

A later period in the history of these spillways can be discerned from the character of the trench downstream from the spillways. Below where the spillways enter the trench, the trench is more or less accordantly bifurcated by two resurrected "buttes" of Pierre shale bedrock. These "buttes" in most places are covered with either coarse, sorted alluvial deposits (see pl. 19) or a veneer of "planed-off" till residuum, both of which indicate that water once flowed over a good portion of the "buttes". Where the trench weaves among the "buttes", the cross-sectional area of the trench is increased by a quarter to nearly a half. This is almost certainly related to large increments of water from Big Stony spillway.

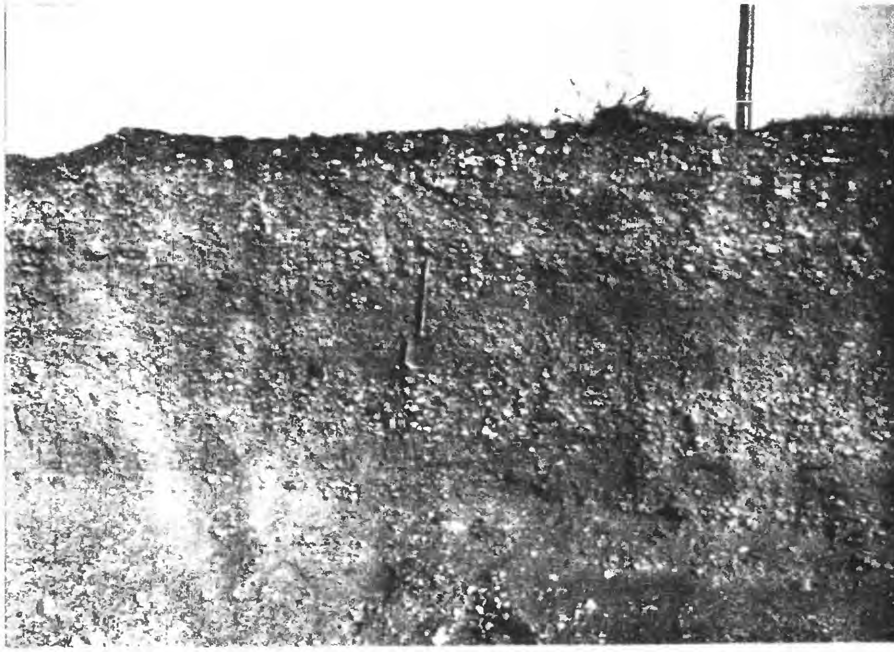
During this period of trench excavation and great flow through Big Stony spillway, the spillway effectively captured the upper reaches of the Warwick spillway, thus preventing the direct route of the Warwick spillway from lowering its mouth at the same rate as that of Big Stony spillway.

In postglacial time, flow of water through Big Stony spillway has been negligible, otherwise the junctions of Big Stony and Warwick spillways would not be accordant.

<u>Source of Water</u>

The large volumes of water discharged into the ancestral and glacial

Plate 18.--Picture taken from north side of westernmost drift-covered shale "butte" which bifurcates trench of Sheyenne River in extreme southwestern part of map area. Looking northeast across trench. Horizontal arrows indicate surface of small terrace above floor of trench; vertical arrow, the village of Pekin. Terrace in NW 1/4 sec. 28, T. 150 N., R. 60 W. (No. 35 --see fig. 9).



A

B

Plate 19.--Alluvial material on surface of western "butte" in trench of Sheyenne River; exposed in pit in the SE 1/4 sec. 29, T. 150 N., R. 60 W. A. Exposure of coarse, poorly bedded and sorted alluvial material in wall of pit. B. "Over-size" material stockpiled in pit; derived from alluvial material. Some of these cobbles have maximum diameters greater than 6 inches.

Sheyenne River through these spillways and contiguous areas must have been available (a) during the retreat of the ice from the site of the North Viking moraine to that of the Sweetwater moraine and (b) later, during the deposition of the Sweetwater moraine. Also water was probably discharged into Stump Lake by way of Harrisburg spillway from a spillway net to the east and north.

Eskers, north of the lakes (see fig. 8) discharged their depositing waters into the lakes. The interlobate channels and associated ice-contact deposits (1) north of West Bay of Stump Lake, (2) south of the village of Crary and (3) through the glacial antecendent of Sixmile Bay of Devils Lake also testify to the copious release of meltwater into the lakes. Meltwater from the ice which deposited the Sweetwater moraine and which laid down no outwash must have also been discharged into the lakes, for there seems to be no other place for it to go.

As the ice front continued to retreat out of the map area in a northerly direction meltwater was undoubtedly in continuous transit through the lakes into the glacial Sheyenne River. This meltwater was probably funneled into the lake mainly through Mauvais Coulee and Harrisburg spillway. As new and lower outlets farther north were opened for meltwater, the amount of water entering the lakes diminished.

Of yet unassessed wider regional significance is the fact that the water passing through Big Stony spillway was largely spent before the excavation of the trench ended. This is indicated by the terrace remnant at the mouth of Big Stony spillway which hangs above the floor of the trench (higher spillway mouth--see fig. 10).

Eskers and Morainal Ridges

It can safely be assumed that the water level in the proglacial lake that must have been in existance during the retreat of the ice from the site of the North Viking moraine to that of the Sweetwater moraine must have had an elevation at least equal to that of the threshold of the Warwick spillway which is higher than 1460 feet above sea level. Water at this elevation would cover many of the morainal ridges and eskers transverse to them in the Grahams Island and Devils Lake 15-minute quadrangles (see fig. 8). Indeed, many of these morainal ridges were either under water or had their crests close enough to the water surface to be planed off when the postglacial-prehistoric high 1453-foot strandline was occupied. The clear association of at least this strandline with morainal ridges and eskers certainly suggests that they were deposited partly in standing water. Subaqueous deposition of eskers and morainal ridges has also been reported by Norman (1938) in a study of the Chigougamau district of Quebec. The pattern of morainal ridges and transverse eskers shown in Norman's map is similar to the ones shown in figure 8 of this study.

Any postglacial tilting in this region would have increased the disparity between the elevations of the ridges and eskers and those of the spillway thresholds. The isobases, as shown on a map in Flint (1947, p. 420), are roughly parallel to the strike of the Devils Lake-Stump Lake complex of lakes. Upham (1896, p. 475) found that tilting for the Norman (highest) beach of Lake Agassiz to be in the order of half a foot to one foot per mile. A distance perpendicular to the isobases between the Warwick spillway and the places where the morainal ridges and eskers are found is between five and ten miles. This would lower the ridges and eskers from 2 1/2 to 10 feet, and would submerge many of the ridges and the lower parts of the eskers even with water at the threshold height of Big Stony spillway, the lower of the two spillways. 18/

18/ Cf. discussion of tilting in part three.

Harrisburg spillway

The Harrisburg spillway is south-striking and more or less parallel to the eastern edge of the map area. It differs from the others in that it is not areally related to any indentation of the high 1453-foot strandline in the North Viking moraine. Simpson believed (cf. above) that this spillway drained Stump Lake. However, an examination of the areal relations of the spillway to East Bay of Stump Lake on figure 8 shows that the spillway itself drained partly into Stump Lake and partly into the Sheyenne River.

The spillway continues northward outside of the map area for more than eight miles. Drainage was fed into the spillway from areas in the McVille quadrangle to the east.

Pierre shale is exposed where the spillway is crossed by State Highway 15 and also in one of the walls of a tributary to the postglacially notched portion (see fig. 8).

On the sides or upper slopes of the spillway a number of sand and gravel deposits are exposed. These may be either terrace remnants or kame terrace deposits. 19/

19/ These pits are respectively, in the NW 1/4 sec. 7, T. 150 N., R. 59 W., in the SE 1/4 sec. 12, T. 150 N., R. 60 W., in the NE 1/4 sec. 36, T. 151 N., R. 60 W., and in the NE 1/4 sec. 19, T. 152 N., R. 59 W. All of these pits, except the second, are indicated on the Pekin and Pekin NE 7 1/2-minute quadrangles as such. The reason for the indecision concerning the fluvial or kame terrace origin of these deposits is the presence of boulders in the pits; all or some of the boulders in these pits may have been removed from nearby fields and dumped in the pits. Most of the exposures were poor and no boulders were seen in place in the sides of the pits.

The extreme southern end of the spillway has been notched in postglacial time. Several small terrace remnants remain above the postglacially notched portion (see fig. 10), and below the level of the large terrace southeast of the village of Pekin.

This spillway was probably started when the ice was close to the site of the North Viking moraine and extended itself headward as the ice retreated northward. When the ice was north of Stump Lake, part of the drainage collected by the spillway was emptied into Stump Lake and the other part into the glacial Sheyenne River. This continued for some time after the ice left the map area completely, though at a considerably diminished rate. This is indicated by the fact that the terrace remnants in the spillway are higher, for the most part than the mouths of Warwick and Big Stony spillways (see fig. 10).

Jerusalem Outlet

The Jerusalem outlet, the former connection between Devils Lake and Stump Lake is conveniently outlined on figure 8 by the high 1453-foot strandline. It is an irregular, uneven floored channel containing "islands" encircled by the 1453-foot strandline. At present it contains numerous seasonal ponds, and swampy places. When the lakes were connected in prehistoric time flow through the Jerusalem outlet must have been very sluggish because of the irregularities in the channel and the obstructing swamp vegetation.

The threshold of the outlet is between 1445 and 1450 feet above sea level, probably around 1448 feet above sea level. It is either in the S 1/2, sec. 28 or in the S 1/2's of secs. 23 and 24, T. 152 N., R. 63 W. Because of the much greater inflow into Devils Lake than Stump Lake during comparatively dry periods like the present, the outlet seems to have acted like a dam spillway in releasing any excess water into Stump Lake. This threshold maintained a viable water plane around Devils Lake, at an elevation of about 1445 feet above sea level which is now represented by cut cliffs and beaches.

Along part of the northern and southern sides of the outlet a faintly discernable scarp has been cut whose base is about 1470 feet above sea level. The scarp was probably cut during the period of great flow from Warwick and Big Stony spillways before their thresholds were cut down. Many low places in the immediate vicinity of the outlet at elevations similar to that of the scarp must have either been under water or occupied by ice during this time.

Brief Historical Summary

1. The probable cause of the areal juxtaposition of the spillways in the outwash, and the ice-contact deposits, kettle chains, or low places in the North Viking moraine is localization over linear "sags" in the Pierre shale bedrock or an earlier drift topography.

2. The first of the spillways to be active was Seven Mile spillway. This spillway was established when a lower exit for meltwater was opened up in the southern part of the eastern flank of the Heimdal moraine. This spillway was still used, and its floor cut down, when the ice later occupied the site of the North Viking moraine.

3. Minco and Long Lake spillways, if water in any great quantities flowed through them at all, were probably active only during or shortly after the deposition of the Warwick and Oberon outwash, respectively.

4. Crow Hill, Seven Mile, Osago and Harrisburg spillways and the early phase of Big Stony spillways were active during the retreat of the ice across the North Viking moraine. The ice-contact deposits in the proximal parts of Crow Hill and Osago spillways were probably laid down intermittantly during this retreat. There is no proof that they were deposited more or less contemporaneously from their northern to southern ends. Only the eskers associated with Big Stony spillway have a morphology and other features suggestive of "conventional" contemporaneous end-to-end deposition.

5. Of the eight spillways, crossing the North Viking moraine, only Big Stony and Warwick spillways are thought to have drained (a) proglacial lakes at the sites of the bays north of the spillways and (b) the large proglacial lake formed by the unification of glacial Devils Lake and Stump Lake. Later, as the ice left the area, and lake limits similar to to those approximately enclosed by the high 1453-foot strandline were

established, at least Big Stony spillway carried water into the Sheyenne River, an activity which continued into postglacial-prehistoric time.

6. Harrisburg spillway also continued to supply meltwater to the glacial Sheyenne River for some time after the ice left the map area. Some of this meltwater was also discharged into Stump Lake.

PART THREE--POSTGLACIAL FEATURES AND HISTORY OF DEVILS LAKE AND STUMP LAKE

Introduction

In postglacial time the areal extent of both Devils Lake and Stump Lake have varied considerably. The lakes had their greatest postglacial extent during the occupation of the high 1453-foot strandline, as shown in figure 8. Within historic time, the levels of both lakes have been falling more or less continuously. The strandlines ca. 1881-1883 and ca. 1927-1928 are also shown in figure 8. The strandlines in 1953 for Devils Lake were approximately the same as those for the late 1920's; East and West Bays of Stump Lake, however, have since been separated.

This variation in the extent of the lakes is a repetition of at least one desiccation in prehistoric-postglacial time. The evidence for this is provided by buried soil zones in lacustrine sand and gravel deposits, and by recently emerged rooted stumps along the shores of Stump Lake.

The exposure of large tracts of former lake bottom in recent years has revealed many interesting details relative to the origin of the lake shore features. A cursory glance at aerial photographs which show the strandlines of the lakes, or an examination of the new 7 1/2-minute topographic maps of the region is apt to give the impression of considerable reworking of the initial drift topography by lake shore processes. This impression however, is erroneous. With few exceptions most of the spits, beaches and unattached bars of the dry lake bottom are associated with boulders and other coarse material. This indicates that these features initially localized and their gross form determined by irregularities in the underlying drift. Test holes drilled across West Bay of Devils

Lake revealed that the large "bar" in the western and southern part of West Bay is underlain by drift at a shallow depth (Aronow and others, 1953, p. 29-30). The "crenate" and "serrate" pattern of the high strandline in many places also shows the control that the drift has exercised over the lakes'outline.

Boulders and cobbles can be found on almost every acre of the dry floor of Devils Lake. 1/ These are essentially a residuum from the re-

1/ In several places in and around Main Bay of Devils Lake are large boulder accumulations some of whose main axes are perpendicular to the general trend of the strandlines. The boulders may be residual from eroded till promontories on the lake shore or from winnowed till rises of the lake floor. They might also be rubble left upon the melting of stranded icebergs released into the lake when ice covered the northern shores of the lake. The form of the accumulations as seen today is undoubtedly the result of concentration and alignment by winter or spring ice on the lake. Some of these deposits are partly submerged in the deeper parts of Main Bay. Assuming that lake ice is necessary for their concentration, they may indicate a previous lowering of lake level (cf. Simpson, 1916, p. 135).

working by waves and currents of the till which seems to underly most of the exposed portions of the lake bottom (see pls. 20 and 21). The cover of lake sediments on the exposed portions is very thin and patchy in most places. Test drilling however has revealed as much as 50 feet of lacustrine deposits in places; much of this is probably glacial rather than recent in age (see Aronow and others, p. 26-28). The "smoothing" of the lake floor where now exposed has been largely a process of filling in the hollows with lake sediments and "planing down" the high places of the original drift topography.

The sections to follow deal with various aspects of the lakes insofar as they are related to their postglacial history.

Plate 20.--Recently exposed portion of bed of Devils Lake, southwestern shore of Main Bay. Picture taken in late August 1953; area was covered with lake water in the spring of 1953. Note (1) the residuum of cobbles and boulders on the planed till surface which floors the lake bed, (2) mats of dried algae, stranded as lake water receded, and (3) patches of white material, which are crusts of chemical precipitate from lake water, principally sodium sulfate (Glauber salt).

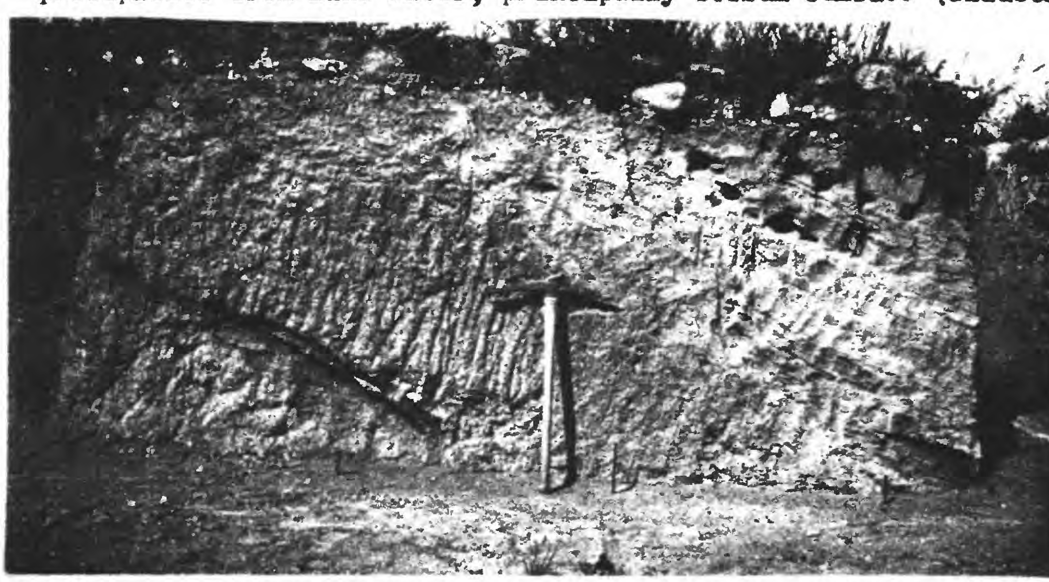


Plate 21.--Till and associated stratified drift in area below high 1453-foot standline. Note surface veneer of coarse material residual from the till after finer size fraction has been removed by waves and currents. Exposure in house excavation in the NW 1/4 sec. 3, T. 154 N., R. 64 W.

Strandlines of Devils Lake and Stump Lake

The term "strandline" has been succintly defined by Flint (1948, p. 163) as

> The line traces on shore rocks, either firm or unconsolidated, by erosional or depositional shore features, developed at mean sealevel or at the level of a lake, whether or not the line is now at mean sealevel or lake level.

The term will be used in this study more or less in accordance with Flint's definition.

Both Devils Lake and Stump Lake are encircled by strandlines which are considerably higher than both the present lake levels and those known within historic time. The two highest strandlines, particularly around Devils Lake, were the ones principally investigated in the field. The highest one is most clearly marked; it generally consists of a cliff cut into glacial till. At the foot of the cliff are usually boulders residual (see pl. 22) from the till. In many places these have been concentrated, in rough alignments, parallel to the cliff, presumably by winter and spring ice when the lake level was equal to the elevation of the cliff base.

Around Devils Lake, the next lowest strandline is generally represented by a beach at the base of which is a small scarp. This strandline is generally somewhat ecomplex in form and certainly is indicative of development during a fluctuating water level.

There has been some confusion in the literature over the elevations of these two strandlines which prompted the writer, as the first basic and logical step in delimiting the prehistoric extent of the lakes, to level these strandlines. This section deals with the results of the leveling, its relation to previous work, the problem of possible tilting, the origin of the strandlines, and possible extensions of prehistoric Devils Lake.

Previous work

Upham (1896), the earliest worker in the Devils Lake region leveled strandlines and recorded (p. 597) the following results, in feet above sea level:

Former strandlines of Devils Lake at Minnewaukan and the city of Devils Lake	1451,	1446,	1439	
Former strandlines at Jerusalem 2/ on Lamoreaux Bay	1454,	1446,	1439	
Former strandlines of Stump Lake	1455,	1443,	1433,	1426

2/ This community, no longer in existance, was in the NW 1/4 sec. 28, T. 152 N., R. 62 W.

It is not clear from Upham's discussion whether he leveled the bases of cut scarps, the tops of depositional features or the upper limits of lacustrine sand and gravel. It probably can be assumed, however, that for the highest strand at least, the elevation given is the base of a cut scarp.

Simpson (1912) leveled strandlines at the City of Devils Lake, Chatautauqua (Lakewood Park), the channel between Stump Lake and the Sheyenne River (footnote, p. 152) and apparently near Grand Harbor (p. 145). The highest strandline, Simpson's "A" stage, was found to have an elevation of 1460 feet above sea level; the next lower strandline, his "B" stage, at 1453.5 feet above sea level. The writer gathers from his discussion (pp. 146-148) that the bases of scarps as well as the tops of beaches were leveled to obtain the elevations of the two highest strandlines.

Easker (1949, pp. 29-30) describes the two high strandlines as occurring at elevations of approximately 1460 and 1440 feet above sea level respectively. Easker apparently did no instrumental leveling and probably the strandline elevations were taken from the nearest 20-foot contour on the 20-foot contour interval 15-minute Tokio quadrangle.

Tetrick (1949, p. 12) reports the existance of "wave-cut morainic knobs" at an elevation of about 1475 feet above sea level in the part of Devils Lake included in the 15-minute Oberon quadrangle. A lower strandline is also indicated as occuring at about 1460 feet above sea level. These elevations likewise were probably determined by recourse to a 20-foot contour interval map (the 15-minute Oberon quadrangle).

Aronow and others (1953) leveled the two highest strandlines along the northern and northwestern shore of West Bay. The leveling was done at or near State Highway 19 from the Benson-Ramsey county line (E 1/2 sec. 34, T. 154 N., R. 66 W.) to the city of Minnewaukan. The rod was held at the break in slope at the bases of cut cliffs. The elevations of the uppermost strands varied between 1450 to 1453 feet above sea level. The majority of elevations fell between 1451 and 1452 feet above sea level. This was referred to as the "J" strandline. The next lower strandline (the "K") was found to have elevations between 1443 to 1447 feet above sea level, the majority between 1444 and 1445 feet. 3/

3/ This summary contains some data not given in the original report.

New strandline elevation data

Since the completion of field work for the report by Aronow and others (1953), additional strandlines in the Devils Lake region were leveled. This new work has consisted of (1) a few more spot elevations and (2) the construction of detailed profiles. Details of spot elevations are given in an appendix, a summary of which is presented here.

(1) Spot elevations at the bases of cut cliffs of the high strandline in an area south of the City of Devils Lake yielded elevations ranging from 1452 to 1454 feet above sea level; the bases of the next lower strandline, from 1443 to 1446 feet above sea level. Other elevations were determined for certain lacustrine sand and gravel deposits (cf. below).

(2) In the course of obtaining the spot elevations, the vague character of the break in slope at the bases of the cut scarps became very apparent to the writer. The disparities of the writer's elevations and Simpson's, since then found largely to be the result of a change in bench mark elevations (cf. below), suggested that some more "objective" method of determining strandline elevations was needed. The method adopted was that of constructing detailed profiles with the leveling instrument directed more or less perpendicular to the strike of the strandlines. Six profiles were constructed: two around Stump Lake and four around Devils Lake. These are shown in figures 17 and 18: their approximate locations shown in figures 19 and 20.

The base of the highest cut scarp was found to range, on the profiles, from about 1452 to 1456 feet above sea level. The two highest elevations were found in profiles A and D, at elevations of about 1455 and 1456 feet above sea level, respectively. These high elevations are believed to result from the presence of thinly covered boulders at the base of the scarps, and slopewash effects (see pl. 22b). The remainder of the elevations all fell between 1452 and 1454 feet above sea level. These data seem fairly consistant with that reported by Aronow and others (1953), with the later spot elevations, and with elevations of sand and gravel deposits (cf. below).

On the profiles made around Devils Lake the crests of beach ridges below the highest scarp ranged in elevations from 1445 to 1448 feet above sea level. Scarps at the bases of beaches were in general poorly developed but seemed to range in elevations from about 1444 feet to 1446 feet above sea level. Where no beaches were developed below the highest strandline, the elevation of the next lowest cut scarp ranged in elevation from 1445 to 1447 feet above sea level.

Around Stump Lake, the strandline below the highest strandline, as shown on profiles A and B has an elevation of about 1442 or 1443 feet above sea level. This is a cut scarp with no associated beach ridge. The writer is not familiar enough with the strandlines around Stump Lake to evaluate the importance of this strandline.

The elevation of the highest strandline for the purposes of discussion and representation on the geologic map (fig. 8) was taken to be about 1453 feet above sea level and is referred to as the high 1453-foot strandline (see pl. 22). The next lower strandline, around Devils Lake, which is marked by beach ridges and cut scarps is referred to as the intermediate or 1445-foot strandline.

A

B

Plate 22.—Views of high 1453-foot strandline. A. Looking northeast, in the NW 1/4 sec. 2, T. 153 N., R. 67 W; north of Minnewaukan. B. Looking southwest, in the SE 1/4 sec. 9, T. 153 N., R. 64 W.; note boulders around base of cliff; Profile was made just outside of right edge of photograph.

Discrepencies with Simpson's data

The discrepancy between the writer's elevations for these strandlines, for it is obvious in the field that the same ones were leveled, and Simpson's seem for the most part to be due to error(s) in the elevation(s) of Simpson's starting point(s). At least one of these, an old USGS bench mark near Chatautauqua (Lakewood Park--see fig. 8) was then given an elevation which was 4.55 feet higher than more recent leveling has indicated. 4/

4/ This benchmark is referred to by Simpson (1912) on p. 120 of his report. It is probably no longer in existance. The old elevation was given as 1439.1 feet above sea level; the present elevation, according to datum of 1929 is 1434.55 feet above sea level, a difference of 4.55 feet. The zero datum of the lake level gage referred to on p. 152 of his report was computed from the incorrect elevation. These matters have been greatly clarified to the writer by correspondance with H.M. Erskine of the Surface Water Branch of the U.S. Geological Survey.

This readjustment of 4.55 feet accounts for most of the difference between the 1453-foot elevation obtained by the writer and the 1460-foot elevation obtained by Simpson for the high strandline. The rest of the difference, about two-and-a-half feet, can be ascribed, no doubt, to lack of uniformity in judging where the break in slope at the base of the scarp actually occurs, and also, possibly, to errors in other bench marks used by Simpson.

Simpson obtained a difference of 6.5 feet between the elevations of his "A" and "B" strandlines which is certainly of the same order of magnitude as the difference of about 8 feet between the somewhat arbitrary elevations for the strandlines established by the writer.

Upham's data and the problem of tilting

Upham (1896, p. 596-597) noted a progressive rise from west to east in the elevation of the highest strandline: from Minnewaukan and the city of Devils Lake (1451 feet) to Jerusalem on Lamoreaux Bay (1454 feet) and to Stump Lake (1455 feet). The outlet of Stump Lake into the Sheyenne River he determined to be 1454.6 feet above sea level. Concerning this rise in strandline elevation Upham says:

> A slight differential uplifting, like that which gave rise to the beaches of Lake Agassiz their northward and eastward ascents, is shown by the glacial [5/] shore-line, which is now level through its western 18 miles from Minnewaukan to the city of Devils Lake, but thence rises eastward about 3 feet in a distance of about 16 miles to Jerusalem, and 1 foot more in the next six miles southeast to the channel of the outlet.

5/ Upham believed this high strand to have been occupied only during Pleistocene time.

Simpson (1912, p. 152) concerning Upham's views on tilting says:

> ...his belief that tilting had occurred between Devils Lake city and Jerusalem outlet--a theory for which no corroborative evidence could be obtained by the author. Careful leveling to the highest shore line at Devils Lake, Chatautauqua and at the Tolna outlet [Big Stony spillway] reveal an elevation of 1460 feet at each point.

The elevation of the high strandline around Stump Lake, given by Upham as 1455 feet above sea level, coincides with the one obtained by the writer in profile A. Some doubt, however, is placed on the validity of Upham's data by his description of the place from which the levels were run. The site is described by Upham (p. 597) as follows:

> The elevations of the former shores of Stump Lake were determined by leveling on the northern slope of a promontory of till, which was an island at the time of the higher shore-lines, rising to 1458 feet in the east part of section 21, township 151, range 61.

The writer has located this hill (see fig. 15) on the 7 1/2-minute Pekin NW quadrangle. The top of the hill is encircled by a 1460-foot contour. The unpublished field sheet for the quadrangle gives an elevation of 1462 feet above sea level for the top of the hill. This discrepancy would raise all of Upham's elevations for the strandlines of Stump Lake by four feet. This would be at considerable variance with the writer's elevations.

The writer believes that the 1455-foot elevation of the high strandline in profile A to be due partly to slump and slopewash and that the actual strandline elevation is more correctly indicated in profile B. Also an examination of the 1455-foot contour on the 5-foot contour interval maps covering Stump Lake (Pekin NE, Pekin NW, Pekin and Tolna 7 1/2-minute quadrangles) shows it to be somewhat "crenulated" in a fachion which is probably the result of erosion of the over-steepened "riser" of the scarp. The 1450-foot contour is definitely "smoother".

The writer's data shows no clear indication of a rise in the high strand from west to east. The lack of clear cut breaks in the topography of the strands, and the ease with which a clear-cut break might be masked by erosion and slopewash perhaps makes the use of this type of data to indicate tilting, in the Devils Lake region, of somewhat dubious value. Any tilting in the Devils Lake region, as thought of by Upham, that may be present must be less than about 3 feet in the 45-mile distance from Minnewaukan to East Bay of Stump Lake.

Probably the prime difficulty in discerning tilting is the presumed strike of the isobases. Flint (1947, p. 420) shows a map on which are plotted in the Devils Lake region isobases for eastern North Dakota taken in part from Upham's leveling of beaches in Lake Agassiz. These isobases strike approximately N. 65° W. and thus sub-parallel the strike of the Devils Lake-Stump Lake complex of lakes. This suggests that evidence of tilting, if any, must be obtained by comparative leveling of the northern and southern shores of Devils Lake and Stump Lake, respectively. In most places, this distance is less than 12 miles. Tilting in Lake Agassiz, as determined by Upham (1896, p. 475), is in the order of magnitude of from half a foot to two feet per mile for the highest (Herman) beach. This would give a difference in elevation between the high strandline on the northern and southern shores of from 6 to 12 feet. This difference in elevation is not borne out by the 5-foot contour interval maps.

This problem should be further investigated with a pattern of profiles arranged north and south of an imaginary east-west axis through the complex of lakes which would be better designed to pick up evidences of tilting (cf. below, next section).

Possible extensions of prehistoric Devils Lake in the northwest part of the map area

E. J. Babcock in his report on the water resources of the Devils Lake region (1902, p. 213) believes that Devils Lake extended as far northwest as the village of Knox (see fig. 23) in Benson County, an observation the writer is unable to confirm. Probably the lake bottom extended upstream in Little Coulee for some distance outside the map area.

Babcock also notes (p. 227) that the lakes in the smaller complex of lakes in the northwestern part of the map area were once larger than at present:

> ...There is little doubt that Lake Irvine, at no very remote period, extended from one mile to three miles farther east, and stretching toward the south, widened out irregularly three or four miles more towards the southeast. At this time Lac aux Mortes, Twin Lakes, and Dry Lake were probably connected and formed one sheet of water, which may have been continuous with Cavanaugh and Sweetwater lakes, thus forming a large body of water which stretched out with irregular shore line toward the southeast, nearly parallel to the present Devils Lake, presenting an appearance similar to the Devils Lake of today. This old lake and Devils Lake were doubtless connected by a long, narrow bay, filling all the low land of the coulee between Lake Irvine and Devils Lake.

The writer is able to confirm the observations that large areas in the vicinity of these lakes are flat and are surrounded by what appear to be cut scarps. Higher places are encircled by cut scarps; there is little doubt that many of these were islands.

The writer has terminated the 1453-foot strandline in most places at the 48°15' parallel (see fig. 8), the northern limit of topographic map coverage. Some places in the northern part of the Grahams Island 15-minute quadrangle have also been questionably included in the areas below the 1453-foot strandline although they are not connected with other parts of the strandline within the map area.

The writer considers it a strong possibility that much of the flat area in the vicinity of these lakes, and the water surfaces of these lakes, are below the elevation of the 1453-foot strandline. The lake flat surrounding Mauvais Coulee also continues outside the map area, probably at least as far as Churchs Ferry. The rather extensive swamp, for example, now occupying the bed of Dry Lake has an elevation of about 1450 feet above sea level. The water surfaces of Cavanaugh Lake and Sweetwater Lake, however, have elevations of 1456 and 1459 feet above sea level, respectively (see Grand Harbor and Sweetwater Lake 7 1/2-minute quadrangles); hence it is doubtful if these lakes were once continuous with a prehistoric Devils Lake.

No data is available on the elevations of the water surfaces of Lake Irvine, Lac aux Mortes, and Twin Lakes, or of the flat areas surrounding them.

The area around this smaller complex of lakes would make an excellent place to determine the possible amount of postglacial tilting. The distance from the southern end of West Bay of Devils Lake to Lac aux Mortes is about 25 miles; a line along which this distance may be measured is more or less perpendicular to the presumed trend of the isobases through the Devils Lake region (cf. above). Scarps in the vicinity of this smaller complex of lakes may be cut in a multiple or complex manner, indicative of an occupation during late glacial times, prior to tilting; this may have been succeeded, after tilting, by a second occupation at the same absolute elevation. On the other hand, if this area has been greatly tilted, the northernmost parts of the strandline may not have been reoccupied at all in the postglacial-prehistoric filling of the lakes.

Origin of the high and intermediate strandlines

Upham (1896, p. 595-597), Simpson (1912, p. 146-147) and the writer believe that the threshold of Big Stony spillway, an old glacial spillway connecting the east end of West Bay of Stump Lake, maintained the water plane at whose altitude the high strandline was cut (see fig. 15). The field sheet of the 7 1/2-minute Devils Lake Mountain quadrangle gives a spot elevation of 1459 feet above sea level for the area of the threshold. The approximately six feet of difference between the elevations of the strandline and the threshold may be explained by several factors, each of which is partly important:

(1) The threshold portion of the spillway is very flat and, although it is a divide, has received considerable amounts of colluvial fill (cf. Upham, 1896, p. 597). This is evident in the field from its uneven, irregular surface.

(2) An examination of table 1 shows that more than 9 feet of annual variation of lake level have been recorded. The usual observed annual variation is from one to two feet. With the lake water at this elevation less saline, and with large shoaling areas supporting rooted vegetation, transpiration probably caused considerable variation in prehistoric lake level. The strandline as seen today can be considered as representing an average of the lake level for a long period of time.

(3) The elevation of the 1453-foot strandline was obtained from the break in slope at the bases of cut cliffs. For any waves to have eroded the shore, the break in slope must have been lower than the lake level. Thus it can safely be assumed that the water plane was at least a little higher than the break in slope. This would also tend to narrow the difference between the elevation of the threshold and the strandline.

The elevation of the water plane of the 1445-foot intermediate

Table 1.--Reported maximum and minimum observed altitudes of Devils Lake[1]

(Referred to datum of 1929)

<table>
<tr><th>Year</th><th>Maximum</th><th>Minimum</th><th>Year</th><th>Maximum</th><th>Minimum</th></tr>
<tr><td>1867</td><td colspan="2">[2] 1,438.3</td><td>1924</td><td colspan="2">1,416.2</td></tr>
<tr><td>1879</td><td colspan="2">1,434.6</td><td>1925</td><td colspan="2">1,414.8</td></tr>
<tr><td>1883</td><td colspan="2">1,434.4</td><td>1926</td><td colspan="2">1,413.7</td></tr>
<tr><td>1887</td><td colspan="2">1,427.0</td><td>1927</td><td colspan="2">1,413.6</td></tr>
<tr><td>1890</td><td colspan="2">1,424.6</td><td>1928</td><td colspan="2">1,412.8</td></tr>
<tr><td>1896</td><td colspan="2">1,424.6</td><td>1929</td><td>1,412.2</td><td>1,411.3</td></tr>
<tr><td>1901</td><td>1,424.0</td><td>1,423.2</td><td>1930</td><td>1,411.4</td><td>1,411.0</td></tr>
<tr><td>1902</td><td>1,425.8</td><td>1,424.6</td><td>1931</td><td>1,411.4</td><td>1,410.0</td></tr>
<tr><td>1903</td><td>1,424.8</td><td>1,423.4</td><td>1932</td><td>1,410.9</td><td>1,409.4</td></tr>
<tr><td>1904</td><td>1,425.0</td><td>1,424.2</td><td>1933</td><td>1,410.2</td><td>1,408.2</td></tr>
<tr><td>1905</td><td>1,425.2</td><td>1,424.2</td><td>1934</td><td>1,408.3</td><td>1,406.5</td></tr>
<tr><td>1906</td><td>1,424.6</td><td>1,423.2</td><td>1935</td><td>1,406.9</td><td>1,406.1</td></tr>
<tr><td>1907</td><td>1,424.2</td><td>1,423.0</td><td>1936</td><td>1,406.7</td><td>1,404.5</td></tr>
<tr><td>1908</td><td>1,423.4</td><td>1,421.8</td><td>1937</td><td>1,404.3</td><td>1,403.2</td></tr>
<tr><td>1909</td><td>1,422.6</td><td>1,421.6</td><td>1938</td><td>1,403.4</td><td>1,402.1</td></tr>
<tr><td>1910</td><td>1,421.4</td><td>1,420.2</td><td>1939</td><td>1,402.7</td><td>1,401.5</td></tr>
<tr><td>1911</td><td>1,420.4</td><td>1,420.2</td><td>1940</td><td>1,402.3</td><td>1,400.9</td></tr>
<tr><td>1912</td><td>1,421.4</td><td>1,420.4</td><td>1941</td><td>1,402.8</td><td>1,402.2</td></tr>
<tr><td>1913</td><td>1,421.8</td><td>1,420.4</td><td>1942</td><td>1,404.5</td><td>1,404.0</td></tr>
<tr><td>1914</td><td>1,420.6</td><td>1,419.6</td><td>1943</td><td>1,404.7</td><td>1,403.4</td></tr>
<tr><td>1915</td><td>1,419.2</td><td>1,418.4</td><td>1944</td><td>1,404.0</td><td>1,403.0</td></tr>
<tr><td>1916</td><td>1,419.6</td><td>1,418.6</td><td>1945</td><td>1,404.7</td><td>1,403.5</td></tr>
<tr><td>1917</td><td>1,418.8</td><td>1,417.2</td><td>1946</td><td>1,405.0</td><td>1,403.3</td></tr>
<tr><td>1918</td><td>1,417.4</td><td>1,416.4</td><td>1947</td><td>1,403.6</td><td>1,403.0</td></tr>
<tr><td>1919</td><td colspan="2">1,418.0</td><td>1948</td><td>1,405.2</td><td>1,404.2</td></tr>
<tr><td>1920</td><td>1,417.6</td><td>1,416.2</td><td>1949</td><td>1,407.2</td><td>1,405.6</td></tr>
<tr><td>1921</td><td>1,416.7</td><td>1,416.6</td><td>1950</td><td>1,415.0</td><td>1,406.6</td></tr>
<tr><td>1922</td><td colspan="2">1,417.2</td><td>1951</td><td>1,415.5</td><td>1,414.3</td></tr>
<tr><td>1923</td><td colspan="2">1,416.3</td><td>1952</td><td>1,414.5</td><td>1,412.5</td></tr>
</table>

1/ Swenson and Colby, table 1 (in preparation).
2/ A centered number is for a single observation during the year.

strandline around Devils Lake was probably determined, as thought by Upham (1896, p. 595) and Simpson (1912, p. 147-148) by the threshold of the Jerusalem outlet between Devils Lake and Stump Lake. The greater inflow into Devils Lake sustained a somewaht more constant water level despite probable high evaporation and transpiration losses. Any excess water was discharged into Stump Lake. The smaller catchment area of Stump Lake indicated that most of its water was probably received for the most part by overflow from Devils Lake.

The channel of the Jerusalem outlet is, of course, outlined by the 1453-foot strandline. Most of the channel lies below the 1450-foot contour and above the 1445-foot contour. Both of these contours when traced through the channel show an irregular pattern, with many depressions and narrow connecting necks.

The threshold could not be clearly located but it is either in the S 1/2 sec. 28 or the S 1/2's secs. 23 and 24, T. 152 N., R. 62 W. The threshold in the second possible location has a minimum elevation of 1448 feet above sea level as determined from the field sheet of the Devils Lake 7 1/2-minute quadrangle. No precise minimum elevation could be determined for the first location.

The uneven floor of the channel suggests that no great volume of water passed through it at any elevation less than 1450 feet above sea level. Flow through the channel, when active, must have been extremely slow because of obstruction by vegetation.

The beaches and cut scarps at about 1445 feet above sea level shown on the profiles (figs. 17 and 18) made around Devils Lake were probably developed under conditions of a fluctuating lake level, only the maximum elevation of which was definitely determined.

A note on the map representation of the high strandline and strandlines around isolated basins

The geologic map (fig. 8) of the Devils Lake map area shows only the high strandline. Five-foot contour interval maps were available for almost the entire area of the lakes shown on the map. The high strandline shown on the map represents essentially a contour interpolated between the 1450-foot and 1455-foot contours. This interpolated contour is believed to vary in elevation from about 1452 to 1454 feet above sea level. In places where the contours were a considerable distance apart, aerial photographs were used to check the contouring. Where sand and gravel deposits were associated with the strandline, the strand was, in most places, drawn to indicate the upper limit of this material. The areal location of the strandline as shown on the map is believed in most places, to be within one-tenth of a mile of its actual location on the ground.

Contour-map coverage was not available for the portion of the map beyond the western edge of the Grahams Island 15-minute quadrangle (Tilden and Minnewaukan East 7 1/2-minute quadrangles). The strandline in the vicinity of the city of Minnewaukan was interpreted from aerial photographs and later spot-checked on the ground during the preparation of the report by Aronow and others (1953). Some spot elevations were also available as a by-product of test-hole leveling in this area. The strandlines west of the northern part of the Grahams Island 15-minute quadrangle were interpreted from aerial photographs; the strandlines were clearly discernable and their locations on the map is thought to be fairly accurate. Strandlines north of the Grahams Island 15-minute quadrangle were for the most part very difficult to interpret from aerial photgraphs because of the very flat topography on which they were developed; not very much was included on this part of the map.

Many times in the compilation of the map the problem arose concerning how much area to include within the high strandline. The most difficult problem was that of a large area of lake bottom below the 1450-foot contour which was connected to the main part of the strandline by a narrow neck of 1455-foot contours. In almost all places these were made confluent with the main parts of the lake on the assumption that during this period of high lake level these were almost certainly filled with water and separated from the main parts of the lake by shoaling thresholds or contained fairly permanent swamps. Some areas near the lake basin are below the 1455-foot contour and not continuous with the main strandline. These are shown on the map by a special strandline symbol. During the high lake stage, it was probable that these basins were occupied by lakes which probably overflowed into Devils Lake in the spring.

Dry lake beds surrounded by cut scarps whose bases are above the 1455-foot contour are also shown by this special symbol. The two largest of these are located north of the City of Devils Lake and southeast of the village of Crary, respectively. (see fig. 8). The dual use of this special symbol is clarified on figure 8 by the giving of the strandline elevations for those basins higher than the 1455-foot contour.

Buried Soils and Fossils in Lacustrine Deposits around Devils Lake, North Dakota

Part of the evidence for the last occupation of the high 1453-foot strandline in postglacial time and for a previous lowering of lake level consists of buried soils and associated fossils in certain lacustrine sand and gravel deposits. These deposits were examined in the course of the detailed mapping of the Devils Lake and Grahams Island 15-minute quadrangles. Other such deposits may of course exist in other parts of the Devils Lake region.

The pits in which these buried soils are exposed can be divided into two general geographic groups. The two groups, the pit designations their locations and highest elevations of sand and gravel found in them are given in table 2.

The pits in group A are among the largest and most extensively exploited lacustrine sand and gravel deposits in the Devils Lake region. They also contain the best exposures. The pits have been opened in groups of tombolos, bay-mouth bars, and spits, deposited at the junctures of Main Bay, Mission Bay and East Bay (see figs. 3 and 21).

The pits in group B have been opened in two spits on the western side of the northern part of Sixmile Bay (see figs. 3 and 22).

When the Devils Lake region was first settled in the early 1880's, the lower parts of these deposits were under water. As the lakes dried up, the tombolo, spit and bay-mouth bar forms of some of these deposits have been exploited in the location of highways and railroads.

Group A

The maximum thicknesses of sand and gravel exposed in these pits in group A ranges from about 8 feet, in pit (e) to more than 30 feet in pit (a).

Table 2

Data on lacustrine sand and gravel deposits containing buried soils

Group and name	Location	Highest elevation of deposit around pits, feet above sea level	Source
Group A			
Pit (a)	NE 1/4 sec. 12, T. 152 N., R. 65 W.	1453.4	instrumental leveling
Pit (b)	SE 1/4 sec. 6, T. 152 N., R. 64 W.	1451.6	"
Pit (c)	SW 1/4 sec. 5, T. 152 N., R. 64 W.	1450 ±	5-foot contour map
Pit (d)	NE, NW, & SE 1/4's sec. 32, T. 153 N., R. 64 W.	1425 ±	"
Pit (e)	NE 1/4 sec. 7, T. 152 N., R. 64 W.	1440 ±	"
Group B			
Pit (f)	S 1/2 sec. 22, T. 154 N., R. 65 W.	1430 ±	"
Pit (g)	NE 1/4 sec. 33, T. 153 N., R. 65 W.	1445 ±	"

All of these pits were floored with sand and gravel and hence these deposits are actually thicker than the available exposures indicate.

The highest elevations of these deposits formed are given in table 2. They range in elevation from 1425 feet to more than 1453 feet above sea level. The maximum elevations are equal to that of the high strandline around Devils Lake and Stump Lake.

The material in these deposits range in size from that of a fine clayey sand to cobbles about 6 inches in diameter (see pls. 23 and 28). The granule, pebble and cobble sizes are rarely well rounded; most of these are subangular to subrounded.

Individual beds are rarely more than two feet thick and can be traced for many tens of feet in the walls of the pits. The beds for the most part are horizontal or have a very gentle dip.

In addition to these general features, three other features of some importance in the genesis of these deposits may be considered:

(1) the soil zones intercalated in the deposits,

(2) beds of sand and gravel which contain distinctly inclined laminations,

(3) beds of very silty and clayey sand.

(1) The buried soils are intercalated with beds of coarser material (see pls. 24, 25, and 26). In many places the coarser material grades into the lower contact of the humified zone. These humified zones range in thickness from less than an inch to 8 inches. Individual soils have a lateral extent of more than 40 feet, as traces in the walls of the pits. Soils were seen to merge in the walls of the pits. In general, the thicker zones were seen in pits (a), (b), (c) and (e), and the thinner zones in pit (d).

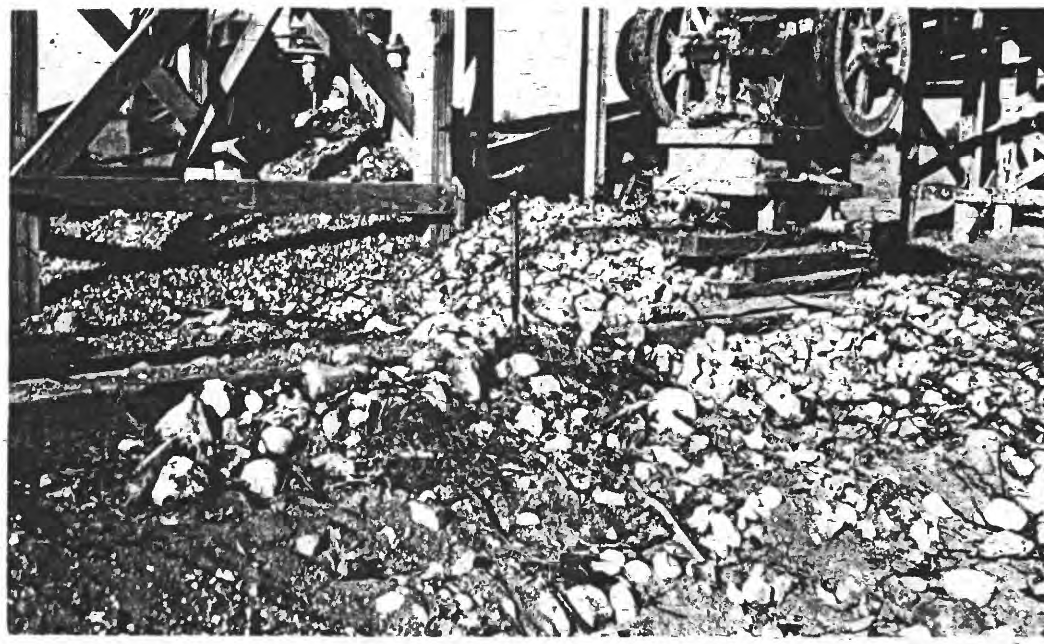


Plate 23.--Over-size material from pit (a). Note coarseness of some of material. Top of shovel is about 6 inches across. This reject pile contains numerous bone fragments which are not clearly visible in this photograph.

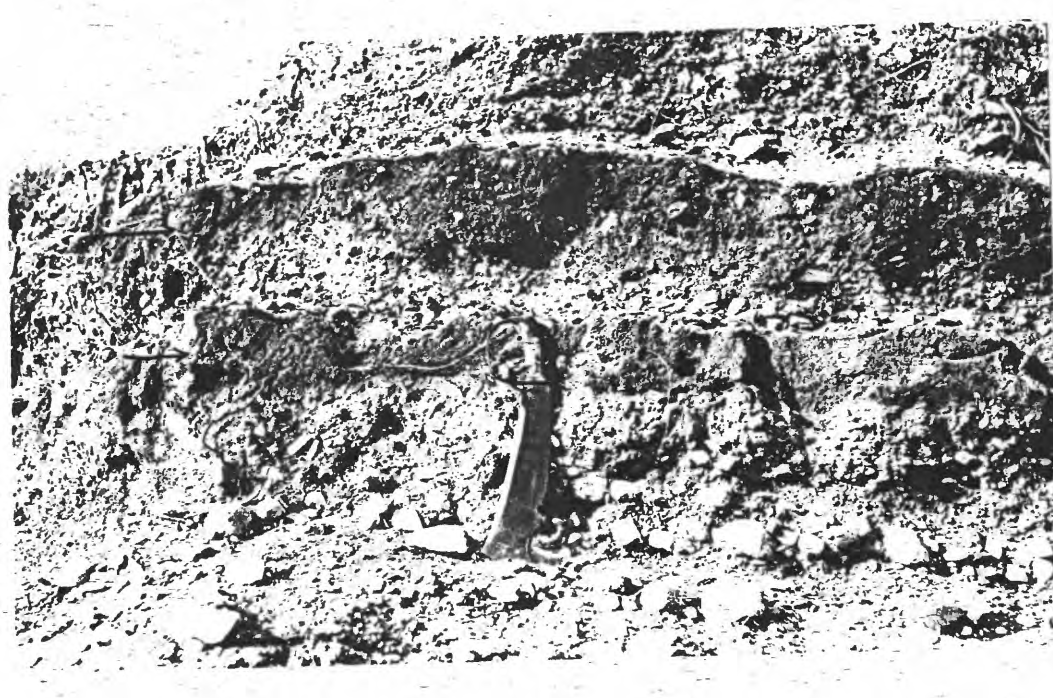


Plate 24.--Buried soils exposed in pit (a). Arrows indicate soils.

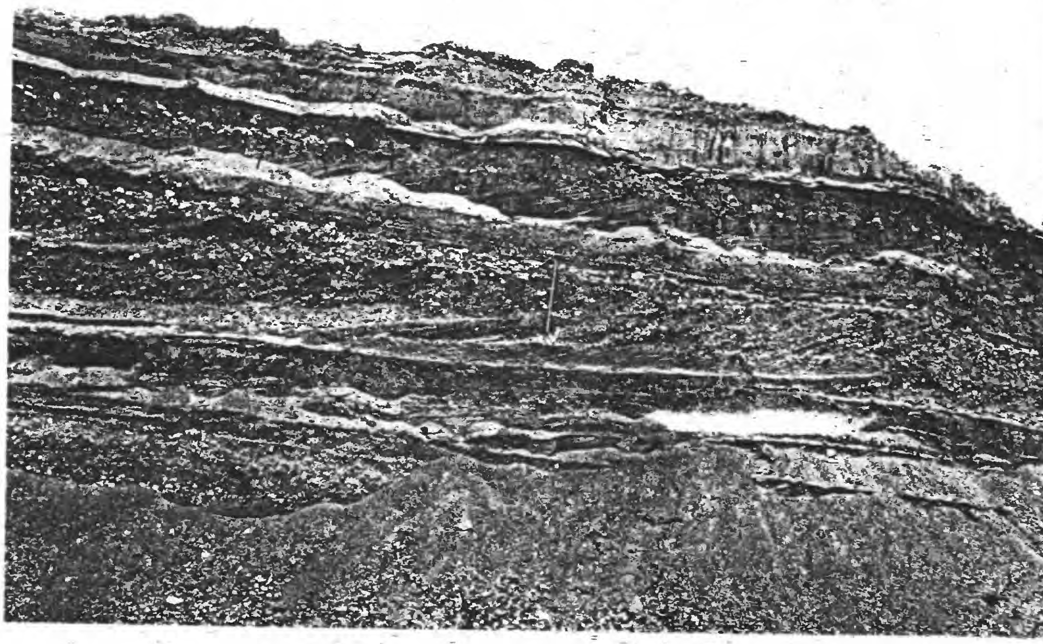


Plate 25.—Succession of buried soils, beds with inclined laminations, and more-or-less horizontal beds exposed in pit (a). These beds and soils were probably developed during a period of intermittently rising lake level.

Plate 26.--Buried soils exposed in pit (c). Arrows indicate soils. Bracketed material in spoil dumped on surface soil.

Elevations of soils were determined in pits (a) and (b) by means of instrumental leveling. In pit (a), the surface of whose deposits rises to over 1453 feet above sea level, they ranged in elevation from 1429 to 1451 feet above sea level. At least four distinct soils were identified below the surface at about 1451 feet, 1449 feet, 1442 feet and 1435 feet above sea level, respectively. The lowest soil, at about 1429 feet above sea level, may be continuous with one at a higher elevation. Soils were also found at elevations between those given here but owing to the lack of continuous lateral and vertical exposures, their stratigraphic positions could not be determined.

For comparison samples of the recent surface soil and one of these buried soils were submitted to the laboratory of the Wisconsin Soil Survey. The recent surface soil was found to have an organic matter content of 2.8 percent; the buried soil, 1.8 percent.

In pit (b), the surface of whose deposits rises to about 1452 feet above sea level, two buried soils were found at about 1444 feet and 1449 feet above sea level, respectively.

Elevations of buried soils in the other pits in this group are, of course, lower than the surface elevations given in table 2. Buried soils at elevations less than 1425 feet above sea level, in pit (d), should be particularly noted.

(2) in pit (a), and to a minor extent in the other pits, beds are exposed that exhibit inclined laminations of sand, granules and small pebbles (see pl. 27). These are in most places over- and underlain by more or less horizontal beds. Typically, a bed with inclined laminations is underlain by a fairly well sorted deposit of sand, or sand and gravel. The contact between these beds is very sharp. The upper contact may be

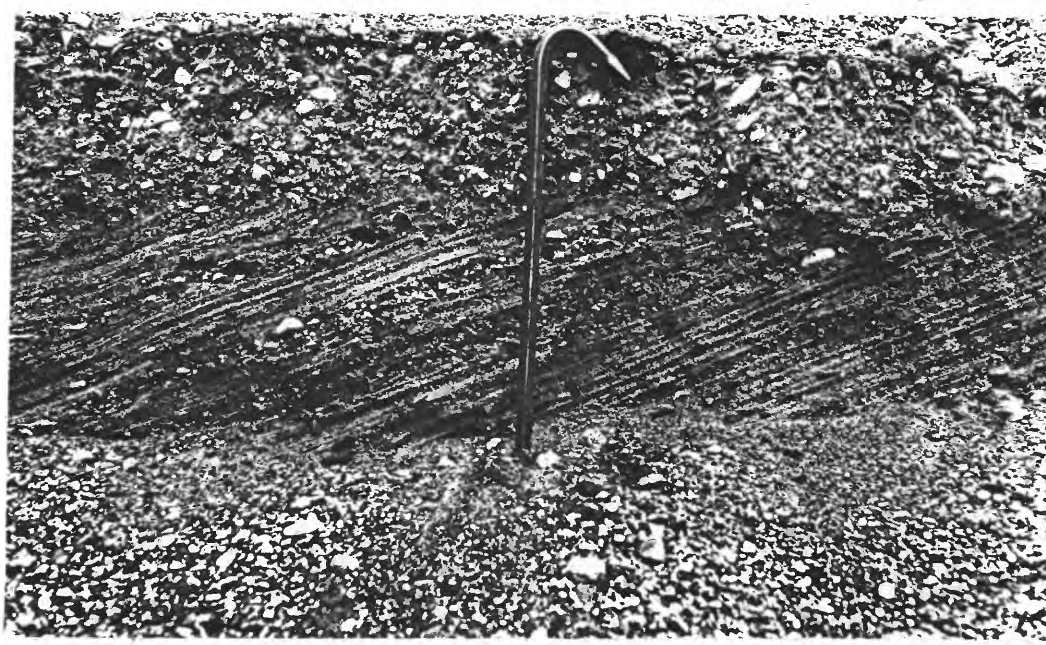


Plate 27.--Bed with inclined laminations, exposed in pit (a).

uneven, and seems to indicate some reworking of the underlying material before or during the deposition of the upper bed. The upper bed may be poorly sorted and contain sizes from sand to very coarse gravel.

The inclined laminations dip uniformly to the east from about 25° to 32°. Strikes range from N. 7° E. to N. 30° E. Laterally the laminations merge into horizontally bedded materials.

(3) Occasional beds of silty and clayey sand ranging in thickness from thin films to 10 inches are exposed in the walls of pit (a). These beds extend laterally for distances greater than 20 feet. The upper surfaces of these beds is fairly level; the lower, uneven. The upper part of these beds is slightly darkened by organic material; the darkening fades out gradually towards the bottom of the beds. Typically these beds are underlain by sandy gravel deposits (see pl. 28).

Plate 28.--Clayey beds exposed in pit (a). These are thought to be lagoonal deposits.

Origin of deposits in group A

The ultimate source of the materials in these deposits is undoubtedly the glacial drift. Wave-work eroded the shores of the lake, winnowed out most of the clay and silt fines, and concentrated the coarser sand to cobble deposits. Reworking of these deposits by the lake water has not gone on for very long nor has it been very vigorous judging from the small number of well-rounded pebbles.

At present, the prevailing wind in the Devils Lake region is from the northwest. It can reasonably be assumed that this same prevailing wind blew at the time of the deposition of these deposits. Waves traveling from a point northeast of Grahams Island southeast to the eastern edge of Main Bay had a fetch of about eight miles (see fig. 8), and thus could strike the juncture of Main Bay with the other bays with considerable force; thus eroding the drift deposits and laying down the deposits exposed in the pits. The strikes of the main axes of these deposits are no doubt the resultants of this prevailing wind from the northwest and rotary currents set by this wind in East Bay and Mission Bay.

The occurrance of the inclined laminations and clayey beds in pit (a) can be interpreted in light of the tombolo form of the deposit in which the pit was opened. The tombolo strikes roughly N. 40° E., which is subparallel to the strike of the inclined laminae (N. 7° E. to N. 30° E.) and which is perpendicular also to the wind from the northwest. It is believed that the long axis of the tombolo was continually shifting more or less parallel to itself depending on the supply of material, lake stage, and the strength of the wind from the northwest. The explanation that best fits the available data is that the inclined laminations were deposited in small delta-like structures on the lagoonal (eastern) side of the tombolo by over-topping storm waves, as described by Thwaites (1946, p. 36) and Thompson (1937, pp. 746-747). Between or during storms and during periods of high water the surface of these inclined laminations may have been truncated, reworked and winnowed, leaving the coarse, poorly sorted material above them.

The clayey beds probably represent deposits in the bottom of the lagoon. The organic material in these clayey beds probably accumulated when the lagoon was shallow and swampy, or totally emergent. The very irregular lower surface has somewhat the involuted character of frost-disturbed deposits. However, any possible frost action seems to have not affected the upper surface of these beds. The uneven contact is probably principally the result of channeling in the surface of the underlying gravel.

The genesis of the soils zones, in relation to the deposits in which they are intercalated can best be understood in terms of the deposits exposed in pit (a).

Plate 27, for example, shows a sequence of beds in pit (a) about 18 feet thick which includes buried humified zones, beds with inclined laminations, and horizontal beds. Such a sequence could have only been deposited as the lake level rose gradually, intermittantly and with slight recessions. As the axis of the tombolo shifted either inclined laminations or horizontal beds were deposited during storms or rapid rises in lake level. When the lake level receded, or remained stationary, the surface of the deposits was emergent. Plants grew, organic detritus accumulated, and a soil developed. During later storms, after a rise of lake level, or during a rapid rise in lake level, the soil was buried by the new deposits of sand and gravel. The merging of buried soil and the occasional unconformable relations between groups of beds containing soil zones suggest that the areal form and cross-section of the tombolo must have been changing with each rise in lake level.

It is not known how long a time was necessary for the development of any of these buried soils. Their ranges of thicknesses may be the result of unequal periods of development or erosion before burial. The recessions or stationary periods of lake level during which they were formed may have been annual: a vernal rise in lake level and an autumnal recession. During the following spring, lake level may have been higher than during the previous spring and the humified zone partly eroded and buried. The duration of periods of emergence may have also been in terms of years. The higher percentage of organic matter in the recent surface soil as opposed to one of the buried soils (cf. above) may be indicative of a longer period of exposure of the surface soil.

The organic material in the buried soil zones was probably not all "residual" in origin, that is, accumulated owing solely to plants growing on the surface. At the present time the material found at the immediate water's edge of Devils Lake and other lakes in the region is largely organic detritus such as short lengths of reedy material and twigs. These may be cast up great distances above the water line by storms particularly in the spring. During the seasonal recession of the lake level, especially in places where the shore is very shelfing, algae which had been growing in the shallow sunlit water may be stranded above the water line in the form of large mats (see pl. 20). Also when the lake level was higher than at present, organic production, and hence organic detritus, was undoubtedly much more plentiful because (a) the water was less mineralized and (b) the higher lake levels created numerous shoaling areas which probably supported rooted vegetation.

Some of the upper soil zones exposed in pit (i) may have been developed in rather recent historic time, as opposed to the prehistoric development of the soil zones in the other pits. The surface elevation of the material in which pit (i) has been opened is about 1425 feet above sea level. An examination of the hydrograph of recent lake levels (fig. 26) shows a stabilization of lake level around an elevation of 1425 feet above sea level for about 16 years (1890-1906). The upper soil zones exposed in this pit may have been developed and buried as the result of seasonal fluctuations and storms during this comparatively stable period.

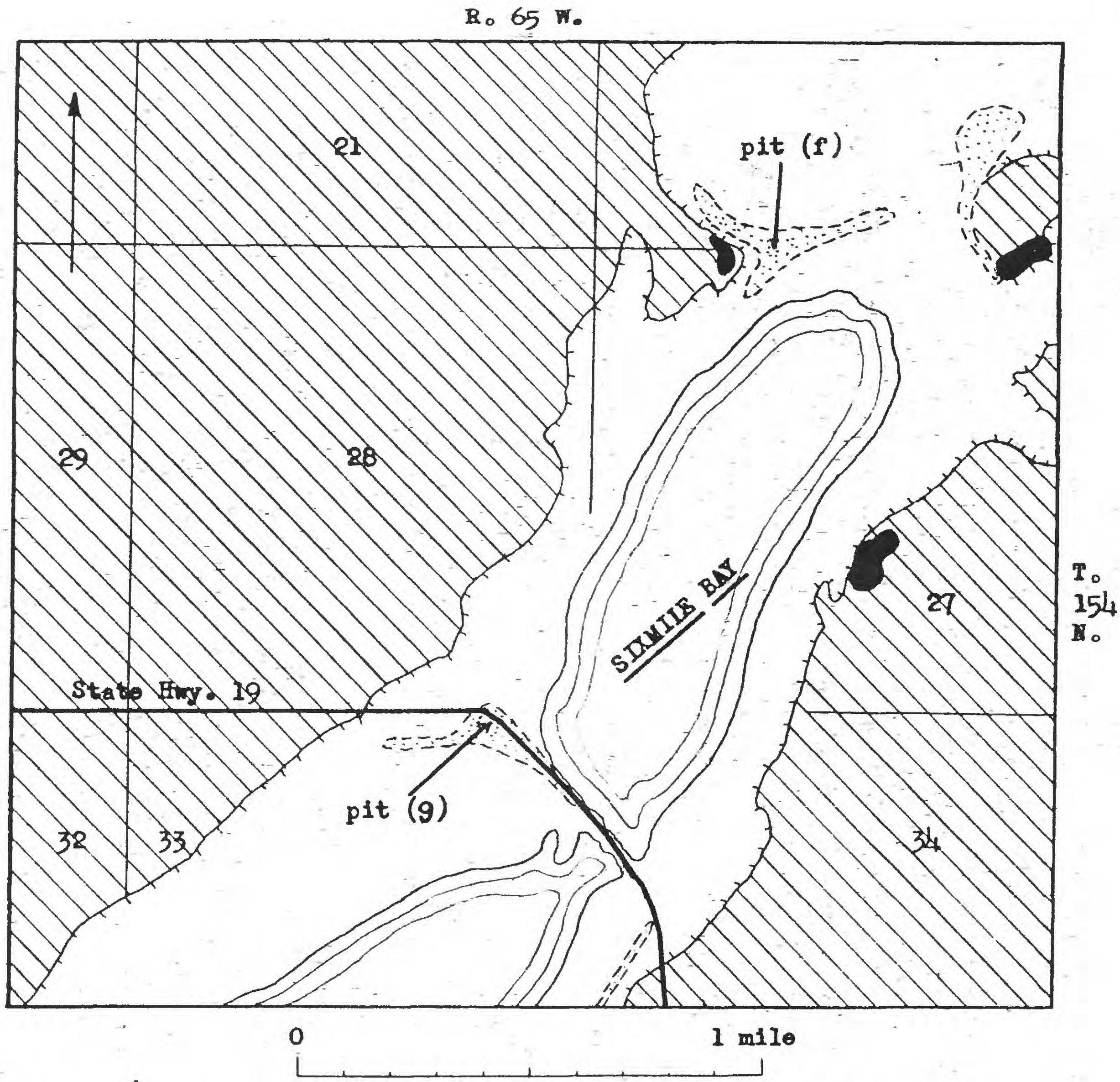


Figure 22.--Geology in vicinity of sand and gravel pits in group B.

Explanation

Deposit of ice-contact stratified drift

Ground moraine

Lacustrine deposits and modified drift

Lacustrine sand and gravel

High 1453-foot strandline

Sand and gravel pit

Note: morainal ridges omitted from ground moraine areas.

Group B

The soils exposed in the pits of group B (see fig. 22) are in general rather thin and poorly exposed. Probably not more than two soils are represented in either pit. They are less than an inch in thickness (see pl. 29).

The elevations of the sand and gravel (see table 2) were found to be about 1430 feet above sea level for pit (f) and about 1445 feet for pit (g). Elevations of buried soils were of course lower than theses surface elevations.

In pit (f) about 17 feet of sand and gravel are exposed, and about 12 feet in pit (g).

The deposits in which these pits are excavated are tied on the landward ends to the western shore of Sixmile Bay. These spit-like features have tended to segment Sixmile Bay. The Bay strikes roughly N. 40° E., and is approximately perpendicular to the present-day prevailing wind. It seems plausible to assume that these deposits were initially localized by irregularities in the underlying drift topography of the lake basin. As these deposits accumulated, they tended to separate Sixmile Bay into a series of oval basins by shoreline processes discussed by Raisz (1934, p. 846-7).

The conditions under which the humified zones exposed in the pits of group B were developed and buried were undoubtedly similar to those of group A.

Plate 29.--Buried soils exposed in pit (g). Arrows indicate soils.

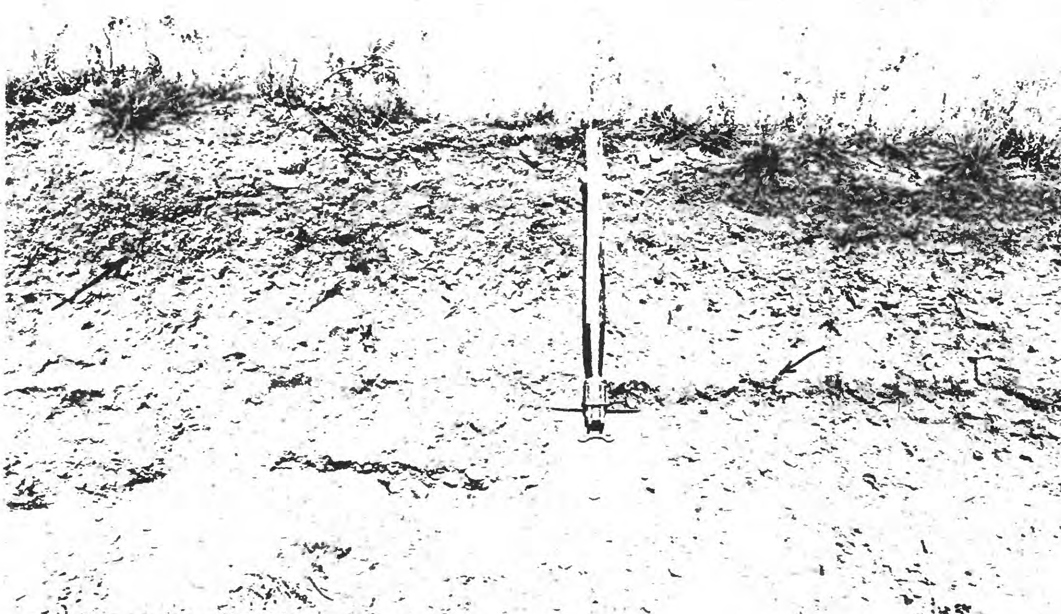


Plate 30.--Buried soils in beach ridge on northern shore of Silver Lake (SW 1/4 sec. 34, T. 155 N., R. 67 W. Arrows indicate soils. Note middle soil merges with surface soil to the right.

Other buried soils in lacustrine deposits

Two other exposures of buried soils were found in lacustrine deposits in the Devils Lake and Grahams Island 15-minute quadrangles. The first was exposed in a drainage ditch at right angles to a beach ridge in the SW 1/4 NW 1/4 sec. 18, T. 154 N., R. 66 W. These zones are three to four inches thick and about one and two feet below the surface soil, respectively. They are developed in a gravelly sand; the soils are more clayey and silty than most of the other material in the beach ridge. The beach ridge is associated with the 1445-foot intermediate strandline and probably represents only a minor incident in the more recent history of the lake.

The second exposure was also found in a beach ridge on the eastern shore of Silver Lake, in the SW 1/4 sec. 34, T. 155 N., R. 67 W. The beach ridge had apparently been eroded during a rise in the level of Silver Lake in the spring of 1950. The erosion of the beach ridge disclosed a thin soil about 2 inches thick buried beneath about 20 inches of sand and gravel (see pl. 30). The surface soil itself seems to have developed in a complex manner: it merges in places with another partly buried soil zone. Both the high 1453-foot and intermediate 1445-foot strandlines encircle Silver Lake. The beach ridge has an elevation about five feet lower than that of the intermediate strandline (as seen on the Tilden 7 1/2-minute quadrangle). Probably the soil was developed and buried during a minor fluctuation of lake level during the most recent desiccation of the lakes in the region.

A note on Cranberry Lake

Cranberry Lake is a large lake in the western part of Benson County, in T. 154 N., R. 71 W. (see fig. 23). Like Devils Lake and Stump Lake, its water surface has diminished in area since the time of the first land survey, which, for the township in which the lake is located, was made in 1890 (see fig. 24). A prehistoric strandline lies above the 1890 lake level. Part of it has been interpreted from aerial photographs and also shown on figure 24.

At the extreme southern end of the lake are large deposits of lacustrine sand and gravel which have been considerably exploited. The owner of the pits, Mr. O.L. Lunde of Esmond, North Dakota, reported to the writer on the drilling of a test hole in the deposits which encountered 20 feet of sand and gravel and ended in sand and gravel. In several of the pits in these deposits, a few thin buried soils were exposed (see pl. 31). Extensive exposures have not been made in these pits, but it seemed that at least two different buried soils were present in these deposits. Probably these soil zones also were developed and buried under conditions of an intermittantly rising lake level.

Mr. Lunde also reported to the writer that a "collection of bones" was uncovered in one place in these deposits under about nine feet of sand and gravel.

The writer believes that these deposits around Cranberry Lake are worthy of more detailed inspection because of the information they may provide on previous desiccations of the lake.

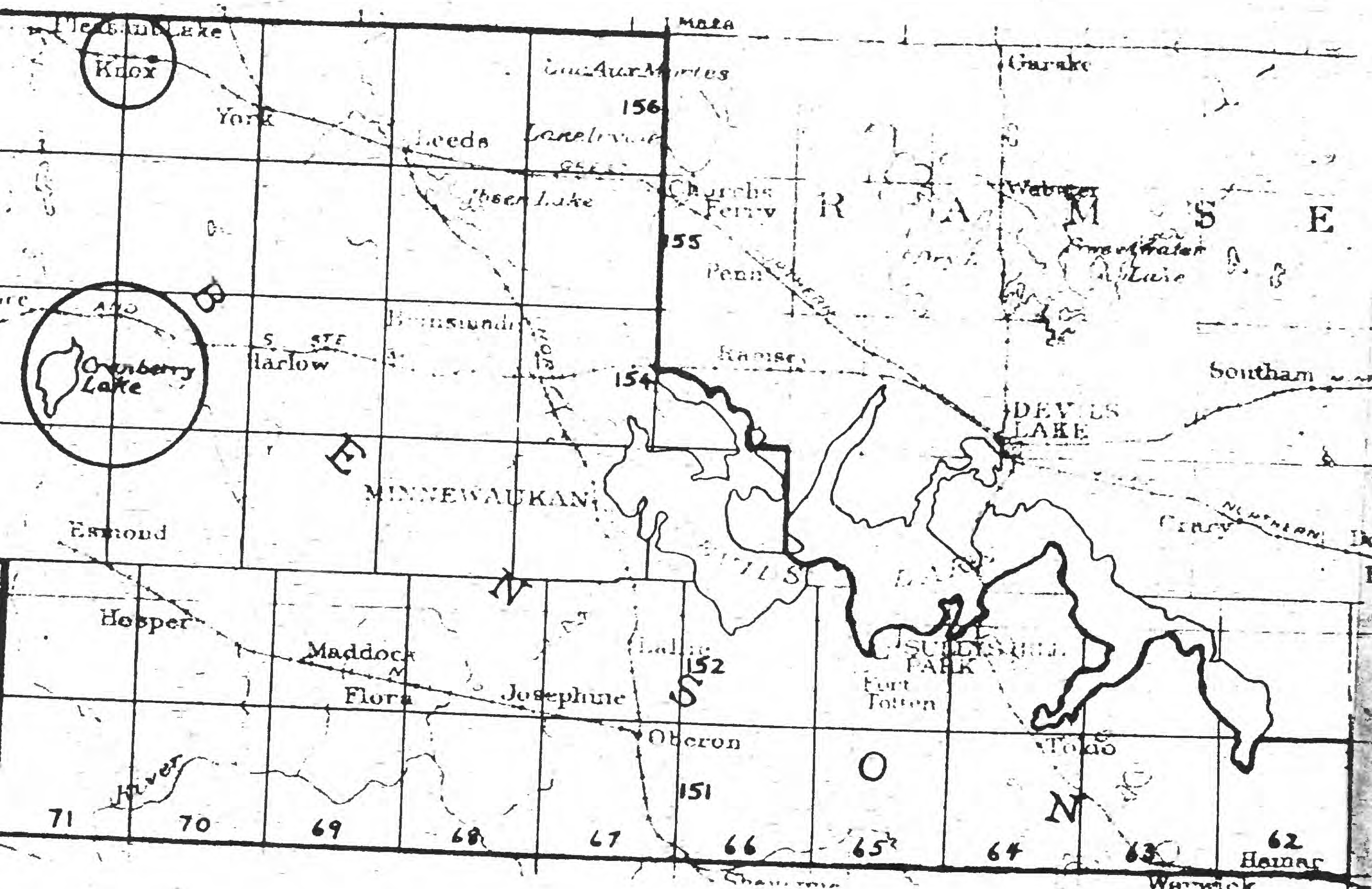


Figure 23.— Map of Benson County, North Dakota showing locations of Cranberry Lake and the village of Knox.

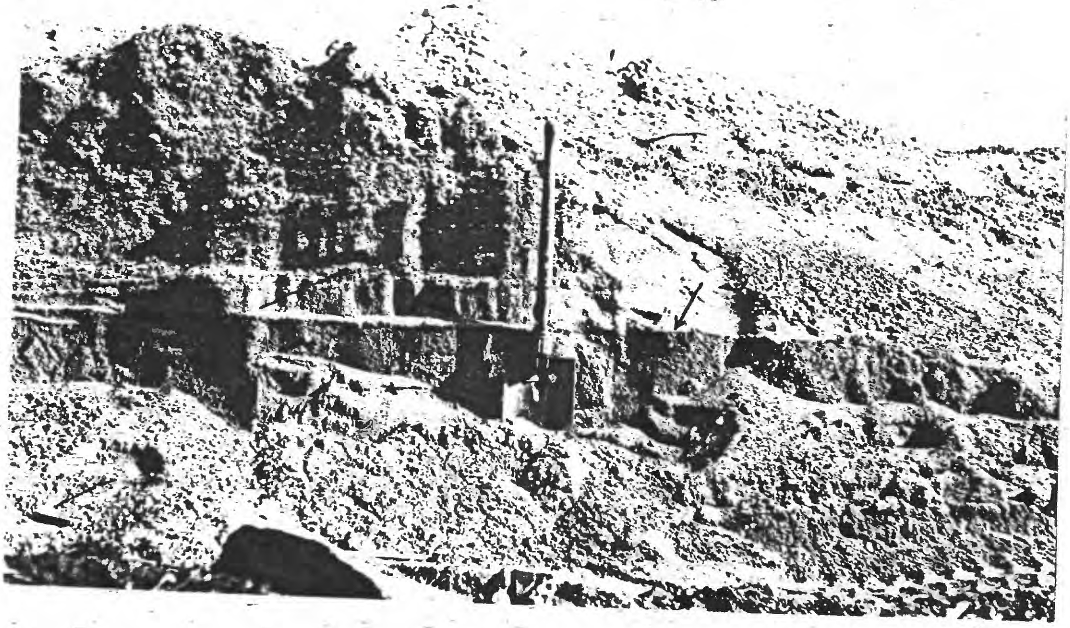


Plate 31.--Buried soil in sand and gravel deposit at southern end of Cranberry Lake, (SW 1/4 sec. 34, T. 154 N., R. 71 W.). Arrow indicates buried soil.

Fossils in lacustrine deposits

These sand and gravel deposits contain numerous bone fragments of vertebrate animals; most of the fragments were probably derived from bison. However, two more or less complete and identifiable bison skulls were found in these pits. The first of these was found by the writer in place in a wall of pit (a) between the 1435 and 1442-foot buried soils. The skull was fragile and had undergone considerable abrasion and reworking before deposition, and leaching since deposition. The second skull was found by workmen during stripping operations in pit (c). It was reported by them to have been found definitely below the surface. It was in much better condition than the first.

The two skulls were submitted to the U.S. National Museum for identification where they were examined by Dr. C. Lewis Gazin who reported (personal communication) to the writer as follows:

> The two bison specimens...are so much alike that I have no hesitancy whatsoever in saying that they represent the same species. The form is not typically the recent type of bison but may well fall within the limits of that species. Its rather small differences from the latter are in the direction of materials from Minnesota which Dr. O.P. Hay once determined as representing Bison occidentalis. Whether Hay's material is actually occidentalis is also open to question, but there is that minor variation away from Bison bison in the direction of B. occidentalis. So, from the bison evidence there is the possibility of some antiquity suggesting possibly a late Pleistocene age or perhaps early Recent rather than anything so young as a couple of hundred years. But again, as stated before, it may well fall within the range of the modern species.
>
> * * *
>
> A further word on the geologic distribution of bison, these are first known in North America from approximately middle, or somewhat earlier, Pleistocene time and range to modern. The earlier species, interestingly enough, are characterized by the larger and more massive heads with a tendency in late Pleistocene to Recent times toward a reduction in these characteristics with the modern bison having relatively lightly constructed horns. As noted in the material you sent in, the horns are somewhat heavier and appear to be directed somewhat more laterally than in the average modern bison.

In addition to the bison skulls and fragments, parts of a human skeleton were uncovered during stripping operations in pit (c). It was reported to have been found below the surface and in sand and gravel. It is not known if this skeleton was incorporated as detritus in the sand and gravel, or was artificially buried. Skull fragments were assembled by Dr. T. D. Stewart of the U. S. National Museum who identified the skull and other skeletal remains as belonging to a middle-aged male low-headed type of Plains Indian. 6/

6/ Personal communications from Drs. Stewart and Gazin.

A femur of a second individual was found later by workmen in pit (c), and also reported to have come from below the surface. Dr. Stewart noted that the femur was more mineralized than the material of the more complete skeleton. This femur is more likely to be detritus deposited with the sand and gravel. All of this material is now in the collections of the U. S. National Museum. 7/

7/ The bison skull found in pit (a) has U. S. National Museum no. 19111; the skull from pit (c), no. 19112. The human skeletal remains have U. S. National Museum Division of Physical Anthropology no. 380,556.

Conclusion

That the 1453-foot strandline was last occupied in postglacial time seems an inescapable conclusion from the evidence of the buried soils and fossils. The writer has no doubt but that it was previously occupied in late glacial times as the volume of meltwater in transit to the Sheyenne River from the waning glacier outside the map area diminished. The maintaining of the strandline by glacial meltwater must have then been followed by at least one desiccation of the lakes comparable to that of the present. The water then rose again, during which the lacustrine sand and gravel deposits containing the buried soils and fossils were deposited. How many times this cycle of rises and falls of lake level was repeated in postglacial time is not known.

The great thicknesses of sand and gravel in these deposits, especially those exposed in pit (a), suggests the possibility that an intermittantly rising water level is necessary for their accumulation.

The apparent great antiquity of the bison skulls suggests that the desiccation and refilling of the lakes during which these sand and gravel beds were deposited must have occurred early in the postglacial history of the region. They may have, of course, been reworked from earlier deposits.

Probably further examination of other lacustrine sand and gravel deposits in definitely closed basins (as opposed to glacial lakes which may lack proximal closure) in North Dakota will disclose the presence of other buried soil zones and fossils.

Stumps, and Recent History of Stump Lake

The water level in Stump Lake when the first land survey was made, 1881-1883, was about 1423 feet above sea level, as determined by comparing the original township plats with the new 7 1/2-minute quadrangles. In 1927, when the 15-minute Pekin quadrangle was made, the lake level was about 1401 feet above sea level. Sometime after 1927 East and West Bays of Stump Lake separated and a road was constructed across the former lake bottom in sec. 7, T. 151 N., R. 60 W. The latest available published lake levels are those shown on the new 7 1/2-minute quadrangles covering the old 15-minute Pekin quadrangle; these maps give the mean elevations for 1950 as 1388 feet above sea level for East Bay and 1400 feet above sea level for West Bay.

As the lake level went down during the 1880's and 1890's rooted stumps were gradually uncovered at the southern end of East Bay. Upham (1896, p. 597) was among the first who noted the presence of

> ....submerged logs and stumps, the latter standing rooted in the soil in which they grew. Many of these logs and stumps have been hauled out of the southeastern bay of Stump Lake by the neighboring farmers for use as fuel.

Simpson (1912, p. 154), writing at a later time, when the lake level had been lowered still more says that

> Not only are the stumps found in place, but many rooted logs are found thrown upon the beach by the waters and ice. In such numbers are these that they literally form log beaches, spits and bars, notwithstanding the fact that the owners of property abutting on the lake have hauled away many loads per year for years back to be used for fuel, posts, and building purposes. In fact, they have furnished the exclusive fuel supply for several farm homes.

When the writer visited the area in the summer of 1953, the stumps and logs were not seen in the profusion described by Simpson. The stumps and logs numbered less than a hundred. After a careful examination of the area only one stump rooted in place was found (see pls. 32 and 33).

The stumps were on a bay-mouth bar and flanking beach (see pls. 34 and 35) at the southern end of East Bay of Stump Lake, in the S 1/2 sec. 32, T. 151 N., R. 60 W. (see geologic sketch map, fig. 25). The bay-mouth bar strikes east and at present seals off a re-entrant of the high 1453-foot strandline which leads into the proximal part of Osago spillway. The eastern end of the bar is tied to the base of a steep bouldery wave-cut scarp. The western end of the bar merges into a beach which, in places is very bouldery. The most prominent group of boulders is more or less north-striking and probably represents the coarse residuum of a till salient into the lake. The beach towards the west narrows, the sand and gravel becomes more patchy and the surface more bouldery, as till, modified by waves and currents forms the predominent material exposed.

The lagoon in back of (south of) the bar, when visited in the summer of 1953 was partly filled with open water and fringed by marsh vegetation. The bar has been artificially cut to allow drainage of the lagoon.

The bay-mouth bar and flanking beach are composed of sand and gravel with an extremely high detrital shale content. This may indicate the presence of Pierre shale bedrock at a shallow depth, for an examination of the area failed to disclose any outcrops. Stream cuts in the bar indicated that the sand and gravel is at least eight feet thick.

The surface of the bay-mouth bar and flanking beach has an elevation of about 1405 feet above sea level, according to the Pekin 7 1/2-minute quadrangle. This is about 28 feet lower than the high

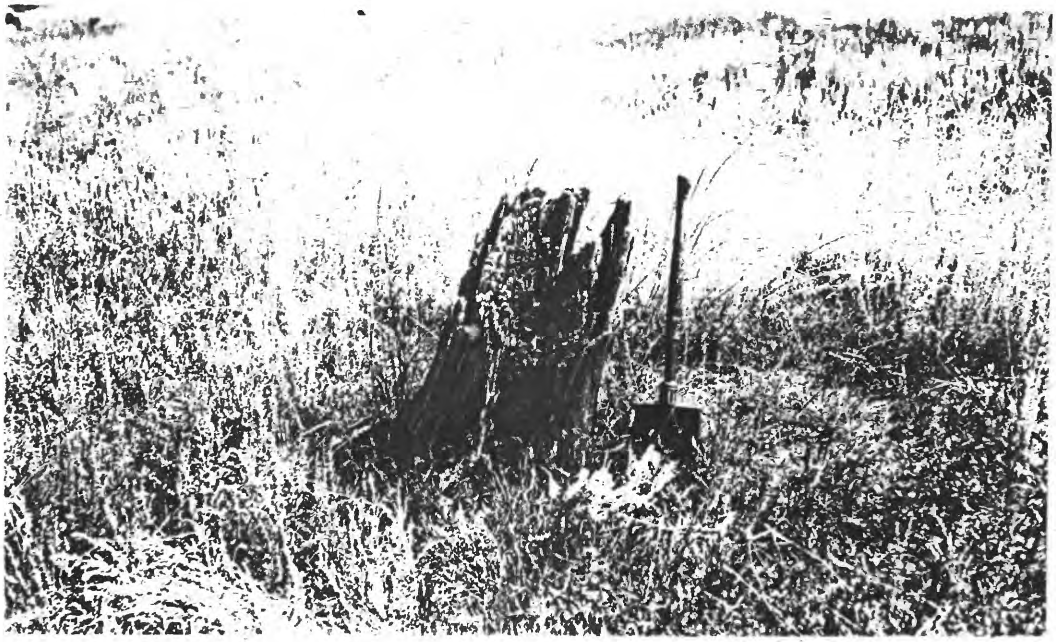


Plate 32.--Last stump to be found rooted in place at southern end of East Bay, Stump Lake.

Plate 33.--Tree trunk on southern shore of East Bay, Stump Lake. This tree trunk was probably originally growing on bay mouth bar where rooted stump found (see plate 32) and later removed by waves and currents.

Plate 34.--Bay-mouth bar on which rooted stumps found; at southern end of East Bay, Stump Lake in S 1/2 sec. 32, T. 151 N., R. 60 W. Viewed from west. Stump Lake on right (south) and lagoon on left (north). Note stumps in middle foreground and to left of Stump Lake on bar. These stumps are not rooted in place.

Plate 35.--Southern end of East Bay, Stump Lake. Note few scattered tree stumps on bay mouth bar; none of these is in place. Stump shown in plate 32 not visible.

1453-foot strandline.

Although it is possible that these features were built when the lake level was at 1453 feet above sea level or lower, from what is known about the fluctuations of the lake levels in the region, it is doubtful if this actually occurred. It seems more likely that these features were laid down during an intermittantly rising water level in a manner similar to the deposits containing the buried soils south of the City of Devils Lake (cf. above). The probable genesis of the bay-mouth bar was the joining of two spits, from the east and west, respectively, which cut off the lagoon from the rest of the lake.

Much of the area between the bar and beach, and the high 1453-foot strandline is a morass of seeps and springs (see fig. 25), as the writer discovered to his dismay after disregarding the warnings of local people. The largest area of seeps feeds several intermittantly active channels which cross the beach toward the lake. Two of these still carried water when seen in the summer (August) of 1953. The lagoon south of the bar is presumably supplied with water by the area of seeps. According to the Pekin 7 1/2-minute quadrangle, the lagoon was about 15 feet higher than the surface of the lake in 1950.

Local people reported that the springs and seeps did not dry up during the drought of the 1930's and that the water is potable for humans and readily drunk by stock. From the writer's experience with what is locally considered potable water, he would estimate that the total dissolved solids in this water were less than 2000 parts per million.

The seeps and springs are probably fed by aquifers associated with the ice-contact deposits of the proximal part of Osago spillway. If no genetic relationship exists between the aquifers and the ice-contact deposits, at least the intake area of these aquifers probably lies within the group of ice-contact deposits and intervening kettles.

The one remaining stump on the bay-mouth bar was pulled out by the writer with the help of a local resident. A portion of the wood was submitted to Dr. Roland W. Brown of the U.S. Geological Survey who reported to the writer (personal communication) that the wood

> ....is from a species belonging to the white oak group. It does not appear to have been mineralized.
>
> The separation of the species of the white oak, based on wood samples alone, is practically impossible. Hence, it is not advisable to say unequivocally that this wood is bur oak (Quercus macrocarpa), but the probability is strong that it is bur oak.

Another portion of the wood was sent to the Geological Survey for radiocarbon dating but at this writing (August 28, 1954) the results have not been made available to the writer.

The writer sectioned the stump and counted the rings. The outermost part of the stump was missing but the count yielded a minimum age of about 100 years before the tree was killed, presumably by rising lake water.

Will (1946, p. 16) discusses an oak stump from the Stump Lake area which he has correlated with a tree ring chronology which he has worked out for North Dakota. He believes that it is "very probable that the Stump Lake oak ceased to grow for some reason in 1541." Mr. Will was kind enough to forward to the writer a photostat of the cross-section of the stump on which the writer counted the rings. The tree was about 235 years old when killed. Correspondance from Mr. Will (Feb. 28, 1949) has indicated that this stump was not found rooted in place but collected from a farm on the western side of East Bay "where there are a great many of these old trees still lying." The writer is pretty certain that these old trees were collected from the area in which the rooted stump was found. However there is the possibility that it may have been carried into the lake by mass movement from the higher parts of the slopes around the lake and not killed as a result of the rise of lake level.

An inspection of many remaining tree trunks and stumps on the baymouth bar and beach by the writer indicated that almost all of them were similar in appearance and hardness to the rooted stump and hence very likely also to be bur oak.

The bur oak (sometimes spelled "burr") is the only species of oak growing at the present time in North Dakota (see Stevens, 1950, p. 115). Will (1949) in a popular article concerning the bur oak says that

> It adapts itself to a variety of soils and areas and is found along the streams of western Dakota, on the bluffs of the Missouri and at times on the Missouri bottoms, and in the wooded areas along the Canadian boundary whehce it grows well up into Manitoba... Along the Missouri bluffs, the bur oak... thrives on the slopes of the Missouri River brakes and almost to the sandstone summits of some buttes, as well as along some of the more inland coulees.
>
> ....Specimens several hundred years old are not too infrequent and they nearly all bear the marks of lightening, windstorms, prairie fires and the rubbing of countless buffalo and cattle. They adapt themselves to varying degrees of drouth, and trees of almost the same size may vary in age tremendously.

Professor Loren D. Potter, Botany Department, North Dakota Agricultural College in response to a query from the writer concerning the bur oak wrote (Jan. 12, 1954) that

> Although it grows on rich bottomlands in the east, it is the most xeric of the oaks to the northwest where it extends into the prairie. Here it may be found along floodplains, not enduring occasional flood, but may be found along upper river terraces or slopes. It is common to gravel soils and to lee slopes of sand dunes. Here root penetration is simplified and may tap water from considerable depths. They may also be grown

on heavy Fargo clay however where the roots are undoubtedly much more shallow.

At the present time only a species of willow are growing on the bay-mouth bar. Bur oaks are growing on the higher slopes around Stump Lake but the preponderant number of trees on the slopes are species of aspen, birch and poplar. This is also true for most of the Devils Lake region.

In general, trees and brush in the Devils Lake region below the high 1453-foot strandline are pretty well restricted to the slopes of cut scarps and to topographic rises in the lake basin which are usually underlain by at least a thin veneer of sand and gravel. The reasons for this are several. Most important among them are:

1) Lower parts of the lake basin often contain swamps with highly mineralized water. This is evident in the late summer and fall when they dry up, leaving encrustrations and efflorescences of salts on the surface. Trees and brush will not grow here because of poor drainage conditions and highly mineralized soil water.

2) Topographic rises, and slopes of cut scarps in most places because of their altitude are well drained. Also the drainage may flush out any mineralized soil water that may be present or prevent its formation by rapid movement.

3) The cut scarps are rarely disturbed by farm machinery and hence allow trees and brush to grow.

4) The coarser material underlying some topographic rises facilitates drainage and prevents the accumulation of mineralized soil water.

5) Coarser material facilitates root penetration by trees and brush; also the coarse character of the material makes water available to plants at lower levels of soil moisture tension than does finer, clayey

material.

The sequence of events following the previous decline in the level of Stump Lake may be reconstructed. In view of the fact that the previous rise in lake level did not disturb the stumps or apparently modify the part of the bar on which the stumps were, it may be presumed that the geometry of the seeps and springs and their feeding aquifers was likewise unchanged from that which exists at the present time. As the lake level went down probably during a dry, warm period the seeps and springs, formerly discharging into the lake under water, discharged down the now emergent slope. Any mineralized water remaining in the beach and bay-mouth bar was replaced by fresher water from the springs in surface and subsurface transit to the lake. As the lake receded still farther, presumably the local water table in the beach and bar also fell, and possibly, the amount of water discharged by the seeps diminished. The oaks began to come into this area because of the proper "xeric" conditions, perhaps too severe for other trees, and because of ease of root penetration. Professor Potter in his communication to the writer suggests that

> It would seem that the invasion of the exposed bed with the resulting lowered water table would not be unlike the movement of bur oak into lower river terraces as flooding ceased and drainage improved. This invasion might have occurred in spite of a warmer and drier atmospheric climate.

The reasons for the decline in lake level are discussed in the section to follow, and in the last section of this part where a local postglacial chronology is also considered.

To complete the record of stumps in the region, the following may be mentioned: (a) Upham (1896, p. 597) found partly submerged stumps rooted in place along the shores of North Washington Lake (see fig. 8), South Washington Lake, and Lake Coe, all in T. 149 N., R. 63 W. After conferring with the locally reputed oldest inhabitant who remembered seeing stumps on the western shore of North Washington Lake, the writer visited the lake. The entire western shore was traversed on foot without finding any stumps. The other lakes mentioned by Upham were not visited. (b) Simpson (1912, p. 154) says that

> Along the shores of Devils Lake, notably on the Chatautauqua [Lakewood Park] shore of Creel Bay, are found a number of rooted logs similar in all respects to those found in Stump Lake; but no well authenticated report of stumps having been found in place can be secured.

The Recent History of Devils Lake

The earliest well-authenticated records of lake levels in Devils Lake begin in 1867 and continue to the present 8/. These are given in table 1 and shown on a graph, figure 26.

8/ Upham (1896, p. 595) believed that the lake level about the year 1830 was about 1,441 feet above sea level (reduced to 1929 datum). The validity of his evidence is questionable.

As can be seen from the graph, the lake level declined, with some minor recoveries almost continuously until 1940, when the level began to rise.

This recent drying-up of the lake has considerably affected the recreational aspects of the region. A shallow-draft sidewheeler used to run excursions from a landing at Lakewood. Swimming was quite popular. Pike were a numerous game and commercial fish until they disappeared in 1889. The disappearance of the fish may have been due to a concentration of toxic substances in the lake water, especially zinc (Abbott, 1924, p. 183-184; Swenson and Colby, in preparation), a drying up of their spawning grounds, "overfishing, and the increasing salinity of the water." (Pope, 1908, p. 20).

Simpson (1912, pp. 155-156) believed that the rapid lowering of the lake level after the settlement of the region was the result of a decrease in run-off and a lowering of the water table. These he thought were due to the break-up of the "thick, tough almost impenetrable sod which favored runoff and prevented evaporation from the soil." However, this was not accompanied by comparable increments to the ground water because of evaporation and transpiration losses, "thus reducing the ground water table and subsequently lowering the level of all permanent lakes and streams and causing many to become

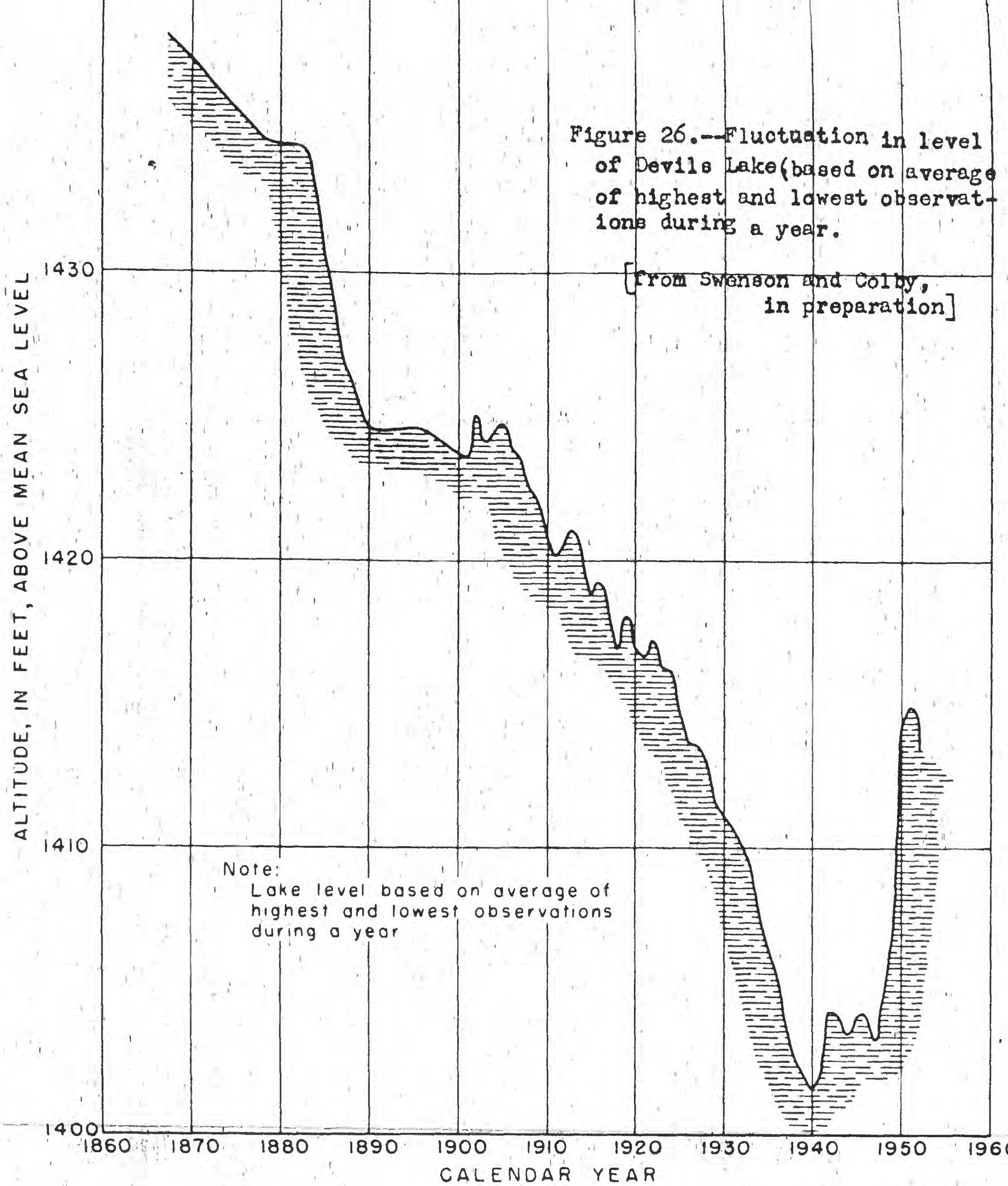


Figure 26.--Fluctuation in level of Devils Lake(based on average of highest and lowest observations during a year.

[from Swenson and Colby, in preparation]

intermittant or temporary and some to disappear entirely."

This and similar views have been rather widely held (cf. Horton and others, 1910, p. 52; Public Health Service, 1952, p. 24). Simpson himself seems to have abandoned this view; in a later discussion (1929, pp. 190-191) he stresses the climatic factors of rainfall and humidity of the atmosphere as they influence the altitude of the water table and evaporation. The lake level, he says, is "subject to many fluctuations that are directly or indirectly associated with the weather and to some significant modifications that are the result of human agencies, such as drainage and the cultivation of the soil, but in general the size, depth, and permanency of the lake depends on the climate."

H.E. Thomas (1951, p. 175) mentions another explanation that has been offered, namely the decimation of the bison herds which had previously trampled and compacted the soil. With their disappearance, infiltration increased and run-off to the lake decreased. Regarding the effects of tillage and cultivation Thomas (1951, p. 175) points out that, although there was but a single farm in the whole Devils Lake drainage basin before 1880, the lake level had already fallen several feet prior to that year.

Swenson and Colby (in preparation) note that precipitation during the summer and fall results in very little run-off. The major part of the run-off is produced during the spring thaw "when the ground is frozen or immediately after the ground thaws in the spring." Hence, it is believed that cultivation of the soil and use of water by crops may have no major effects on run-off.

Basic data on evaporation, run-off into the lake, and ground water inflow are inadequate or lacking. However, on the basis of a series of extrapolations from other areas in North Dakota for evaporation, the assumption that ground-water increments to the lake are 5% of inflow into the lake, and streamflow measurements of Mauvais Coulee from May 1949 to December 1952, Swenson and Colby (in preparation) have made a number of rough calculations regarding the relationships among run-off, or inflow, evaporation, and lake stage between 1930 and 1952 (see fig. 27).

They estimate that about 55 or 60 square miles of drainage area is needed to maintain one square mile of lake surface. By maintain they mean neither rise or fall of lake level within that square mile. Therefore the 3,940 square miles of the total interior drainage basin could support only about 60 to 70 square miles of lake surface.

In May 1952, the total surface area of the lakes in the Devils Lake-Stump Lake complex, and of the lakes in the northwest part of the map area, was estimated to be about 75 square miles, an area larger than is likely to be maintained by an average of 0.23 inches of run-off per year.

In the ten year period from 1930 to 1940, the lake level fell about 10 feet (see fig. 26). Precipitation during this period averaged 15.9 inches, the temperature, 39.1° F., and the estimated evaporation from a free water surface, 34.1 inches.

In the second ten year period from 1940 to 1950 the lake level rose 14 feet. Rainfall averaged 18.2 inches, temperature, 38.5° F., and estimated evaporation, 27.5 inches.

In the second ten year period the precipitation and temperature were above their long term averages of 17.5 inches and 38.1° F., respectively (see figs. 27 and 28). Evaporation was calculated to be about 8% lower than an extrapolated long term average. It was during

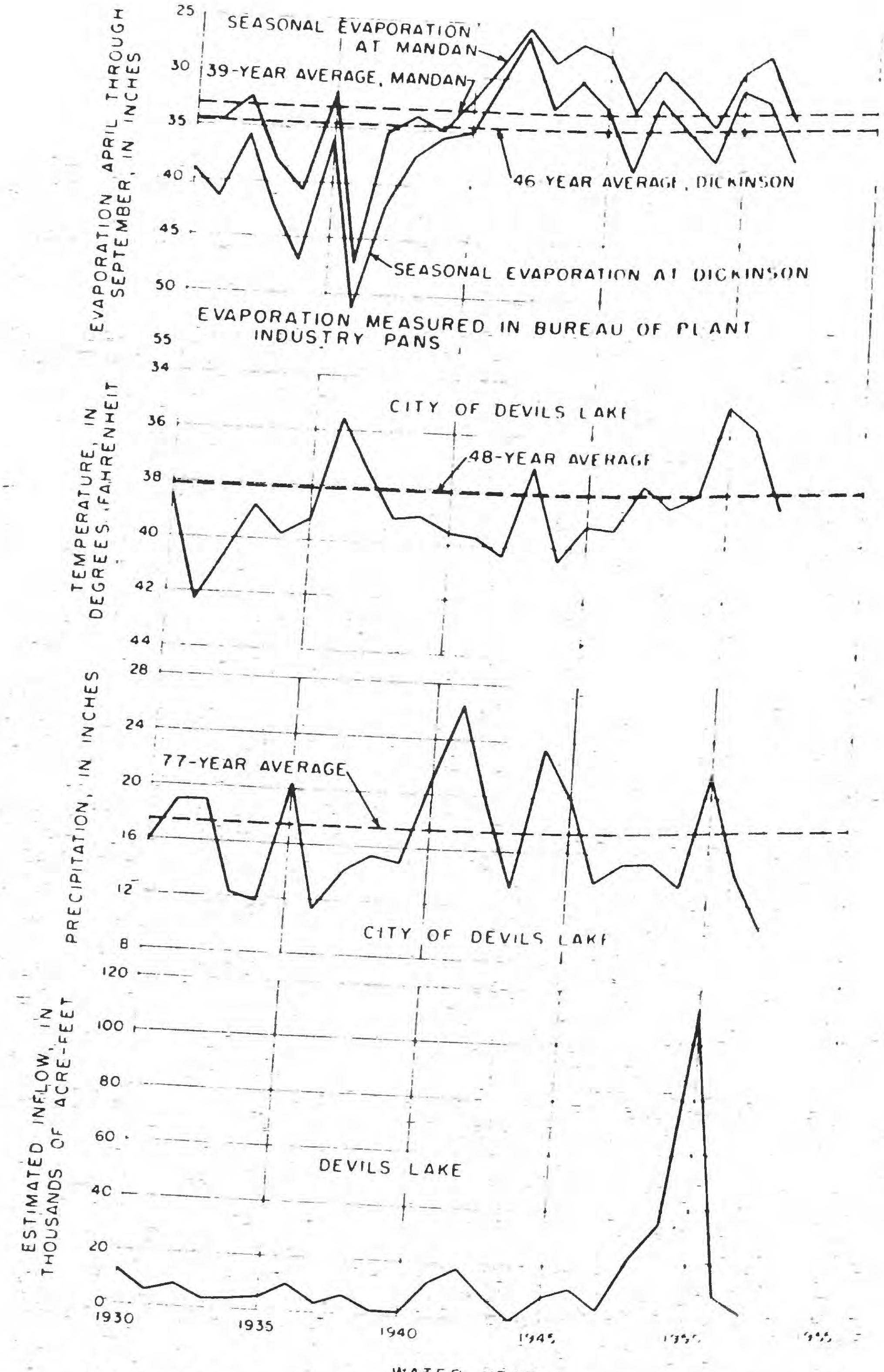


Figure 27.—Computed annual inflow to Devils Lake and significant climatological factors.

[from Swenson and Colby, in preparation]

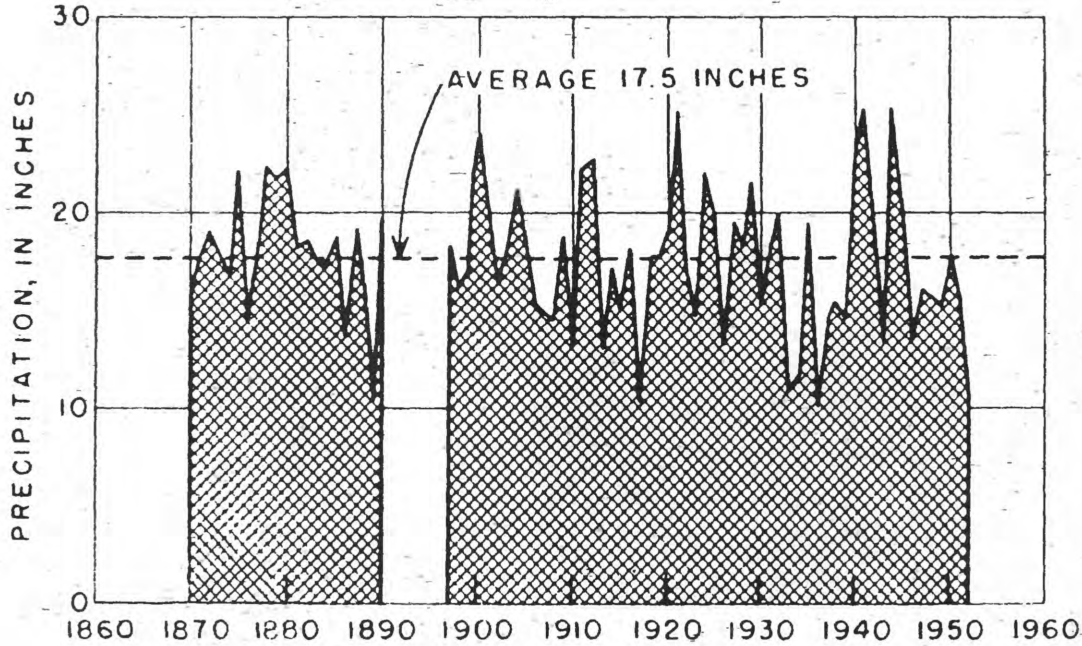


Figure 28.--Annual precipitation at Devils Lake, 1870-1952

[from Swenson and Colby, in preparation]

this period of near average climatic conditions that the lake level rose 14 feet. Swenson and Colby conclude that: "This rise in lake level is not likely to have been caused by changes in agricultural practices but probably was due to small changes in the weather."

Presumably, similar extrapolations and calculations would show similar climatic control for the decline in lake level prior to 1930.

A Note on Chemical Quality of Water in Devils Lake and Stump Lake

The decline in lake level of Devils Lake and Stump Lake has led to a separation of many parts of these lakes from one another, and a considerable diminution of area and volume, or total desiccation, of many parts.

The decrease in the volume of the lakes has increased the concentration of dissolved solids in the waters of the remaining lakes. The following remarks from Swenson and Colby (1954) sums up the available information:

> Scattered records from 1899 to 1923 and more comprehensive data from 1948 to 1952 show a range of salt concentration from 6130 parts per million (ppm) to 25,000 ppm in Devils Lake water. Although the concentration has varied, the composition of dissolved solids has not changed appreciably. Lake waters are more concentrated in the lower part of the basin; for periods of record, the salt concentration ranged from 19,000 to 106,000 ppm in East Bay of Stump Lake.

Two recent chemical analyses by Swenson and Colby (in preparation) of water from Main Bay of Devils Lake and East Bay of Stump Lake, respectively, shown in table 3, give a good idea of the compositions of these waters. It may be noted that the principal dissolved solids in these waters is sodium sulfate (Glaubers salt).

The great concentration of dissolved solids in East Bay of Stump Lake shown in this analysis is about three times that of sea water. It testifies to the effectiveness of the lake as a "sink" for dissolved solids and as an "evaporation pan" since the complex of lakes ceased draining into the Sheyenne River.

Table 3

Chemical analyses of lake waters from Devils Lake region, North Dakota (in parts per million)

Analyzed by H.A. Swenson and B.R. Colby, U.S. Geological Survey

Lake Date of Collection	Main Bay of Devils Lake May 15, 1952	East Bay of Stump Lake 1/ June 16, 1949
Silica (SiO_2)	7.5	21
Iron (Fe)	.18	.13
Calcium (Ca)	40	86
Magnesium (Mg)	352	5,580
Sodium (Na)	1,780	22,100
Potassium (K)	178	1,340
Bicarbonate (HCO_3)	537	985
Carbonate (CO_3)	70	188
Sulfate (SO_4)	3,760	55,400
Chloride (Cl)	838	9,920
Fluoride (F)	.4	1.2
Nitrate (NO_3)	2.8	6.7
Dissolved solids		
Residue on evaporation at 180°C.	7,440	2/ 108,000
Sum	7,300	95,100
Hardness as $CaCO_3$ Calcium, Magnesium	1,550	23,200

1/ Referred to as eastern Stump Lake by Swenson and Colby

2/ Average of 11 samples.

[Data taken from Swenson and Colby (in preparation) tables 6 and 8]

Discussion of Postglacial Chronology

For the purposes of immediate discussion, a simple scheme for the postglacial chronology of the Devils Lake region is given here:

1. The first occupation of the high 1453-foot strandline in late glacial time.

2. A dry period when lake levels declined, and which lasted at least 100 years.

3. A moist period when the lake levels rose and the high 1453-foot strandline was reoccupied.

4. The contemporary drier and warmer period with declining lake levels.

These are the minimum number of events that can either be deduced from the available data or safely inferred. The writer has no doubt that this scheme is oversimplified and that a multiplicity of events is concealed by the several items in the chronology. The evidence, and the ambiguities therein, is now considered for each of the items:

1. The cutting of Big Stony spillway was certainly an event in glacial time. Flow of water through the spillway in postglacial time was probably negligible, otherwise the junctions of Warwick and Big Stony spillways would not be accordant. The establishement of the threshold maintaining the high 1453-foot strandline must have been in late glacial time, and the strandline maintained was the high 1453-foot strandline.

2. The dry period is evidenced by the lowest buried soil zone in the lacustrine sand and gravel deposits and by the trees, now stumps, in Stump Lake. This lowering of lake level is probably comparable to the contemporary one. Aside from the inherent simplicity of the scheme, there is nothing to show that the events which produced these evidences were synchronous (cf. below).

3. The moist period of intermittantly rising lake levels is indicated by the sequence of buried soils and lacustrine sand and gravel deposits,

as well as by the submergence of the trees. That these events may not have been synchronous is suggested by:

(a) the apparent great antiquity of the species of bison whose skeletal remains were found in the sand and gravel deposits (assuming they were not reworked from earlier deposits), and

(b) the apparent recency of the rooted stumps of Stump Lake which probably could not have passed through a series of rises and falls of lake level without either being washed away by waves and currents or being buried during modification of the bay-mouth bar. Further support for the recency of this event may be given by Will's dating (1946, p. 16) of the death of the tree whose stump he analyzed. He believes the tree was killed in 1541. Before his date is fully accepted two points must be considered.

(1) Will's work is the first dendrochronology for North Dakota. It is based essentially on one tree stump of known age found near Bismarck, North Dakota. Until this tree is cross-checked with several others of known age, his dating must be considered uncertain. It may be noted that Oltman and Tracy (1951, fig. 11) show a .6 correlation between the Bismarck weather station and stations in and around the City of Devils Lake. Will's report is a pioneer work in its field in North Dakota and a good deal of painstaking labor was obviously expended in its production; the writer hopes that this worthwhile enterprise will be continued.

(2) The stump dated by Will was not found rooted in place. The tree may have grown in a higher part of the lake basin which was not inundated by the rise in lake level and carried into the lake by intermittant streams or mass movement.

If Will's stump is as it is alleged to be, this dry per od lasted for at least 235 years, which is about double the time shown by the stump rooted in place. A possible check on the authenticity of Will's stump may be made by cross-checking it with the stump found in place by the writer.

A rise in lake level sufficient to have submerged the trees in Stump Lake would not necessarily have attained the elevation of the high 1453-foot strandline. This may mean that the contemporary decline in lake level may not have immediately followed the occupation of high 1453-foot strandline, as shown by the buried soils in the lacustrine deposits.

4. Swenson and Colby (in preparation) have pointed out the probable relations among rainfall, temperature, runoff and the lake levels in the Devils Lake region. These relations tend to support the belief that the causes of the recent desiccation are largely climatic; earlier views stressing man's activities do not seem valid at this time. That the previous desiccations have been climatic in origin seems indisputable.

The correlation of this rather sketchy local chronology with schema that have been offered for North America and Europe rests on the assumption that the glaciation whose products mantle the surface in the Devils Lake region is Mankato in age and that the desiccations and fillings of the lakes are restricted to postglacial time. Direct correlations with the type area of Mankato drift are not available, but Flint believes (e.g., see 1953, p. 169) that Mankato ice was the last to invade South Dakota and hence was present in North Dakota.

Most of the postglacial chronologies and glacial chronologies for events outside the Wisconsin drift border for the midwestern part of the

United States have been built up from pollen studies and expressed in terms of forest successions (e.g., Sears, 1948). A postglacial forest succession for North Dakota has not yet been worked out and interpretation of the literature on forest successions for Minnesota, Michigan and Wisconsin and adjacent states cannot be easily extrapolated to include North Dakota (e.g., see Buell and Cantlon, 1951; Potzger, 1945). Recourse is made to the more generalized sequences for North America to furnish some perspective in time for the events in the Devils Lake region. The following correlations should be considered rather tentative for the most part and mainly suggestions as to where to place in time the meager data on the Devils Lake region.

A. The earliest postglacial dry period is known variously as the Climatic Optimum (Flint, 1947, p. 487-499), Thermal Maximum (Deevey, 1953, p. 277-279) and Megathermal Phase (Judson, 1953, p. 59). It has been subdivided into several minor phases which, for the present, are irrelevant to the Devils Lake region. According to Deevey (1953, p. 279), "The time of maximum temperatures lasted from about 5000 to about 600 B.C." The desiccation of the lakes prior to the accumulation of the sequence of buried soils and lacustrine sand and gravel deposits may be tentatively assigned to the Thermal Maximum on the basis of the apparent antiquity of the bison skulls.

B. The rise in lake levels during which the sand and gravel deposits with the buried soils were laid down may be related to the Little Ice Age following the Thermal Maximum. In this period, many lakes in the Basin and Range province, previously dry, were reconstituted, and many mountain glaciers in the western part of the United States reformed and readvanced (see Flint, 1947, p. 494-497; Matthes, 1949, p. 209-215).

C. The lowering of the lake level and the concomitant growth of the bur oaks in Stump Lake may be associated with dry periods in the 15th and 16th centuries in western North America shown by Brooks in a table for climates in the Christian era (1951, table III). If Will's date is correct, this period began in North Dakota about 1300 and ended about 1535, a time interval much longer than any around this time that the writer has been able to find in the literature (e.g., see Antevs, 1948, p. 14; Schulman, 1951, p. 1028; 1953, p. 210-212)

D. The submerging of the trees by the rising lake water may have been synchronous with a presumed moister period extending from about 1550 to 1850, as deduced from the expansion of glaciers in the Alps, Scandanavia and Iceland (see Matthes, 1949, p. 215; Brooks, 1951, p. 1009).

E. In a recent study of climatic trends and the relation between precipitation and runoff in the Missouri River basin Oltman and Tracy (1951) conclude after an analysis of data from selected weather stations that long term trends are in the direction of decreasing annual precipitation for most of the basin and increasing annual temperatures for the entire basin. Their conclusions tend to support for the Missouri River basin the now generally established climatic amelioration of the past hundred years (see Flint, 1947, p. 499-500; 1951, p. 1019-1020; Brooks, 1949, p. 376; 1951, p. 1009-1010). Presumably the trends found by Oltman and Tracy are also reflected in the lake levels of the Devils Lake region, which is contiguous to the Missouri River basin, though considerably distorted by the complex system of overflowing basins feeding the lakes.

Considering the apparent "sensitivity" of these lake levels to slight changes in climate, levels similar to those of today, as well as levels maintained at higher elevations by the Jerusalem outlet (1445 feet above sea level), must have been frequent. Brooks (1951, table III) lists about six major dry periods that have affected western North America since the beginning of the Christian era. No doubt each of these dry periods was reflected in lower lake levels for the Devils Lake region; the evidence available however indicates perhaps only two or three of these.

APPENDIX

Spot elevations of strandlines south of the City of Devils Lake determined since the completion of Aronow and others (1953) are as follows:

1) The crest of a prominent hill 1/ south of the City of Devils Lake, just west of State Highway 20 in the NW 1/4 SW 1/2 sec. 3, T. 153 N., R. 64 W., was found to have an elevation of between 1452 and 1453 feet above sea level; the cut cliff at the base of the hill, between 1445 and 1446 feet above sea level:

2) The continuation of the crest of this hill on the east side of Highway 20 had an elevation of between 1446 and 1447 feet above sea level; the base of this part of the hill, north and south of the crest, between 1443 and 1445 feet above sea level.

3) The two highest strandlines on the east side of a hill in the NE 1/4 SE 1/4 sec. 29, T. 153 N., R. 64 W., were found to be, at the bases of cut scarps, between 1444 feet and 1445 feet, and between 1452 feet and 1454 feet above sea level respectively. Profile D (see below) was constructed at this site.

4) The elevation of the base of a cut scarp just west of Highway 20 in the SE 1/4 SE 1/4 sec. 16, T. 153 N., R. 64 W., was found to be between 1453 and 1454 feet above sea level.

Details of elevations of certain lacustrine sand and gravel deposits south of the City of Devils Lake are given in the text in the section following the one on strandlines.

1/ Local residents may identify it as the one on which the "Ranch" is located.

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