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PREGLACIAL RIVER VALLEYS OF MARQUETTE, GREEN LAKE, AND WAUSHARA COUNTIES

CHARLES M. FLEMING
Greendale, Wisconsin

Abstract

Buried preglacial river valleys lying in three Wisconsin Counties were identified and mapped. Their physical dimensions were obtained by way of a mathematical model that was used to describe a valley cross section. The network of buried valleys that was discovered corresponds in part with the successive damming of the ancient Wisconsin River by the advancing and most recent glacier. The underlying Precambrian bedrock apparently influenced the glacier's direction of movement as well as the courses of some of the preglacial rivers in this region.

INTRODUCTION

In preglacial times, the ancient Wisconsin River flowed from the northern highland of Wisconsin and Michigan southward into central Wisconsin. There it had carved out of the Baraboo hills the famous Devils Lake gorge and, turning westward at Merrimac, concluded its journey at Prairie du Chien where it met the ancient Mississippi River (Martin, 1932). If glaciation had never occurred, the modern Wisconsin River would still be following this course, but the invasion of the last continental glacier squeezed the Wisconsin River out of its ancient valley in central Wisconsin and permanently diverted its flow to its modern valley bordering Adams and Juneau Counties (Alden, 1918). Prior to glaciation, the ancient river made a great loop in central Wisconsin which extended from the vicinity of Friendship to Green Lake before it entered the gorge at Devils Lake. Neither the loop nor the gorge are used by the river today.

Even though glaciation had significantly scoured the land, the buried bedrock underlying Marquette, Green Lake, and Waushara Counties still has etched in it the preglacial river valleys that once contained the Wisconsin, Wolf, and Fox Rivers. The existence of these buried preglacial valleys has been known for more than one hundred years; their presence, however, is inconspicuous and their exact locations can only be found by means of well drillings and borings. Occasionally, the top of an ancient valley is visible, but, generally, the valleys are completely buried beneath glacial drift. On top of the drift, lacustrine deposits have created, along practically all these ancient valleys, the wetlands that abound in these three counties.

Immediately prior to the four Pleistocene glaciations that are known to have touched Wisconsin (USGS, 1976), most of the limestone bedrock that once uniformly covered this region had already eroded away (Martin, 1932). Rolling hills of sandstone dotted with crags, buttes, and pinnacles were features of the preglacial landscape as they are in the landscape of the Driftless Area of Wisconsin today. In preglacial times, the Wisconsin River was one of the largest rivers in Wisconsin. In central Wisconsin, its valley was approximately 600 feet deep and 4 miles wide at the crests. The river entered Marquette County from the west in the town of Westfield, at an elevation of 503 feet above sea level with respect to the bottom of its channel, and proceeded eastwardly on the first leg of a great loop as shown in Fig. 1. The Wisconsin River met the ancient Wolf River at Neshkoro and the ancient Fox River at Green Lake, the eastern extreme point of

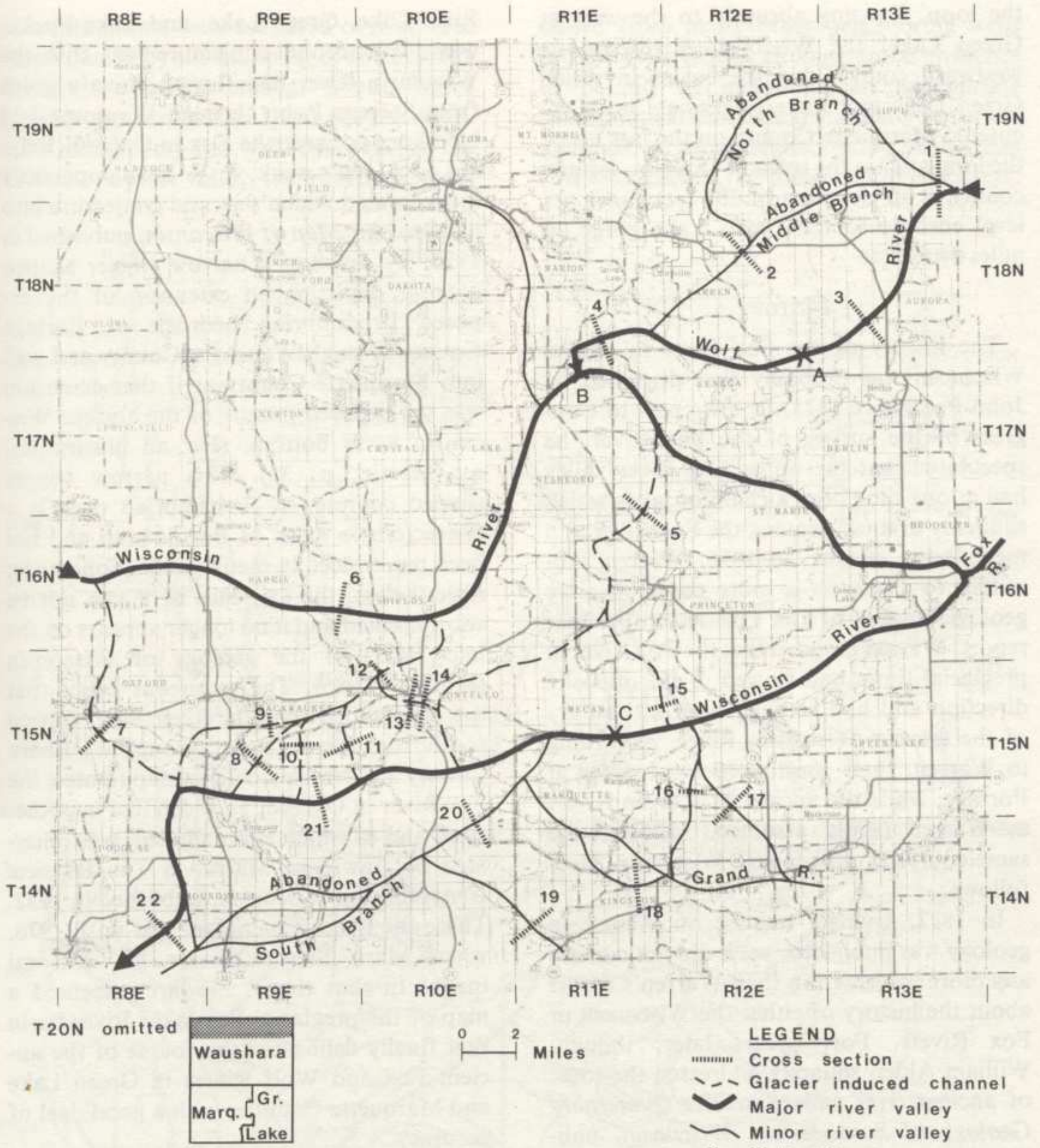


Fig. 1. Map of preglacial river valleys of the Wisconsin, Wolf, Fox, and Grand Rivers. The three wells A, B, and C are listed in Table 1. The twenty two cross sections of the river valleys and channels are listed in Table 2.

TABLE 1. Important Wells Marked in Figure 1.

Well	*Elevation of bottom above sea level*
A	473 feet
B	462
C	420

the loop. Turning abruptly to the west at Green Lake, the Wisconsin River, on its westward course, dug the basins in which Green Lake and Lake Puckaway lie. It reentered Marquette County on the last leg of the loop and, in the town of Douglas, left the county at an elevation of 382 feet above sea level enroute to the Devils Lake gorge 20 miles away.

HISTORY

The history of the Fox River in central Wisconsin was probably first discussed by John Petitval in 1838. In his report to Congress of the survey of the Fox River, he speculated that the upper Fox River valley had at one time been a chain of lakes which suddenly drained, leaving the Fox River as a meandering stream. In 1876, Warren submitted to Congress a more comprehensive geologic report of the Fox River. In that report, Warren asserted that the Fox River in preglacial times had flowed in the opposite direction and had actually been a tributary of the ancient Wisconsin River. According to Warren, their confluence was located at Portage, while the ancient Wisconsin River, as Warren tacitly assumed, followed the same course as the modern Wisconsin River follows.

In 1877, Irving's treatise on Wisconsin geology was published, yet it did not contain any more information than Warren's report about the history of either the Wisconsin or Fox Rivers. Forty years later, though, William Alden squarely addressed the topic of ancient river valleys in *The Quaternary Geology of Southeastern Wisconsin,* published in 1918, and his opinion about the ancient Wisconsin River has been the authoritative one ever since. He offered two conjectures pertaining to the course of that ancient river. The first was that the confluence of the ancient Wisconsin and Fox Rivers was located in the town of Oxford where the Wisconsin River, flowing southeastwardly through the village of Oxford, joined the Fox which was flowing westwardly through Rush Lake, Green Lake, and Lake Puckaway. The second conjecture was that the Wisconsin River had flowed directly south from Stevens Point through Wautoma and Neshkoro to meet the Fox in Oxford. Relying on Alden's work, E. F. Bean apparently incorporated Alden's second conjecture into his *Geologic Map of Wisconsin,* published in 1924, by drawing a narrow trigger shaped contour depicting an extension of the exposed Precambrian bedrock of Portage County through Waushara County and well into Marquette County as if that extension was the exposed granite of the ancient Wisconsin River bottom. (For an illustration, see Martin, p. 35). This narrow trigger shaped contour of Precambrian rock is a characteristic mark of Bean's map and has been reproduced in many publications since; nevertheless, the existence of it can not be substantiated and it no longer appears on the latest map of the geology of Wisconsin (Mudrey, 1985). The erroneous belief that the ancient Wisconsin River had flowed south from Stevens Point through Waushara County and Neshkoro Township to meet the Fox River in Oxford, as Alden had hypothesized and to which Bean alluded, was reiterated by Lawrence Martin in *The Physical Geography of Wisconsin,* published in 1932. There the issue remained at rest until 1976, when Mark Stewart wrote his doctoral thesis. In that thesis, Stewart presented a map of the preglacial Fox-Wolf River basin that finally delineated the course of the ancient Fox and Wolf Rivers in Green Lake and Marquette Counties with a good deal of accuracy.

DISCUSSION OF THE DATA

For the purpose of this article, the information obtained from the Wisconsin Department of Natural Resources well constructor's reports, from the Wisconsin Department of Transportation highway test borings, and from Alden (1918) provided 780 data points upon which the locations of the preglacial river valleys were deduced.

The data points were scattered over an area encompassed by the mapping of the bedrock topography shown in Fig. 2 and which equaled approximately 1,000 square miles. Even though very few wells ever reached the bottom of a river valley, the information obtained from many other neighboring wells provided sufficient circumstantial evidence to permit, by means of an appropriate mathematical model and standard statistical methods, an accurate description of the sizes and locations of the preglacial river valleys.

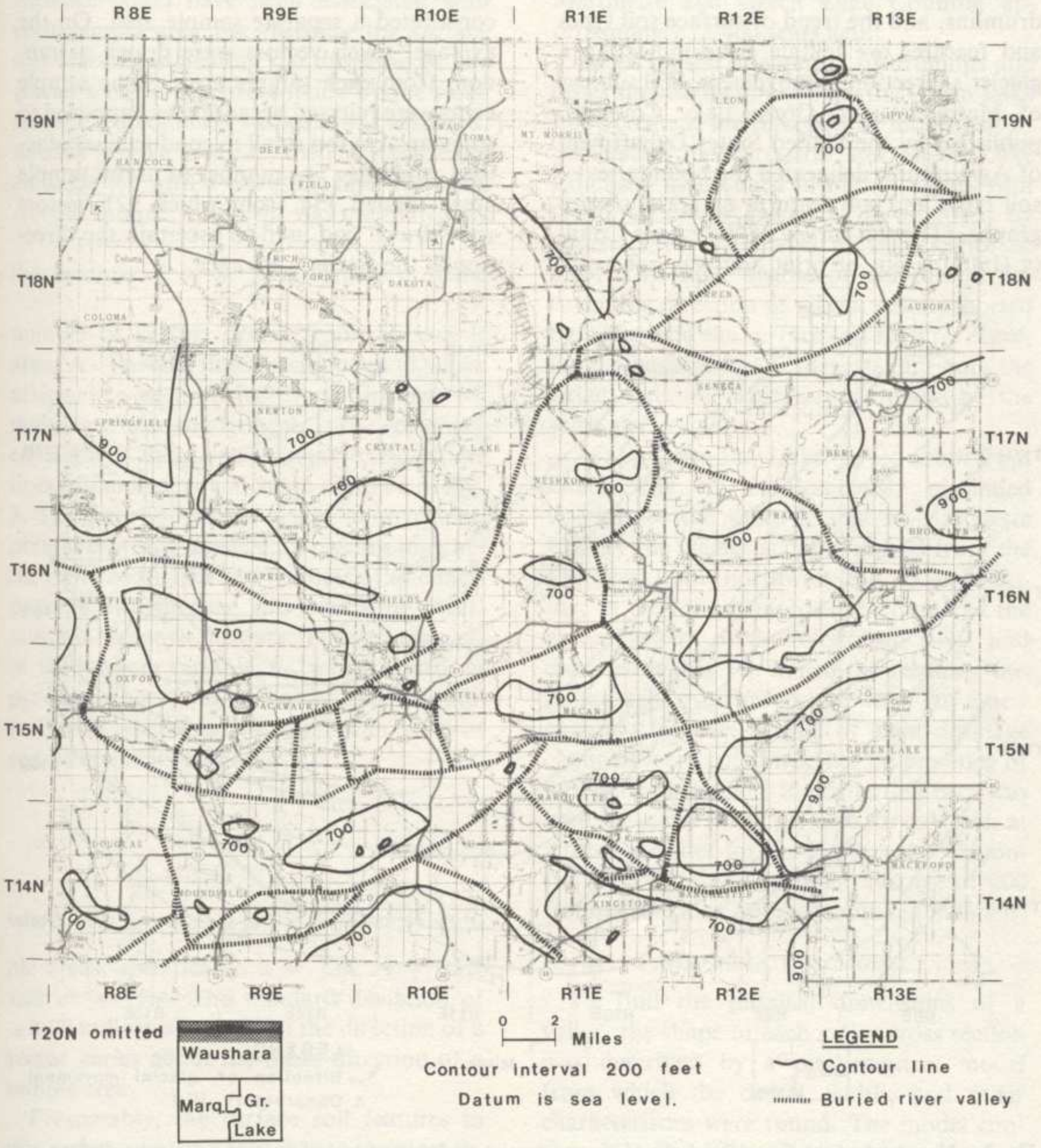


Fig. 2. Topographic map of the bedrock of Marquette, Green Lake, and southern Waushara Counties. It is based on data found primarily in well constructor's reports.

Knowing the dimensions of the river valleys helped to discriminate between what was a tributary, a glacier induced channel, and the main Wisconsin River valley itself. The analysis revealed a complex network of buried river valleys which was a result, in part, of the glacier's movement across this region.

The direction of glacial striae, the axes of drumlins, and the trend of surface soil types and features are telltale signs indicating a glacier's direction of movement. Soil surveys of Marquette and Green Lake Counties, published by the United States Department of Agriculture, delineated the boundaries of soil types and soil features on aerial photographs. (The soil survey of Waushara County (1909) is out of print and was not available). The direction of the longitudinal axis of a drumlin and the trend of soil features as outlined on the aerial photographs represent vectors of the glacier's movement.

The soil surveys of Green Lake and Marquette Counties utilized 69 non-overlapping aerial photographs. Each photograph was divided into two equal parts and each half constituted a separate sample area. On the average, seven vectors were drawn at random from each sample area. Some sample areas were rejected because they happened to cover an area too small to conduct a satisfactory sampling. The number of useful sample areas totaled 134 from which 921 vectors were drawn and used to ascertain the direction of the glacier's advance.

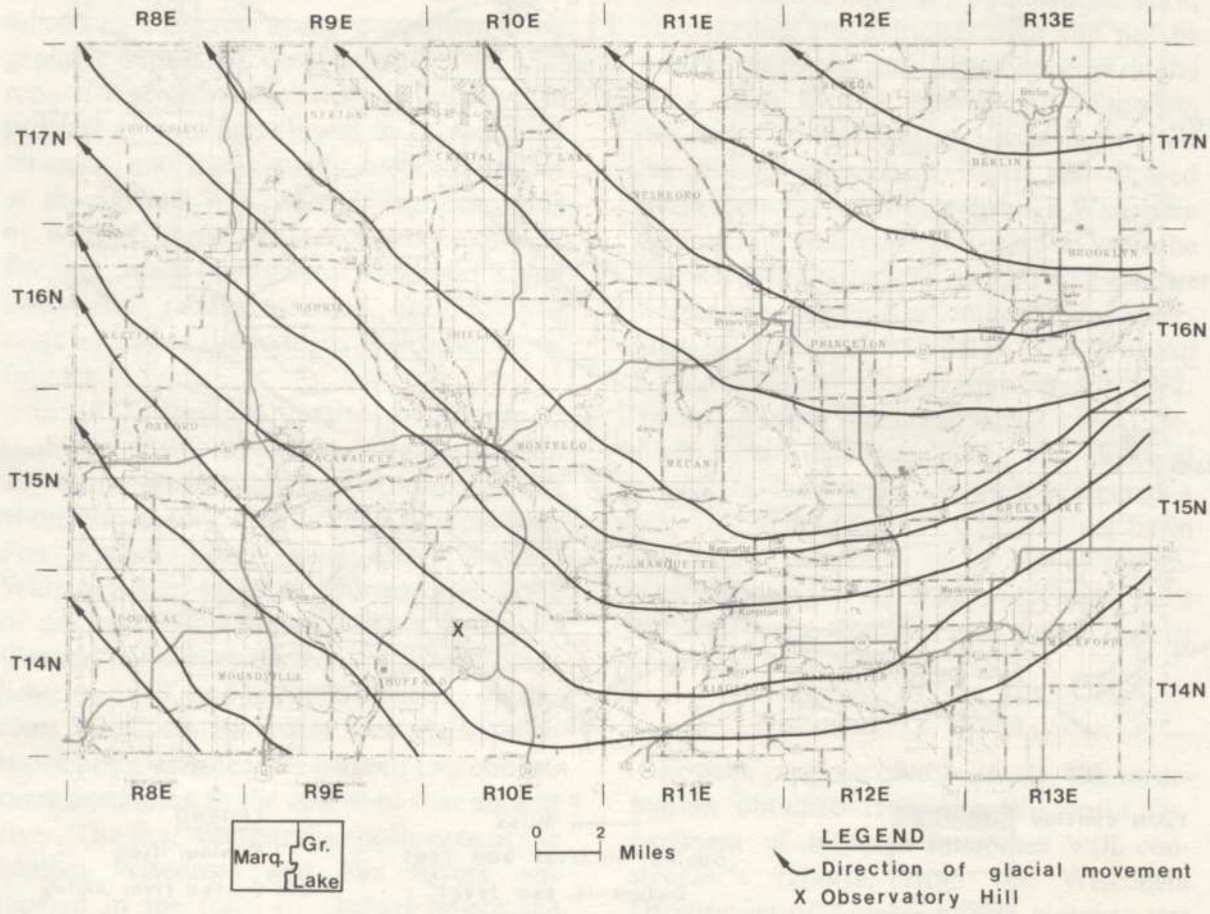


Fig. 3. Movement of the Green Bay Lobe of the continental glacier. Surface soil features indicated on USDA soil survey aerial photographs were used to map the direction of movement of the glacier. The glacier moved on a bearing of approximately 46° west of north through Marquette County.

The horizontal township lines of the Wisconsin coordinate system served as the reference lines throughout the task of measuring the direction of each vector. The angle which a vector made with one of these lines was considered a random variable with a common variance. Actually a different variance could have been associated with each sample area but, because the surface soil features indicating the direction of the glacier's movement were made by the same ice sheet, a common variance was assumed. In each sample area, A_j, the i^{th} vector made an angle θ_{ij}, with a township line. For each A_j, the sample mean, $\bar{\theta}_j$, was computed by the formula: $\bar{\theta}_j = \frac{1}{n_j}\sum_{i=1}^{n_j}\theta_{ij}$, where n_j is the number of vectors drawn from the sample area, A_j. Parallel lines of slope tan $(\bar{\theta}_j)$ were assigned to each A_j for every j in order to make a field of tangents. The resulting envelope of these lines is represented by the lines of movement which are outlined in Fig. 3. The direction of the glacier's movement, obtained in this manner by piecing together the trend of surface soil features of one sample area with another, still retains the uncertainty inherent to the data. The variance, σ^2, of the random variable, θ_{ij}, was assumed, as previously noted, to be the same for all i and j. It was estimated by the mean sum of square errors, as follows:

$$\hat{\sigma}^2 = \frac{1}{N-k}\sum_{j=1}^{k}\sum_{i=1}^{n_j}(\theta_{ij}-\bar{\theta}_j)^2$$

where $N = \sum_{j=i}^{k} n_j$ and k is the number of sample areas; specifically, k = 134, N = 921, and $\hat{\sigma}^2 = 75.4$. The standard deviation of ±8.7° indicates how much the direction of a vector varies about the mean direction of a sample area.

Presumably, the surface soil features in this region owe their existence to the most recent glaciation and subsequent weathering. If previous glaciers had covered the area, then the soil features made by them would have been obliterated by a succeeding glacier. The Wisconsin stage of glaciation is the most recent of the four Pleistocene glaciations that have touched Wisconsin. According to Maher (1982), the Green Bay Lobe of that glaciation disappeared from Marquette and Green Lake Counties approximately 12,400 years ago.

Based on the orientation of drumlins and other surface features which the Green ~~Lake~~ BAY Lobe created, the direction of movement of the glacier in Marquette and Green Lake Counties, as outlined in Fig. 3, agrees with the direction of glacial striae reported by Alden (1918) at a level of significance of 0.05. This high degree of correlation between the direction of glacial striae reported by Alden and the surface soil features forming the basis of Fig. 3 suggests that both the striae and soil features were made by the same glacier.

As the Green Bay Lobe moved south from Green Bay, it simultaneously expanded laterally to the west, so that in Marquette County the glacier actually moved from the southeast to the northwest (Fig. 3). In so doing, as the ice advanced, it encountered the eastern extent of the Wisconsin River and dammed it (Fig. 4). When the resulting impoundment overflowed, the water cut a new channel. In time, a total of eight drainage channels were cut (Fig. 1). The presence of well defined channels indicates that each was used for many years, perhaps for centuries at a time, in order for the impounded Wisconsin River to erode away an average of 200 feet of sandstone for each drainage channel.

MATHEMATICAL MODEL

To find the physical dimensions of a valley, the shape of each valley cross section was described by a mathematical model from which the depth, width, and other characteristics were found. The model consists of three parabolas joined together in a manner that ascribed a parabolic shape to the sides and bottom of a hypothetical valley

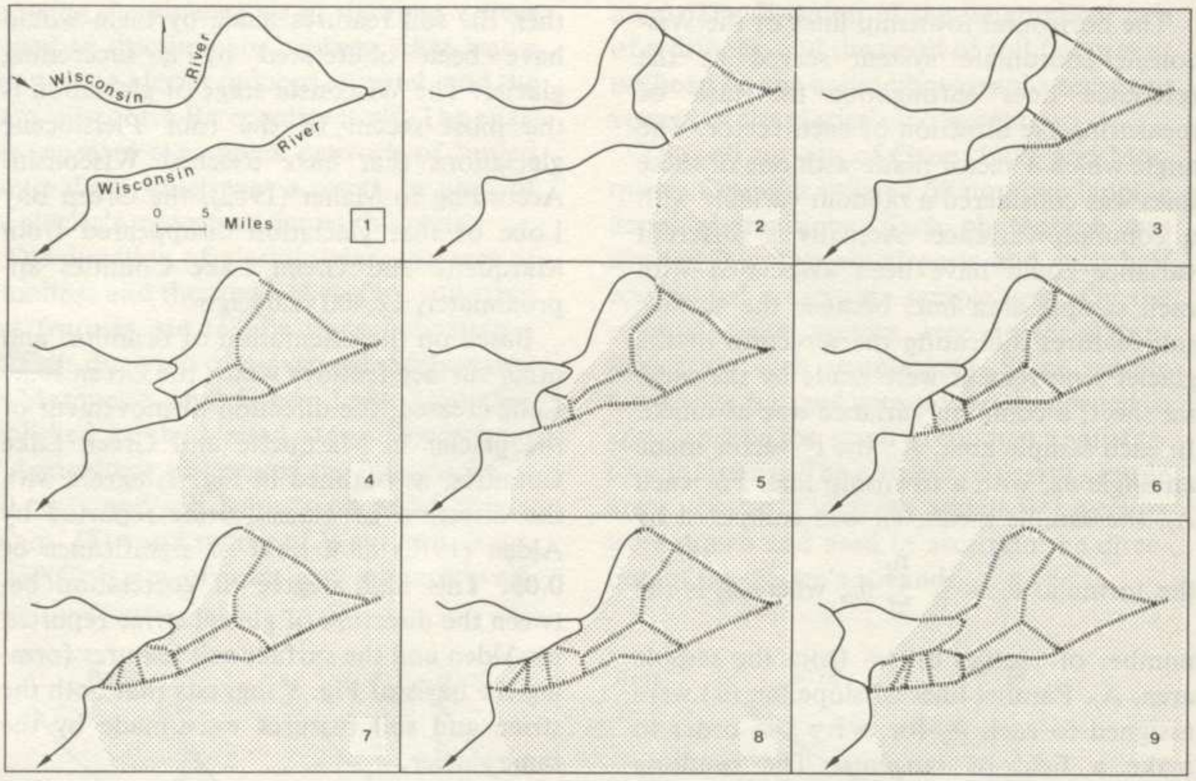


Fig. 4. Stages portraying the sequential damming of the ancient Wisconsin River by the advancing glacier. Stage 1 shows the course of the Wisconsin River before glaciation; it is the same course shown in Fig. 1. Stages 2 to 9 depict a possible association of each drainage channel with the terminus of the glacier. The glacier is shown by the dotted pattern. The dashed lines show the valleys buried under the ice. The area in this figure covers Marquette and Green Lake Counties.

cross section. The model cross section was defined by the following equations:

$$y_{I} = a(x-b)^2 + c \qquad b \le x \le x_2 \tag{1}$$

$$y_{II} = p(x-e)^2 + q \qquad x_2 \le x \le s \tag{2}$$

$$y_{III} = a(x-d)^2 + c \qquad s \le x \le d \tag{3}$$

where $s = 2e - x_2$ and is based on the stipulation that the cross section be bilaterally symmetrical. The purpose for dwelling on the derivation of a mathematical model arises from the chance to exploit the information supplied by that special circumstance wherein a buried valley is spanned by three water wells (Fig. 5). In this particular situation, the wells happen to bracket the location of the bottom of a valley and the elevations of the bottoms of the wells indicate the degree of curvature of a valley wall.

As will be seen, there is not enough data available to obtain a complete mathematical description of a hypothetical valley cross section as proposed via equations (1), (2), and (3), unless some artificial constraint is imposed upon the model. There are many con-

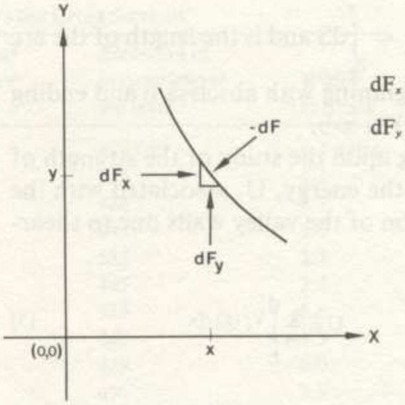
Fig. 5. Hypothetical valley cross section. The relative locations of the wells must be observed when using the equations found in the text.

ceivable constraints that could be used to make the model work, but the one given below by equation (7) worked very well.

The model so described by equations (1)–(3) requires the numerical solution of seven unknown parameters and hence the formulation of seven independent equations from which a unique solution may be obtained. From time to time, three water wells did line up to span a valley as illustrated in Fig. 5 and gave rise, thereby, to three equations. To obtain the necessary seven equations, four constraints were imposed on the model so as to complement the equations already provided by the three wells. The first two constraints that were chosen impose on the model the continuity from A to E (Fig. 5) which would naturally exist and the bilateral symmetry needed to make a simple second order model simpler. (The bilateral symmetry which was sought for the cross section warranted the condition, $e = (b + d)/2$). For the third constraint, parabolas I and II were appropriately joined at C to make the first derivative continuous all along the curve.

At this point, we have imposed three constraints on the model with one more to go. If, by good fortune, the buried river valleys were to have been spanned geographically by four wells lying in a straight line instead of the three, then all of the necessary information would be at hand. But, since the chance of having four wells drilled as such did not occur and because an arrangement of that kind frequently did occur with three water wells, a special constraint had to be found that would fulfill the requirement needed to arrive at seven independent equations and which would at the same time reasonably incorporate into the mathematical model some aspect of nature.

Recognizing that the forces acting on a valley wall must balance in order to preserve static equilibrium, the internal forces that bind the wall together were presumed to be equal and opposite to the outward forces that act to tear the wall apart. The outward forces acting on a valley wall are, in general:



$$dF_x = P(x,y)\,dy$$

$$dF_y = P(x,y)\,dx$$

where P(x,y) is the cumulative effect of the weathering and the pressure pushing outwardly at (x,y) due to the weight of the wall. The resultant force is $dF = P(x,y)\,dS$, where $dS = \sqrt{dx^2 + dy^2}$. Taking into account the assumption that the outward forces are equal and opposite to the internal binding forces, the resultant shearing force, dV, is:

$$dV = -P(x,y)\,dS$$

The function P(x,y) took the form of

$$P(x,y) = P_o \frac{(S_1 + S_3)^2}{4S_1S_3}$$

where P_o is a constant and S_1 is the length of arc AB and S_3 is the length of DE. For example.

$$S_1 = -\frac{b}{2}\sqrt{1 + 4a^2b^2} - \frac{\sinh^{-1}(2ab)}{4a}$$

It was reasoned that the nearer the points B and D lie to one of the valley's crests, the more pronounced the shape of the valley, and therefore the greater P(x,y) ought to be. In the other extreme case, it was reasoned that P(x,y) should approach some constant, P_o, when the valley becomes very shallow. Consequently,

$$dV = -P_o \frac{(S_1 + S_3)^2}{4S_1S_3}\,dS$$

$$\text{or } V(x) = -P_o \frac{(S_1 + S_3)^2}{4S_1S_3}\,S(x) \quad b \leq x \leq d \qquad (4)$$

where $S(x) = \int_b^x dS$ and is the length of the arc (Fig. 5) beginning with abscissa b and ending with x; $S(x) \cong x-b$.

Drawing upon the study of the strength of materials, the energy, U, associated with the deformation of the valley walls due to shearing is:

$$U = \frac{k}{A}\int_b^d V_y^2(x)\,dx \qquad (5)$$

where k is some constant, $V_y(x)$ is the vertical component of V(x), and A is the cross sectional area above the bottom of the valley;

$$V_y(x) \cong \frac{(c-q)}{(e-b)}\,V(x)$$

$$A \cong a(x_2-b)(e-b)^2 \qquad (6)$$

The final and fourth constraint that we want to impose on the model dictates that the energy, U, be a minimum.

In the course of the mathematical development, it was convenient to express the parameters of equations (1)–(3) in terms of e, the mid-point of the valley, as follows:

$$a = \frac{(y_3-y_1)x_2 + (y_2-y_1)(x_3-2e)}{x_2(x_3-2e)(x_2+x_3-2e)}$$

$$b = \tfrac{1}{2}\,\frac{(y_3-y_1)x_2^2 - (y_2-y_1)(x_3-2e)^2}{(y_3-y_1)x_2 + (y_2-y_1)(x_3-2e)}$$

$$c = y_1 - ab^2$$

$$d = 2e-b$$

$$p = a\,\frac{(x_2-b)}{(x_2-e)}$$

$$q = a(x_2-b)(e-b) + c$$

where y_1, y_2, and y_3 are the elevations above sea level of the bottoms of wells 1, 2, and 3 respectively. The relative locations of the water wells to e shown in Fig. 5 must be met in order to make the above expressions valid.

With the parameters expressed in terms of e, the task of obtaining the physical dimensions of a valley reduces to choosing e such that U, from equation (5), is minimized. In other words, the problem amounts to solving the equation

$$\frac{dU}{de} = 0 \qquad (7)$$

where, from equations (4)–(6),

$$U \cong \frac{kP_o(d-b-x_3)^4\,a(x_2-b)(e-b)}{6\,b^2(d-x_3)^2}$$

The solution of equation (7) which requires the use of numerical analysis pertains to that situation when, according to the model, the locations of three water wells are co-linear and they happen to span a buried valley.

To check whether or not the model adequately explains the data, a diagnostic plot of residuals versus predicted values generated by the model was made and is given in Fig. 7. The observed values are the elevations above sea level of the bottom of those wells that came into the path of a rotated cross section. The original cross sections were all rotated about their mid-points to make them perpendicular to a valley. Sometimes one of the nearby wells would intersect the rotated cross section and as a result would supply a data point with which to check the adequacy of the model. The funnel shaped pattern exhibited in Fig. 7 indicates a

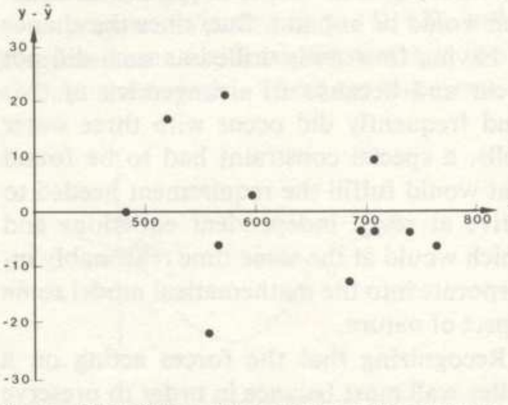


Fig. 7. Plot of the residuals versus predicted elevations above sea level from the model. An observed value is denoted by *y* and a predicted value by *ŷ*. Both coordinate axes are marked in units of feet. The funnel shaped pattern indicates a possible correlation between the expected elevation and variance.

TABLE 2. Parameters of Valley Cross Sections

Cross section[1]	a[2]	*Elevation of crests above* sea level	*Elevation of bottom above* sea level	*Width* at crests
1	−30.4 feet/mi^2	760 feet	475 feet	6.3 miles
2	−64.3	699	515	4.2
3	−67.9	731	486	4.1
4	−183.0	788	447	3.0
5	−154.0	696	535	2.3
6	−125.0	721	485	3.5
7	−36.1	935	576	6.6
8	−77.0	807	469	4.3
9	−48.0	787	429	6.0
10	−86.7	654	491	2.8
11	−77.0	723	549	3.5
12	−47.3	687	552	3.5
13	−1152.0	991	477	1.4
14	−1140.0	681	442	1.0
15	−723.1	638	519	1.4
16	−267.0	805	577	1.9
17	−95.0	837	674	2.7
18	−241.0	831	492	2.5
19	−302.0	813	592	1.7
20	−90.3	767	538	3.6
21	−99.0	814	394	4.3
22	−130.0	788	389	4.1

1. Corresponds to cross sections labeled in Fig. 1.
2. Refers to the leading parameter of equations (1) and (3).

possible correlation between the expected elevation and variance. The standard deviation of the elevations based on the mean sum of square errors is ±12 feet.

The twenty two cross sections listed in Table 2 and labeled in Fig. 1 reflect the benefits of the mathematical analysis. For some of the buried valleys, cross sections could not be obtained because the wells did not lie in a straight line or there were not enough wells in the area. Using the available cross sections and certain wells, the slope of the ancient Wisconsin River was found to be 1.6 ± 0.1 feet/mile and that of the ancient Wolf River, 1.8 ± 0.8 feet/mile. Furthermore, the results listed in Table 2 show that the depths of the glacier induced channels are approximately 200 feet deep. In one case, for instance, cross sections 13 and 14 reveal the existence at Montello of a 520 foot deep, 1 mile wide channel which as it exists today drops 35 feet in 0.5 miles.

In addition to the results of the mathematical analysis, information from several wells proved to have been particularly important in locating the buried valleys and it is tabulated below (Table 3).

TECHNIQUES USED IN CONSTRUCTING THE MAPS

Information obtained from well constructor's reports provided most of the data used in constructing the map of the preglacial river valleys and the topographic map of the bedrock. The location, annotated with the depth of bedrock, of each well was plotted on graph paper at a scale of 1 mile to a half inch. Centered at the location of the deepest wells, a circle was inscribed having a radius such that the circumference equaled

TABLE 3. Important Wells

Location T.N.-R.E.-Sec.	Owner	Material at bottom	Elevation of bottom above sea level
14-8-25	Endeavor Farms	SS[1]	485 feet
14-9-21	Turner	SS	552
14-10-11[2]		SS	575
15-8-17[2]	Creamery	SS	610
15-9-21	Vanearn	Granite	488
15-9-34	Preuss	Sand	436
15-10-6	Quinn	SS	558
15-10-16	Hauserman	Granite	485
15-10-36	Lettuce Cooling Plant	Granite	490
15-11-22	Klawitter	SS	420
15-11-30	Tidd	SS	717
16-8-15[2]	L. Kruger	Granite	512
16-9-25	Shimpack	Granite	485
17-11-4	Doiro	SS	462
17-13-6	Berlin Conservation Club	SS	473
18-11-34	Bartol	Clay	486
18-13-22[2]		SS	475

1. SS = Sandstone
2. Obtained from Alden (1918), otherwise obtained from DNR well constructor's reports.

the contour level of 700 feet. In effect, each of these wells was placed at the bottom of an imaginary bowl whose rim stood at 700 feet above sea level and whose bottom equaled the depth of the well. The radius of the bowl was obtained from the mathematical model in the following way. In those special cases where three wells fell in a straight line while spanning a valley, the shape of that cross section was estimated according to the procedure described earlier. The parameter *a* and the parameter *c* of all the cross sections were averaged together and the result served to describe a typical cross section. Knowing the depth of a well and height of the rim, in this case 700 feet, the radius was found by using equations (1)–(3) with the averaged parameters. The radius found in this manner can not account for the variability from one valley to another, nonetheless, ~~following~~ the path of the overlapping circles traced out a rough picture of where the preglacial river valleys existed.

Wells lying in the vicinity of the valleys were used in a triangulation method to locate as accurately as possible the bottom of a valley. Before taking that step, however, it was necessary to estimate the slopes of the ancient Wisconsin and Wolf river beds. Employing the method of least squares, estimates of the slopes were obtained based on the cross sections and wells marked in Fig. 1. Knowing the elevation of the river bottom at any point along a valley and the elevation of the bottom of a well lying on a valley's fringe, the distance of a well from the bottom of a valley was found by again using the model this time with the parameters associated with the cross section nearest to the well. From these wells an arc was swung with a radius corresponding to that distance which the valley's bottom was supposed to lie from a given well. Three intersecting arcs gave give a fix for the location of the bottom of a valley. Two intersecting or almost intersecting arcs were also used, if they were on opposite sides of a valley. And as a final resort, usually to compensate for gaps that sometimes occurred in the mapping of the valleys especially in the towns of Neshkoro and

Seneca, a single arc was used to reckon a position of where the bottom of a valley ought to be. Based upon the fixes, the midpoints of the valley cross sections, and the locations of certain wells that happened to reach the bottom of a valley, the locations of the preglacial river valleys were ascertained. The result was Transferred translated to the pertinent section of the Wisconsin Department of Transportation 1984 District Highway Map.

The method of contouring could have been used to accomplish the same end instead of the triangulation method that was actually employed. The contouring that was done is shown in the topographic map of the bedrock (Fig. 2). The levels were drawn freehand so that the accuracy of the levels is only about ±100 feet, whereas the accuracy of the elevations based on the mathematical model is ±12 feet. Because of that greater degree of accuracy, the method of triangulation was adopted for use in making the map of the preglacial river valleys. Once the map was made, approximately half of the mapping was field checked as time permitted. The map was also checked against aerial photographs and USGS topographic maps. In general, it was found that the wetlands in these three counties lie in the remnants of the ancient valleys.

The technique used in constructing the map of the glacier's movement was already explained earlier in the section pertaining to the discussion of the data.

INFLUENCE OF THE PRECAMBRIAN BEDROCK

To what degree the Precambrian bedrock influenced the courses of the ancient rivers and the glacier's movement in this region is largely a matter of conjecture. The Precambrian bedrock that underlies the sandstone and limestone is composed of granite and rhyolite. These igneous rocks were formed 1.765 billion years ago during a period of volcanic activity occurring to the northwest of Marquette County (Smith, 1978b). In subsequent ages, the sedimentary rocks of sandstone and limestone were formed on top of the Precambrian rock as a result of successive cycles of sedimentation associated with advancing and retreating seas (USGS, 1976). In a few instances, the Precambrian bedrock protrudes to the surface and is exposed as granite at Montello and Red Granite and the rhyolite of Observatory Hill in Marquette County and at Endeavor. Whereas the rhyolite forms the Precambrian bedrock in southeastern Marquette and Green Lake Counties, granite constitutes the bedrock in the northwestern section of the counties. The boundary between the two types of rocks bears 50° east of north (Smith, 1978b), and is essentially perpendicular to the direction of flow of the molten rock. The dashed line labeled T in Fig. 8

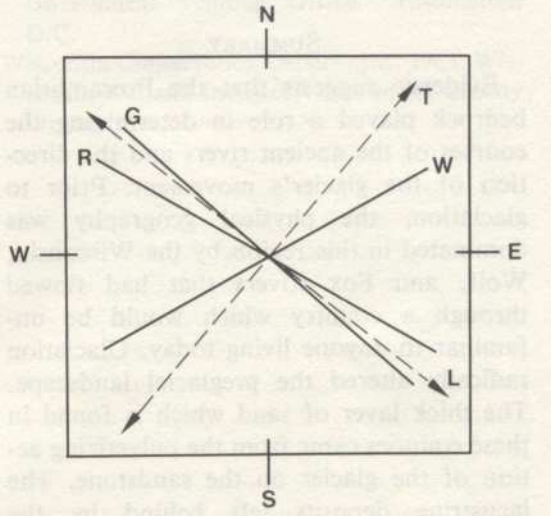


Fig. 8. Relation between aspects of the Precambrian bedrock and the direction of the glacier's movement and the courses of ancient rivers.

T = Axis of the contact between granite and rhyolite (Smith, 1978b).
L = Axis of the direction of flow of the molten igneous rock (Adopted from Smith, 1978b).
G = Direction of movement of the glacier in Marquette and most of Green Lake Counties.
R = Course of the ancient Grand River.
W = Course of the abandoned south branch of the ancient Wisconsin River.

The close associations of T and W and of L, G, and R suggest that the Precambrian bedrock influenced the courses of preglacial rivers and the glacier's direction of movement in Marquette and Green Lake Counties.

shows the direction of the contact between the granite and rhyolite, the granite being to the left and the rhyolite to the right. The dashed line labeled L in the same figure shows the direction of flow of the molten rock. The direction of the glacier's movement, G, and the course of the ancient Grand River, R, lie very close to L and appear to be correlated with the direction of flow of the molten rock. Also the course of the abandoned southern branch of the ancient Wisconsin River, W, seems to be correlated with the contact between the granite and rhyolite, T. Although the topography of the Precambrian bedrock is unknown, it appears from Fig. 8 that the bedrock affected the courses of preglacial rivers and the glacier's movement in this area.

SUMMARY

Evidence suggests that the Precambrian bedrock played a role in determining the courses of the ancient rivers and the direction of the glacier's movement. Prior to glaciation, the physical geography was dominated in this region by the Wisconsin, Wolf, and Fox Rivers that had flowed through a country which would be unfamiliar to anyone living today. Glaciation radically altered the preglacial landscape. The thick layer of sand which is found in these counties came from the pulverizing action of the glacier on the sandstone. The lacustrine deposits left behind by the retreating glacier helped to create the many and extensive wetlands remarkable to this region. Marquette County, in 1938, had the greatest proportion, 29%, of wetlands to its size of any county in the state (WCD, 1963).

The eight drainage channels associated with the successive damming of the ancient Wisconsin River were created by the advance of the Green Bay Lobe through Green Lake and Marquette Counties during the Wisconsin stage of Pleistocene glaciations. The network of buried valleys was discovered primarily by means of well constructor's reports and mapped with the aid of a mathematical model that was designed to describe a hypothetical valley cross section. All of the preglacial river valleys in these counties are buried as a result of glaciation. What once were deep river valleys are now hidden. Only the muck farms and wetlands most visibly mark the locations of those valleys today.

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