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BEGINNING AND RECESSION OF SAINT ANTHONY FALLS¹

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INTRODUCTION

It is now 30 years since Professor N. H. Winchell first discussed the history of Saint Anthony falls and 20 years since his final description of "The Recession of the Falls of Saint Anthony" was published.²

The conclusions which he then reached have stood without revision or notable modification to this time. Both his description of the sharply defined gorge in which the Mississippi river runs from the falls at Minneapolis to near its junction with the Minnesota river and his interpretation of the gorge as the work of the gradually receding waterfall appear to have been generally accepted as final. The Saint Anthony gorge stands therefore today with that of Niagara falls, as one of the great geological timepieces by which the duration of time since the Glacial period may be calculated.

The gradual recession of Saint Anthony falls for the distance of about 8 miles in about 8,000 years, marking the time since the final melting of

¹ Manuscript received by the Secretary January 21, 1908.

² Geological Survey of Minnesota, Fifth Annual Report, 1877, p. 175. Final Report, vol. II, 1888, p. 313.

the glaciers from the north, as calculated by Winchell, seems fully evident from the phenomena and data as he represents them to us. His presentation of the subject is such that little discoverable evidence would

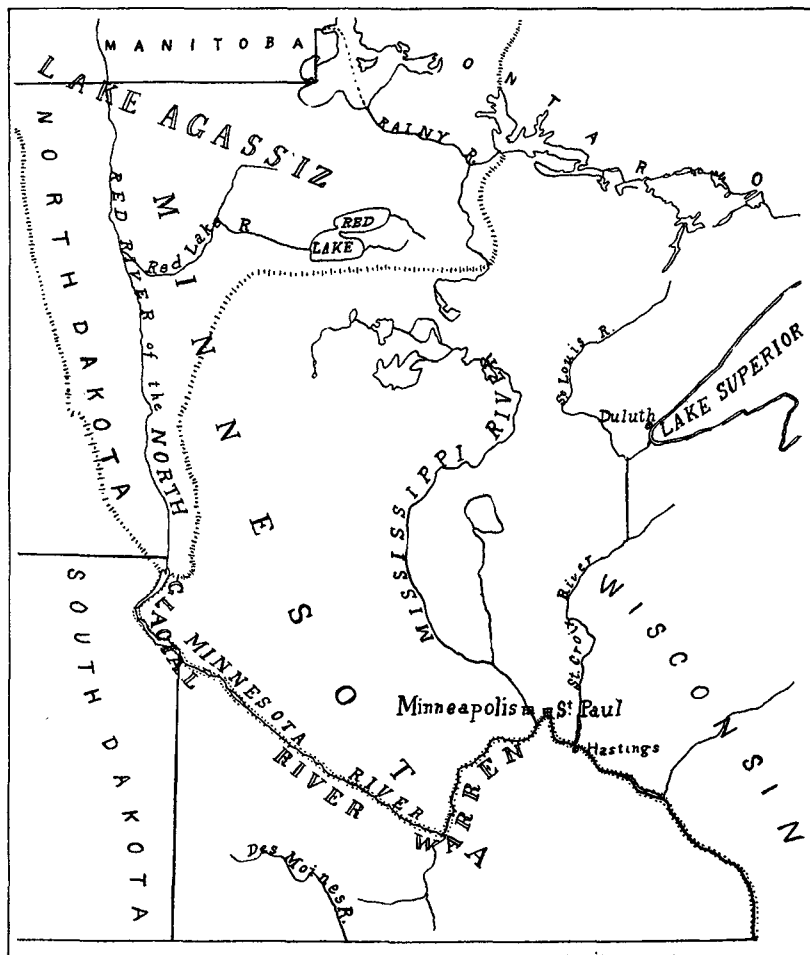


FIGURE 1.—Map showing the general Relation of Glacial Lake Agassiz and River Warren to the Minnesota and Mississippi Rivers

appear to have escaped his attention, and therefore no great modification or reversal of his conclusions might be expected.

More than 10 years ago I came by accident upon evidence which had been previously overlooked, and which led me to think that Winchell's interpretation might be open to important modification. This idea was

shared by my fellow-student, Arthur H. Elftman, to whom I am indebted for assistance also in some resurveying of the gorge. That the matter is here presented is due to the friendly suggestion of Frank Leverett, Dr Warren Upham, and Professor C. W. Hall.

In the following paragraphs the general method and results of Winchell's work on "The Recession of the Falls of Saint Anthony" are adopted, as are also the particulars of the same in so far as newly discovered evidence does not demand revision.

In 1890 Dr U. S. Grant announced³ a discovery that the gorge in which Minnehaha creek flows from the falls of the same name to its confluence with the Mississippi river is in greater part the gorge of an abandoned arm of the river rather than that of the creek. His discussion of this particular feature brings out the additional detail in regard to the recession of Saint Anthony falls, namely, that the falls upon a smaller arm or stream receded proportionately less than that upon a larger arm or stream and the whole rate of recession is lessened by the dividing of the falls. Grant's conclusions are in accord with Winchell's. Evidently Doctor Grant took no note of certain terraces which stand within the abandoned gorge which he described.

I shall adopt in this paper the general results of Doctor Grant's study, with such addition as the evidence of terraces within the gorge requires. It is in fact from studying these terraces and similar ones in another abandoned gorge which I had found some 10 years ago, and later still others along the main gorge, that I have been led to revise for myself, first Grant's interpretation of Minnehaha gorge and then Winchell's account of the Saint Anthony Falls recession. It is my aim at this time to consider, in the light of new evidence, especially the beginning and early stages of Saint Anthony falls and the gorge at Fort Snelling. The entire history of the gorge and its relation to events of the Glacial period are included.

CONTRASTING VALLEYS OF THE MISSISSIPPI AND MINNESOTA RIVERS

At the junction of the Mississippi and Minnesota rivers the valleys present a strong contrast. The valley below the junction and that of the Minnesota above the junction are one, in that they are continuous in direction and are alike in being one-half mile or more wide, flat bottomed, and bordered by steep slopes 100 feet or more high. In contrast, the Mississippi valley above the junction runs at an angle with that below,

³ "Account of a deserted gorge of the Mississippi near Minnehaha falls." *American Geologist*, vol. 5, 1890, p. 1.

and is a veritable gorge, only a fourth of a mile wide, over 100 feet deep, its steep talus-covered sides crowding the river. This relation is shown in figure 2.

For several miles in each direction from their junction these valleys are cut into the same geologic formations. The features in which the valleys are alike are therefore referable to influence of the ground rock forma-

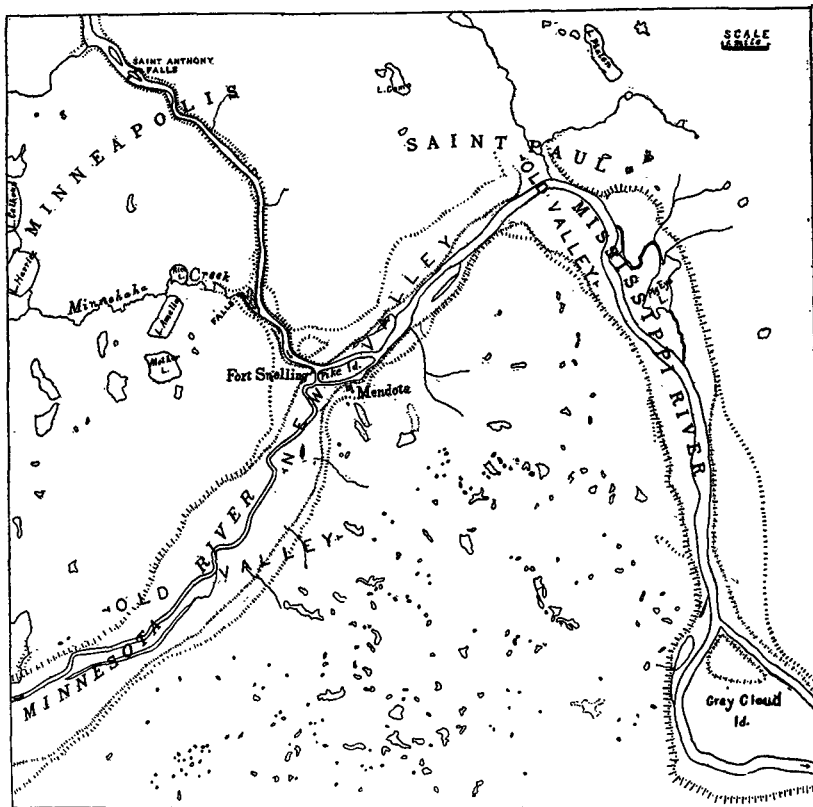


FIGURE 2.—*Map of the Minnesota and Mississippi Rivers near their Confluence*
Showing the relation of old and new valleys and of the upper and lower scarps bounding the terraces of the rivers

tions, while the contrasting differences are due to other causes, namely, to the different streams which made the valleys.

It has been heretofore supposed that the large, broad Minnesota-Mississippi valley is an "old" valley, in contrast to the gorge of the Mississippi, which is a "young" valley. The walls of the latter are fresh or talus-covered only, while the walls of the former have been described as

"old." In fact, the walls of the larger valley from 2 miles above the confluence of rivers to 6 miles below it are "young." That which N. H. Winchell⁴ and others have written about the Minnesota and Mississippi course being "old" is true above and below the limits just mentioned. There the glacial drift lies down over the walls of the valleys.

The old valleys and new valleys referred to here are respectively pre-Glacial and post-Glacial valleys. Understanding of the distinction between them involves some general knowledge of the geologic formations of this region. Not including alluvial deposits, dune sands, talus, etcetera, the formations are the following:

(1) The glacial drift, consisting of loose boulder-clay, sand, and gravel from 0 to 100 feet or more thick, is the topmost geologic formation.

(2) Next is the base of the Galena (Trenton) series, comprising practically horizontal strata with eroded upper surface. From 0 to 80 feet of shale overlies 35 feet of limestone. For the greater part the shales are absent and the glacial drift rests on the limestone, which consists of two beds, namely, about 15 feet of massive limestone on 18 feet of laminated limestone. At the base of the latter the strata are shaly for 2 or 3 feet.

(3) The next subjacent formation is the Saint Peter sandstone, which is over 150 feet thick and passes below the rivers' levels. It is friable, easily eroded, and the removal of it by streams causes the several cascades of the region, which plunge over the persisting ledge of limestone. The top of the Saint Peter sandstone and the limestones is practically level, so that the height of any waterfall here is determined by the depth to which the sandstone is excavated by the stream. The steep sides of the valleys also are generally due to the easily eroded Saint Peter sandstone and the lateral cutting by the streams, by which the more firm limestone ledge is brought out, often as a cliff skirted by a talus slope.

The valleys in the neighboring region about the confluence of the Mississippi and Minnesota rivers may be classified into three kinds:

A. Old valleys, with cliffs or slopes covered by undisturbed boulder-clay or other glacial drift. Some of the old valleys are quite or entirely buried. Lakes Minnetonka, Calhoun, and others lie in such drift-covered valleys.

B. Reexcavated old valleys, which were partly buried by glacial drift, but later are occupied by streams again.

C. New valleys, which have been made since the glacial deposits were made and whose cliffs are not covered by glacial drift.

In short, the last, or Wisconsin, glacial drift was deposited or filled over all preexisting valleys in this vicinity, leaving it for later streams to either reexcavate the old valleys or cut new ones. The valley and gorge from Saint Anthony falls to the junction at Fort Snelling is clearly a new course made by the Glacial and Recent Mississippi. The valley of

⁴ Geological Survey of Minnesota, Fifth Annual Report, 1877, p. 176.

the Minnesota, with that of the Mississippi below the confluence, as said, has been heretofore considered as a pre-Glacial valley, reexcavated by the Glacial river, the river Warren, and its successor, the Minnesota.

It is my view that the larger valley, the Minnesota-Mississippi course, from 2 miles above Fort Snelling to 6 miles below it (see figure 2), is also not pre-Glacial, but is a new course cut by the glacial floods and the river Warren. The pre-Glacial course may have run by a now buried valley south of the present course—that is, from a few miles above Fort Snelling, eastward, in the direction of Hastings, or Gray Cloud island, there joining the present Mississippi's valley. The pre-Glacial river corresponding to the Mississippi may have entered the Minnesota valley above the present confluence, coming by way of the present lake Minnetonka and Purgatory creek. At Saint Paul the new course of the river joins another pre-Glacial valley, which it follows thence southeastward.

The history of the two contrasting valleys at the confluence of the Minnesota and Mississippi rivers is therefore the same excepting in the matter of magnitude and changes of the rivers which made them. The rock formations are alike and the same lime rock ledge and fresh talus slopes bound their sides. Only in size the valleys are contrasted, indicating that the Minnesota valley originally carried the main stream, but now the tributary.

The glacial river which followed the present Minnesota valley and thence the Mississippi was the main stream at the time of the ice-retreat. As shown by terraces in the Minnesota valley⁵ and by the scarp above the lime rock bench which lies between Fort Snelling and Saint Paul, this river flowed for a time at a high level, to or above the present 820-foot contour line. At that stage it was one mile wide in its steep-sided channel at Saint Paul. It spread out over a large part of the present Fort Snelling reservation. Its bottom was above the limestone ledge. Correspondingly the Glacial Mississippi was about one-half mile wide, as indicated by scarps and terraces.

As noted by Winchell,⁶ there could have been no Saint Anthony falls at that high stage of the river. The flood in the Minnesota River valley must first "recede," or rather the channel from Saint Paul to Fort Snelling must be cut down below the limestone ledge, before the falls could have formed at Fort Snelling. In what exact manner the channel was cut down is somewhat uncertain. It may be noted, however (see figure 2) that this valley is double—that there is one distinct

⁵ Warren Upham: *Geological Survey of Minnesota, Final Report*, vol. ii, 1888, p. 91.

⁶ *Geological Survey of Minnesota, Final Report*, vol. ii, 1888, p. 338.

channel below the other. The higher lies above the limestone ledge and is bounded by clay-shale and glacial morainic deposits, into which it has the appearance of having been cut by a large stream. The other is half as wide as the higher one and lies below the limestone ledge and in the Saint Peter sandstone, which appears in its bounding walls. This condition of double valley extends from above Fort Snelling to the center of Saint Paul city. Related to the lower channel are terraces of limestone shingle within the valley at west Saint Paul, and potholes and loosened limestone blocks along the left wall of the channel, such as a gradually receding cataract would produce in making the channel; also an island of Saint Peter sandstone stands⁷ midway in the valley of the Minnesota river, southwest quarter of section 33, Mendota, marking the place where such a receding cataract should have died out upon encountering the pre-Glacial channel of the Minnesota river. These phenomena are readily explained by the hypothesis that a cataract once receded from Saint Paul to and above Fort Snelling, even though they may not constitute indisputable proof of the same.

Further evidence appears from comparison of this double valley with that of other channels which are known to have been cut by recession of falls or rapids. Dr U. S. Grant, in studying the abandoned gorge at Minnehaha, emphasizes "the fact that the river did not cut its gorge of the same width as the channel in which it was flowing before wearing through the limestone."⁸

Whether the view which I present of the cutting of this double valley is accepted or not, it will be agreed by all who may study this part of the valley that it is swept clear of glacial drift and owes its present form and size to the Glacial river, a stream vastly greater than that which now meanders within its rocky walls. The deeper, narrower channel now serves as a valley for the Mississippi and Minnesota, with accompanying floodplain, swamps, and lakes. It will be conceded, too, I hope, that the river did not necessarily recede in volume as it was first drawn from the wide upper channel into the deeper, and therefore narrower, one.

According to the view which I have taken from the evidence already presented, the contrast in the valleys at the confluence of the Minnesota and Mississippi rivers is due directly to the size of the streams which made them. The valley from Saint Paul to and beyond Fort Snelling, which may be termed the River Warren valley, was made in a way very

⁷Upham: *Op. cit.*, p. 81.

⁸Grant: *Op. cit.*, p. 4.

similar in all respects to that of the Saint Anthony gorge, which indeed is a continuation of the former.

BEGINNING OF THE SAINT ANTHONY GORGE

The erosion of Saint Anthony falls and gorge of the Mississippi began near the present Fort Snelling at a time when the Glacial river Warren (see figure 1) was at full volume. Winchell has estimated this beginning to have been at a much later time. He says:

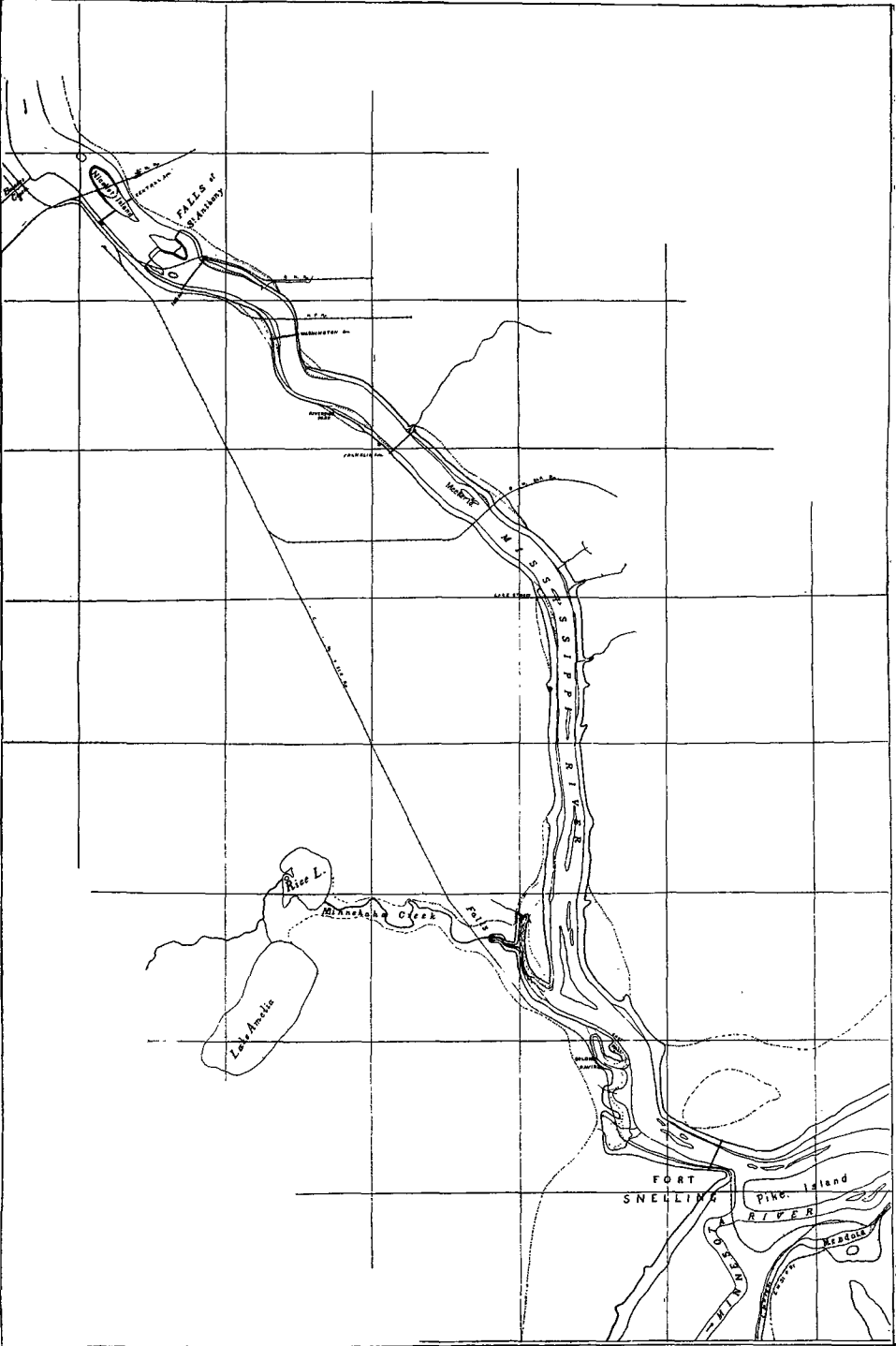
"There is reason to believe that the volume of the Mississippi was reduced to its modern stage before that of the Minnesota. When the Minnesota valley was finally relieved of the drainage from lake Agassiz, the falls of Saint Anthony may be said to have fairly entered upon the uniform recession which has been above considered."

The Mississippi river undoubtedly did quite reduce to its modern stage while the river Warren was yet at full volume, and it may be assumed that such reduction in volume was affected by the final melting of the glaciers from the head of the Mississippi, as Winchell has above said; but that the Mississippi river was reduced to its modern stage before the recession of the falls began above Fort Snelling is not fully evident, and it is more than probable that the river Warren reduced to the Minnesota River stage long after the recession of the falls began. Besides the evidence which I have already presented, a study of the terraces within the gorge of the Mississippi will be given in a later paragraph to show when the falls began. The mouth of the gorge will be now described for the same purpose.

The gorge of the Mississippi at Fort Snelling is remarkably narrow, and its mouth appears as if truncated by the larger valley—the Minnesota (see plate 1). There is an abandoned channel or arm of the Glacial Mississippi, or, perhaps more strictly, of the river Warren, a half mile north and east of the mouth of the gorge. The land immediately on the west side of the gorge is also not high. The mouth of the gorge of the Mississippi is in fact far out in the original flat valley of the river Warren, on the upper end of what was evidently once an island.

From the position of the gorge's mouth it might be taken that the Mississippi had originally "plunged" by the shortest route over the wall of a preexisting Minnesota valley. Such a view appears to be the one entertained by Winchell. However, the reason for the narrowness and also for the particular location of the gorge's mouth may be explained only by the existence of a buried narrow pre-Glacial valley which could

² Winchell: *Op. cit.*, p. 338.



MAP OF THE MISSISSIPPI RIVER FROM MINNEAPOLIS TO FORT SNELLING
Showing the recession of Saint Anthony falls

control the Mississippi's course at that place. The buried valley is evident at Mendota, opposite the mouth of the gorge, on the south side of the valley of the river Warren. An embayment lies in the valley's wall at Mendota. The back of the embayment is drift-covered or drift-filled, while the limestones and sandstone end abruptly on either side, as in case of a cross-cut buried valley. This buried valley may be a small branch from the buried pre-Glacial Minnesota lying south of Mendota, and it may have headed possibly a mile northwest of the present mouth of the gorge of the Mississippi. Such a valley transverse to the river Warren could have influenced that river's abandonment of the left channel and at the same time drawn the Mississippi into its present course.

In cutting the deeper channel, as before described, the river Warren followed obviously the right side of its older high and wide valley (see figure 2). The abandonment of the channel on the left side of the island opposite Fort Snelling is accounted for in a general way as due to the drawing of the stream to the deeper channel as it was made. In particular, however, one circumstance requires explanation, namely, the abandoned left channel beds upon the limestone ledge, as low as the crest of Saint Anthony falls would be at any stage. From the upper end this channel appears to be a course of the Mississippi abandoned just prior to the recession of Saint Anthony falls. At the lower end there is no channel nor alluvial beds and no evidence of a cataract where the Mississippi could have plunged from this channel into the deeper valley of the river Warren. The only explanation for that circumstance is that the river Warren for about a mile below the present Fort Snelling and the Mississippi for about a mile above that point may have settled in their valleys simultaneously and quickly as the oblique pre-Glacial valley at Mendota was encountered by a receding cataract of the former river, which would be first at a point about opposite the lower end of the left channel. Into this drift-filled and easily eroded course the rivers Warren and Mississippi could quickly settle, causing the abandonment of the left channel at once.

There appears therefore to have been no Saint Anthony falls at Fort Snelling, but rather the river settled into a narrow, easily eroded pre-Glacial valley at that place. The time of this event was while the river Warren had not yet cut its valley to near completion.

EARLY STAGES OF THE FALLS

Distinct evidence that there were falls or strong rapids on the Mississippi above the mouth of the gorge is found first about a mile upstream,

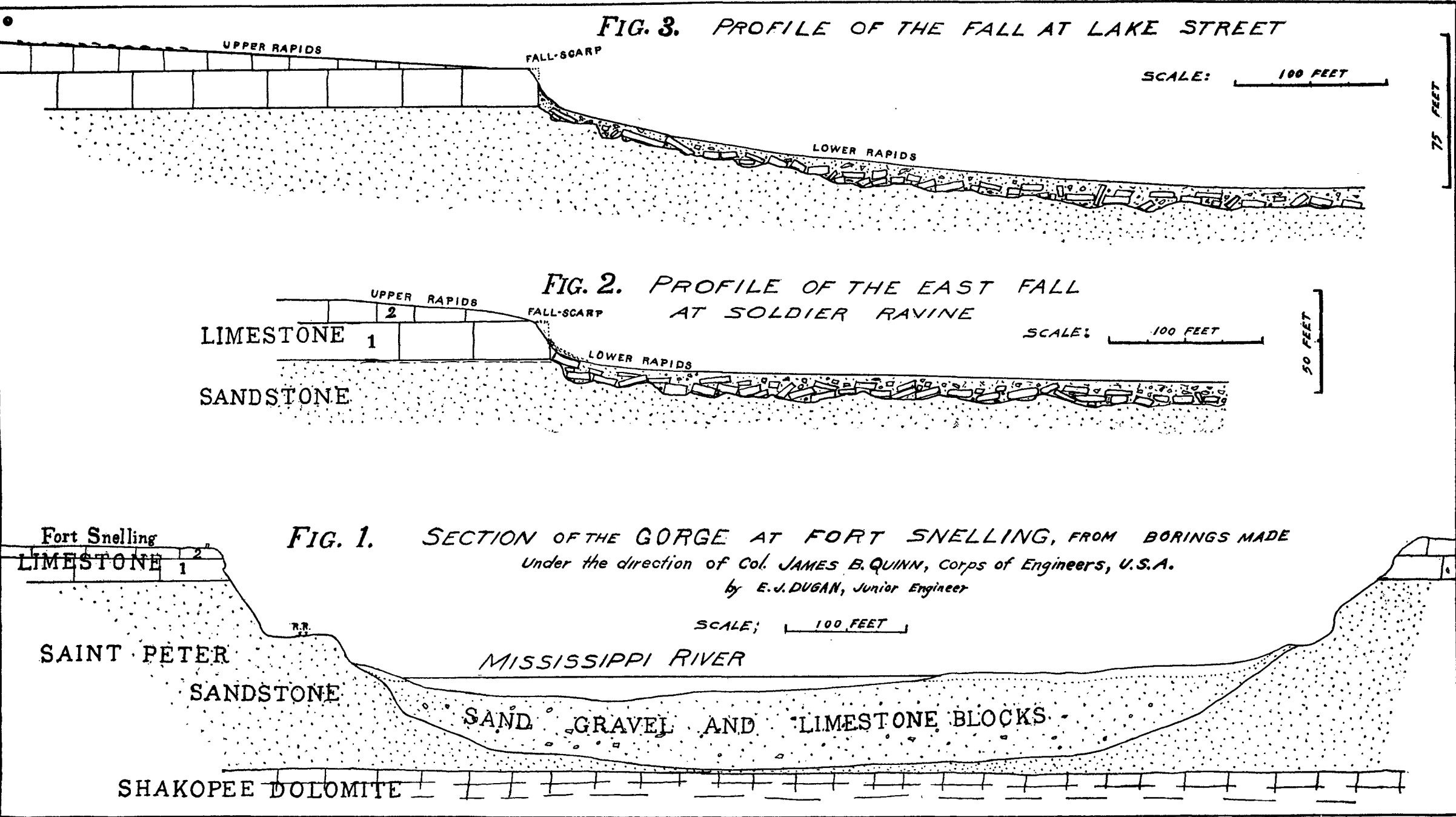
on the west side of the river. From the angle in the right wall of the gorge, in southeast quarter of section 20, township 28 north, range 23 west, for three-fourths of a mile to the north line of the section, there are scarps and terraces within the gorge which show quite unmistakably the former presence of falls and the character of the same. At Minnehaha other such evidence exists, as shown on the map, plate 1.

The best defined evidence is perhaps that near the north side of section 20, where there is an abandoned gorge which was once an arm of the Mississippi. This gorge does not appear in either name or form on any map known to me. Lately I have heard it called Soldier ravine. It is a clearly defined gorge about 800 feet long and 200 feet wide, flat bottomed and with steep slopes. It opens upon the right side of the main gorge at one end and ends blindly at the other. At its lower end it is like a "hanging valley" in relation to the main gorge. There is no stream or line of drainage now entering this gorge, although a steep gulch is cutting at the hanging end. This ravine and a roadway reveal that the floor of the gorge is made up for a depth of 5 to 15 feet of limestone blocks, with a few drift boulders resting on a very uneven or pockety surface of the Saint Peter sandstone. On the right and left, at the mouth of this gorge, are terraces about 10 feet above the floor, which consist likewise of blocks and boulders. These terraces have the same height as the bottom of the gorge at its head, namely, 35 to 40 feet below the top of the level limestone ledge. The head of the gorge has steep slopes like the sides. There appears to have been no filling in of the bottom such as to increase its original height.

Leading into the head of Soldier gorge, there is a channel 10 feet deep, 60 feet wide at the bottom and 100 feet over the top, which appears to represent the final stage of the stream which made the gorge. The channel is cut partly in drift, but mainly in the limestone. It runs now from the head of the gorge 200 feet back to the edge of the next cliff, where it is cut off. The channel is about one-half as wide as the gorge, and correspondingly the head of the gorge is narrowed or rounded. At earlier stages there was probably a larger stream that made Soldier gorge.

The evidence therefore indicates that Soldier gorge is an ancient abandoned branch of the Saint Anthony gorge, built by a receding cataract, the height of which was about 35 feet, measuring from the top of the limestone ledge to the bottom of the gorge. The gorge was abandoned somewhat gradually. The history of this gorge from beginning to end, I find, is involved in an interpretation of the bench which was an island on the east side of the gorge.

There was doubtless a fall on the arm of the river on the east of the



SECTIONS AT FORT SNELLING

Figure 1 is a section across the Mississippi river near the mouth of Saint Anthony gorge; figure 2 is a profile of the ancient fall 1½ miles above Fort Snelling; figure 3 is a profile of the ancient fall 4 miles above Fort Snelling

island, and the recession of that one to a point above the other doubtless caused the abandoning of this, the shorter gorge. The bench or island did not merely divide the streams, the falls, and the gorges, but it, too, gradually uncovered and extended as the gorges were making. For example, on the east side of the island there is the remnant of the wall of a cataract and gorge. The crest of this cataract is level with the top of the island (figure 2, plate 2), and shows that the stream flowed across the north part of the bench, descended by a short rapids 10 feet, plunged then 25 feet, and then fell about 5 feet more in the next 50 yards. At that point the terrace is cut entirely off by the steep cliff made by lateral erosion by the Mississippi. Along the cliff a person can see the nearly longitudinal section of the entire rapids and fall. The front of this fall extends in straight line northeast to southwest and the stream ran southeasterly. Above the fall the river at that stage covered the top of the limestone bench, there being notably no deepened channel for the stream.

The east fall just described must represent a stage when Soldier gorge was half made, since the latter extends so much in front of the other. At the southwest corner of the island there is similar evidence of a cataract which relates to the terrace at that point, though it is not so clearly marked off as that of the east fall. It may, however, be mentioned as the west fall, contemporaneous with the east fall, indicating the stage to which Soldier gorge had then cut. The approach of the stream to this west fall is over the top of the limestone bench which later became the greater part of the island.

The island appears, in short, to have been produced by the dividing of the falls, and not the dividing of the falls due to an already existing island. The island at first was small and located at the brink of the falls. As the gorges on either side grew longer, the intervening bed of the stream was abandoned, thus extending the island. Finally this became the west bank of the river after Soldier gorge was abandoned. The island may have once extended some 500 feet farther north than the bench now does, that much of the cliff having since been cut away by the Mississippi at its present stage. If the island was so extended, the point at which the main fall and gorge intercepted the stream which was flowing to Soldier gorge might be some 750 feet north of the last named.

What I have called the east fall may in fact have been either a middle fall or for a time part of the main east fall. In either case the main east fall appears to have receded in a course which was well toward the present left wall of the gorge of the Mississippi here. The Soldier gorge was the shorter one and therefore had a more rapid descent to the junction than the other had. Exact comparison is, however, not practicable.

Southward from the mouth of Soldier gorge, there are other block-covered terraces skirting the limestone scarp for half a mile, which formed in part the sites of falls and in part the walls of consequent gorges alongside of falls. The Mississippi river at that early stage swept over the limestone bench west as well as east of the present railway track above the limestone scarp. The terraces here are all intercepted by the sandstone scarp which bounds the foot of the main gorge at no great distance from the limestone scarp, and they are crossed by three creeks, which have made deep ravines, so that their evidence is obscured. Their surface appears to have been covered by fewer and smaller limestone blocks than the more northern terraces were, and the Saint Peter sandstone, being thus less protected, has suffered more from subsequent erosion. The last terrace toward the south is notably little protected by limestone blocks. It is high, however, a few feet only from the top of the sandstone. The near-by limestone scarp on the north lacks the upper limestone bed. There appears to have been at this point a rapids or fall of 20 to 25 feet only, though the bed of the channel was 30 to 35 feet below where the top of the limestone would be if the limestone formation was entire here as it is elsewhere.

Briefly stated, the evidence shows us that the Saint Anthony falls at this early stage was as low as possible—that is, measuring from the top of the limestone which formed the crest, the falls were 35 to 40 feet to the bed of the river. The limestone is nearly 35 feet thick, so that the foot of the falls nearly coincides with the top of the Saint Peter sandstone. This sandstone was excavated 5 to 20 feet, this depth being filled again by blocks of limestone and debris. The descent from the foot of the fall in Soldier gorge is gradual, while that of the east fall is at first more rapid. From the evidence altogether, I estimate that the bed of the Mississippi at a distance from the fall, as at Fort Snelling, was 60 feet below the top of the limestone ledge at this stage. From this ledge now to the river is about 100 feet, and to the rock bottom of the gorge at Fort Snelling 175 feet, as shown in plate 2, figure 1.

THE GORGES AT MINNEHAHA FALLS

The Minnehaha gorge begins at the mouth of the creek, on the right side of the Mississippi river, about half a mile above Soldier gorge, just described, and two miles above Fort Snelling. It extends for half a mile (see map, plate 1), and then, as U. S. Grant has made known, it branches, each branch extending about one-eighth of a mile to an abrupt head. The gorge as a whole may be distinguished into three parts—the

gorge of Minnehaha creek above the junction, that below the junction, and the abandoned branch. The abandoned branch and that below the junction Grant interpreted as the work of a former arm of the Mississippi river, while the part of the Minnehaha gorge above the junction is exclusively the work of that creek. To a certain degree that interpretation is correct.

Minnehaha creek flows some 20 feet wide above and below the falls. At the falls it spreads out over a short rapids, and then plunges 60 feet into the gorge of its own making. The stream descends more than 40 feet from the base of the fall to its mouth. For 600 feet from the fall it flows in the part of the gorge which it alone has eroded. This Upper Minnehaha gorge is about 200 feet wide. At its head it forms nearly a semicircle, with the falls at its deepest part. The fall is thus apparently in a gorge much greater than its own width, though in fact the bottom of the gorge is only wide enough for the fall and the stream. The height of the falls is nearly the full depth of the gorge at its head, and fully half this depth is in the easily eroded Saint Peter sandstone. Deeper erosion is prevented mainly by the blocks of limestone which have fallen on the sides and bottom of the gorge and over which the stream rushes in its rapid descent from the foot of the fall. From the Upper gorge the stream enters what may be termed here the Lower Minnehaha gorge, through which it descends gradually to the Mississippi river.

The Upper and Lower gorges are alike in respect to narrowness at the bottom and rapid descent, and since the Upper gorge is crooked, its junction at nearly right angles with the Lower gorge is not an exceptional feature. The sole reason for distinguishing the Lower Minnehaha gorge from the Upper is because there is a third part which extends continuous in direction, width, and depth with the former. This branch of the gorge is now fenced as a deer park and may be designated the Deer Park gorge. It extends with slowly decreasing depth for about 1,000 feet from Minnehaha creek and ends blindly. Grant interpreted this and also a distinct channel which runs from above the end of the gorge to the Mississippi as the course of an ancient arm of the river, which they must be. The channel is flat bottomed, cut quite down to the limestone ledge, and is 300 to 400 feet wide, with an escarpment 10 to 15 feet high on either side. The left scarp runs from its north end, on the brink of the present gorge of the Mississippi, around in a curve back to the same near the mouth of Minnehaha creek. The right scarp coincides with the right wall of the Deer Park and Lower gorges.

That there was an island in the Mississippi dividing a main east arm from the longer west arm before Saint Anthony falls had receded to the

mouth of Minnehaha creek is therefore evident. That the Lower and Deer Park gorges were cut first by an arm of the river is also evident, and was done doubtless with a receding cataract at every stage. In the end of the Deer Park gorge was once a large cataract. There is no reason to question Grant's theory for the abandoning of the channel and gorge on the west side of the island, namely, that the cataract on the east side reached the head of the island first, and thus drew all the stream from the west channel. That the Deer Park gorge was made and abandoned at a time when the Upper Minnehaha gorge had been only begun is evident from comparison of distances reached by two gradually receding falls, Saint Anthony falls having receded 6 miles while Minnehaha falls receded one-eighth of a mile in the same time. The great size of the stream accounts for the rapid making of Deer Park gorge.

A feature which has been overlooked and which compels some revision of Grant's interpretation of the three parts of the gorge is that of a strong terrace within the Deer Park and Lower gorges. Considering the tract of land between the abandoned channel and gorge and the Mississippi river, the top of this tract is rather level and may be called the first terrace. It is bordered by a quite uniform scarp of the abandoned channel, as before described. Between this scarp and the gorge is the second terrace, resting on the limestone ledge. The descent from the limestone ledge to the bottom of Minnehaha gorge is in places a single scarp, but mostly there are two scarps with a distinct terrace, the third terrace between them. On the point of land between Minnehaha creek and the river the third terrace is well shown. Two large buildings of the Soldiers' Home stand on it, and their third-story windows are about on a level with the first story of buildings which are on the next higher terrace. The third terrace here is about 30 feet below the second and 75 feet above the river. Its top for 10 feet or more is made up of great blocks of limestone which rest on Saint Peter sandstone, all of which is well seen in the nearly vertical cliff next to the river.

The third terrace is a part of the original floor of the gorge, and the great angular limestone blocks on its top show it to have been made at the foot of receding falls. The same terrace extends, with one narrow interruption, up to a point nearly opposite the mouth of the Upper gorge. It extends again in the Deer Park gorge for short distances, and in the middle of the gorge's head a remnant lies at about 30 feet below the top of the limestone ledge. In one place midway in the Lower gorge a little lower terrace lies on the side of the third terrace.

From the position of these block-covered terraces I am led to think that the fall was 30 to 40 feet high, and that the gorge when abandoned by the

river was 30 feet deep at its head, 40 feet deep midway, and possibly 45 feet deep at the mouth. The original height of Minnehaha falls was 30 feet, whereas it is now 60 feet. Minnehaha creek has not only cut back its gorge one-eighth of a mile, but has deepened it, meanwhile eroding the bottom of the Lower gorge 40 to 70 feet deeper. The Deer Park gorge has also deepened. Two lines of drainage from near-by swampy tracts enter, one at each corner, at the head of this gorge, and those have changed the outline of the original crest of the old fall, as well as deepened the gorge.

THE LAKE STREET TERRACES AND FALLSCARP

For two miles above the mouth of Minnehaha creek the gorge of the Mississippi has a north to south course, with no ancient terraces within the gorge and narrow ones or none at the top. The limestone ledge on either cliff is surmounted by 20 to 40 feet of shales or by glacial drift. The shales appear to be continuous on the left side and to extend for the greater part along the right side. These, with the included crystalline limestone strata, are additional to that which the river encountered in the first 2 miles above Fort Snelling. The second 2 miles of Saint Anthony falls' retreat was peculiar in that respect, but as to the effect of that peculiarity we know little, since the long, straight gorge there is the only record of the river.

In the next, or fifth, mile from Fort Snelling the gorge curves toward the west. Here, as a person would expect, there are some terraces on the inner curve. As shown on the map (plate 1), a high terrace runs across the north half of section 5. This terrace is 15 to 20 feet above the top of the limestone ledge and is marked off by a well defined scarp on the west side. The stream appears to have made an island on the east side of the terrace. The height of the terrace rather indicates that it was abandoned by the river a long time before Saint Anthony falls reached that part of the gorge. I compare it to the high terrace at Minnehaha creek. Also, near the bottom of the gorge, there is a long terrace, with a remnant of a fallscarp at its northwestern end, and above this there was formerly a sloping approach, or upper rapids, where a stone quarry now yawns. From notes taken over 10 years ago, when the quarry was small, I am able to describe that part also. Saint Anthony falls left a well preserved record of its course, including upper rapids, fallscarp, lower rapids, and river bed, here within an eighth of a mile above the west end of Lake Street bridge—that is, the southwest corner of section 32. A profile of the fall is shown in plate 2, figure 3.

The scarp, which once formed the west end of the fall here, stands

transverse to the right wall of the gorge. Its crest is 30 paces long, measured from the bank above it to the cliff by which it is now cut off. Upstream from this remnant of the falls formerly extended a sloping triangular area of the upper rapids. It rose over 15 feet in the 120 paces from the top of the falls back to the point where it was cut off by the convergence of the bank above and the cliff below it. Formerly many small river shells were found under the limestone shingle, there being a foot of such debris between the soil and the limestone floor, so that these as well as the slope and position of the terrace proved it to have once been the river bed above the falls. The descent of the rapids, 15 feet in 120 paces, extended from the top of the upper limestone to its base.

The crest of the fall rested on the top of the lower limestone. The scarp of the fall is now covered in part by the quarry dump, but it was formerly regular, presenting a low cliff bordered by a talus slope, in all 20 feet high—that is, reaching from the top to the bottom of the lower limestone. Originally this appears to have been a vertical fall of 20 feet. From the foot of that scarp a steep slope, covered by limestone blocks and debris on Saint Peter sandstone, runs with a gradient of 1 in 5 for 100 feet. It changes then to a gradient of 1 in 10, decreasing gradually to 1 in 100; so that the bed of the river at 100 paces from the fall was 75 feet below the top of the upper limestone—that is, upper rapids—and 60 feet below the crest of the falls. The heights here are: upper rapids, 15 feet; fall and cataract, 40 feet; lower rapids, 20 feet.

The terrace below the fallscarp consists of limestone blocks 1 foot to 10 feet in diameter and boulders, filling over the very unevenly eroded surface of Saint Peter sandstone from 5 to 15 feet deep. The terrace is 50 to 75 feet wide now and 40 to 20 feet above the river. At 350 feet from the fallscarp the terrace has been disturbed by the building of Lake Street bridge, but remains intact close beyond that obstacle. There it is 20 feet above the present river, has nearly as little gradient as the river, and extends 60 paces wide for 400 paces. Another part of the same is seen a little farther along, beyond a 10-foot lower terrace which suddenly widens back to the foot of the bluff here, after it has paralleled the main terrace in a narrow strip for a long distance.

The falls at this stage cut the gorge here originally 30 or more feet deeper than it did at and below Minnehaha. (Compare figures 2 and 3, plate 2.)

OTHER TERRACES

In the last 3 miles up to the present Saint Anthony falls each turn in the river's gorge preserves some record in the form of terraces and scarps

within the gorge. Likewise terraces remain above the sides of the gorge. The retreat of the falls, and hence the direction of the gorge, appears to have been influenced somewhat by the direction of the joints in the limestone beds, so that the course of the river preceding the falls' recession is not exactly followed by the gorge.

Most of the terraces have been disturbed more or less by stone quarries and the like, doubtless some of them before Winchell began his study of the falls. There remains clearly defined nearly all of the terrace which occurred 10 to 15 feet above the limestone ledge, in several places, and some part at least of another, 0 to 5 feet above the limestone ledge, which accompanied the former generally. River shells occur in gravels along the scarp between those two terraces.

Within the gorge terraces occur in several places. On the left wall of the gorge, at Meeker island, a narrow but characteristic block-covered terrace begins at 55 feet below the top of the limestone ledge, 35 feet above the normal river level, and descends with decreasing gradient 15 feet in 100 yards, and then for another 100 yards maintains about the same elevation, 20 feet above the river.

In Riverside park, at the north end of Twenty-seventh avenue south, on the right wall of the gorge, is to be seen the extreme end of a fall-scarp and below it a rapidly expanding terrace. The present wall of the gorge cuts obliquely across this scarp, so that all or nearly all of the original rapids above the fallscarp had been cut away even before a stone quarry was begun here. In the quarry 4 feet of hard crystalline limestone strata and interlaminated shale of bed number 3 appears above the 14 feet of the regular upper limestone (bed number 2) and the lower limestone. Since the crest of the fall appears to have been at the top of the lower limestone, there would have been 18 feet descent in the rapids above the fall. The old fallscarp is not well preserved in form, but its top is seen 60 feet above the present river bed, and it has a gradient of 25 feet in the distance of 60 feet. Thence a descent of 20 feet in 200 paces is followed by a gradient which parallels that of the present river for another 100 paces. The terrace in this part becomes 100 feet wide and then narrow again. Quarry dumps now conceal the narrow part for a long distance, but I remember that it was continuous with the block-covered strip which lies 15 to 20 feet above the river's normal level at the Franklin Avenue bridge.

The entire descent in falls and rapids at Riverside was thus 60 feet, the river flowing thence 15 feet above the present normal level. The now remaining terrace displays on its edge next to the river a fine profile of the very irregularly eroded surface of Saint Peter sandstone, covered 10

to 20 feet deep by debris, including limestone blocks 1 to 25 feet square and 1 to 6 feet thick. These blocks are almost exclusively from the lower limestone.

At the old Chevertown steamboat landing, between the ends of Pleasant and Delaware streets, and on the boulevard, on the left side of the gorge, another remnant of the fallscarp is preserved. The nearly right-angled turn in the wall of the gorge preserves the edge of an upper rapids and the fallscarp. These evidence that here also rapids descended 15 feet over the upper limestone to the fall. The fall was 25 feet high, measured from its crest at the top of the lower limestone. Below that scarp the block-covered river bed, now a terrace, slopes from west to east and is 45 or 50 feet below the top of the limestone ledge and 25 feet above the river at normal stage. The terrace runs some 300 yards to where it is scarcely 15 feet above the river. A terrace which is from 10 to 5 feet lower borders it on the south side.

A sloping block-covered terrace runs under Washington Avenue bridge, on the right side of the gorge, but the works of man have changed it too much for the present purpose; also, on the left end of Tenth Avenue bridge, the "east side flats" once presented doubtless a good record, but it has been defaced by early quarrying and late grading. It can be seen, however, that the limestone ledge had been eroded or glaciated here, so that 5 feet of the upper limestone was lacking. The block-covered terrace began at the base of the lower limestone and sloped in some way down to about 10 feet above the present level of the river in a fourth of a mile. The height here was probably, of the upper rapids, 10 feet; of the falls, 20 feet; of the lower rapids, 20 feet; total, 50 feet.

This last terrace is so close below the position¹⁰ at which the falls stood when they were seen by Father Hennepin in A. D. 1680 as to represent practically the same stage.

THE NICOLLET ISLAND RAPIDS

Before considering the Saint Anthony falls proper, which N. H. Winchell has described quite fully, I wish to call attention to what may be called the Nicollet Island rapids, to which due attention has not been paid heretofore.

The limestone ledge which formed the crest of Saint Anthony falls, and which is practically horizontal from Fort Snelling to the falls, shows a rise upstream above the falls. "At the falls it amounts to about an inch in 100 feet; it increases soon to 3 or 4 inches in 100 feet, and at Central avenue it is about 5 feet in 100 feet."¹¹

¹⁰ Winchell: *Op. cit.*, p. 336 and plate Y.

¹¹ Winchell: *Op. cit.*, p. 291.

As a result of this pronounced dip with the stream, the limestone ledge which forms the crest of the fall rises above the bed of the river opposite the lower end of Nicollet island, and at the upper end of the island it is wholly above the river, the Saint Peter sandstone reaching some 20 feet above the water level. The river channel on either side of Nicollet island has been cut through the limestone formation and partly into the Saint Peter sandstone. This condition extends up the river a fourth of a mile beyond Nicollet island, where, as Winchell describes it, a drift-filled pre-Glacial valley is met. The rise of the limestone is toward the side of that valley.

Briefly stated, the Mississippi river flows along the pre-Glacial valley for some miles in a southerly direction to the mouth of Bassett creek. The old valley continues in the direction of the creek, southwesterly, while the river turns southeasterly over the side of that old valley. The Mississippi river, at an early stage, must have encountered the limestone which bordered the old valley, since the ledge was there at the present 820-foot contour line. There is indeed evidence of thickly deposited silts to indicate that the Mississippi river and Bassett creek were impounded back of the limestone ledge for a time.

The river channel would encounter the limestone on its upturned edge, and a rapids would soon result from such a barrier. As the river cut its way obliquely through the limestone the rapids must *pari passu* descend the river. At an early stage the river flowed in a rapids in part over the now high and rocky upper end of Nicollet island, while in its last natural stage (1856) I learn that the rapids began opposite the lower end of the island, reaching thence to the falls.

There has been evidently this Nicollet Island rapids descending the river, cutting the limestone ledge at one edge, while Saint Anthony falls ascended the river, cutting the ledge at the other. In its last stage Saint Anthony falls has entered the reach of the Nicollet Island rapids. The last stage is therefore very different from earlier ones.

SAINT ANTHONY FALLS

To the description of Saint Anthony falls I need add but little. This fact should be noted, however, that the last stage of the falls differs as compared to earlier stages in that the lower limestone remains alone, the upper limestone having been cut away under the river by the Nicollet Island rapids, into which the falls had receded. An artificial dam above the falls now raises the water to about the level of the upper limestone—that is, to 795 feet above tide—which appears to have been the height of

the river above the falls in its earlier stages. Excepting for the artificial dam above the falls, the river there might be 15 feet lower than it was in earlier stages. Winchell had estimated that the limestone formation dips 15 feet from Fort Snelling to the falls, but I am not able to find by using the contour map of the U. S. Geological Survey that such is the case. The lowering of the river above the present falls much rather began with the joining of the Nicollet Island rapids and the rapids above the falls and the consequent reducing of the upper limestone. This lowering would be gradual. Very probably Father Hennepin saw the falls of Saint Anthony (1680) before the river had cut all the upper limestone from its bed, and possibly the change was not complete when Carver (1766) saw it. The increased rate of recession of the falls, too, since Carver's time, as calculated so nicely by Professor N. H. Winchell, may be due to the changed condition of the falls and rapids.

With the bed of the river resting on the top of the *lower* limestone only, the last stage of the falls began. The manner of recession has become a matter of historic record. While since 1871 the front of the falls has been protected by an "apron," yet the recession had been well observed before that time.¹² I have seen two breaks in the crest which have occurred in the last few years. "It is not so much the excavation at the foot of the falls that causes the recession as the excavation of the sandstone just below the lime rock by water that enters natural joints in the rock and comes in contact with the crumbling sandrock, causing dislodgement and final downthrow of large blocks."¹³ Recently caves formed under the limestone and enlarged until the ledge fell. Blocks once thrown down were farther lowered by eroding of the sandstone from under them gradually, so that a block-covered rapids extended from the foot of the falls to where the blocks had been brought as low as the undermining of them could proceed.

CONCLUSION

As already stated, the Minnesota-Mississippi valley from above Fort Snelling to Saint Paul is not a pre-Glacial valley, but a Glacial and post-Glacial one, which was cut to its maximum depth by the river Warren, in the same manner as the Saint Anthony gorge was made by the Mississippi river. The recession of Saint Anthony falls may be taken as having begun in a fall or rapid of the river Warren over 5 or 6 miles below the confluence of the Minnesota and Mississippi rivers. That fall ended above the confluence on the river Warren in the Minnesota valley. The

¹² See Annual Report Chief of Engineers to the Secretary of War for 1870, p. 278.

¹³ Winchell: Op. cit., p. 340.

recession of Saint Anthony falls proper is a continuation of the former on the Mississippi above the confluence.

During the entire recession two events are presumed necessarily to have influenced the volume of the rivers: One was the melting away of the glacier from the head of the Mississippi (see figure 1), presumably causing a marked reduction in volume of the river from its Glacial to its modern stage. The other was the breaking of the ice-barrier and opening of drainage to the northward, by which lake Agassiz was drawn off and the river Warren reduced to the Minnesota river stage.

Regarding the reduction of the Mississippi river, a double system of terraces and scarps is evident above the walls of the Saint Anthony gorge in several places.¹⁴ These belong undoubtedly to the river at stages preceding the making of the gorge. They are interrupted by the widening of the gorge, and thus are not continuously traceable, but yet appear to represent two distinct stages of the river. The lower of the two lies distinctly within the upper, so that a person may readily interpret them as representing respectively the modern stage and the Glacial stage of the Mississippi. The higher or Glacial Mississippi terrace extends from Nicollet island to and continuous with the terrace and scarp of the river Warren, as shown in plate 1. The lower terrace coincides with the present river channel above the falls and is evident for 6 miles, or to the mouth of Minnehaha creek. I have not distinguished it beyond the Soldier ravine. The change in the Mississippi river consequent to the melting of the glacier from its head may be referred to the stage of the river to which the making of the Soldier gorge belonged—that is, when the falls were $1\frac{1}{2}$ miles above Fort Snelling.

The reduction of the river Warren may also be correlated with a stage of the recession of Saint Anthony falls and the making of the gorge. The rock gorge of the Mississippi at Fort Snelling is 75 feet deep below the level of the river (figure 1, plate 2), and the valley thence to Saint Paul is the same. The falls did not excavate to that depth, as is shown by the evidence seen in terraces and also by comparison with the gorge above Lake Street bridge at lock and dam number 2, where the river was found to run on the sandrock bottom of the gorge. The bottom of the gorge at Fort Snelling and thence to Saint Paul is to be considered as a refilled valley. The time of the maximum depth may well be considered as that of the last days of the river Warren. The time of maximum depth of the gorge should also correlate with the time of greatest height

¹⁴ A still higher and very distinct terrace runs parallel to the east side of the gorge, but it belongs to the time of glacial occupation preceding the forming of the Mississippi river proper, and is not considered here.

of the falls at the temporary head of the gorge. The stages indicated by terraces and fallscarps show the height of Saint Anthony falls and rapids together to have been as follows: At Fort Snelling, no falls; at 2 miles the descent was 40 feet; at about 4 miles, 75 feet; at 6 miles, 55 feet;¹⁵ at 8 miles, 50 feet. The time of the reduction of the river Warren may therefore be correlated with the falls when at Lake Street bridge, or about half way from the mouth to the present head of the gorge.

Regarding the rate of recession, it can not be said to have been uniform. For the 5 miles below Fort Snelling I have no data from which to calculate directly, but from above that point the first mile of the gorge of the Mississippi was evidently taken up by the river very quickly, by reason of a pre-Glacial valley there. Thence for a mile—that is, to Minnehaha creek—the evidence of the waterfall is seen. It evidently reached in depth only to the base of the limestones, where the stream, rebounding from the limestone blocks which had fallen, could surge back and undermine the scarp by washing away the friable sandstone. The limestones are jointed at intervals of 10 to 40 feet, and this facilitated the caving off of blocks. That both limestones were thrown down together is evident, since the upper is mingled with the lower in the debris now found in the terraces. The lower limestone predominates, however, and this is evidently because the upper is not so thick and, moreover, had been reduced by erosion in the rapids, which extended 50 or 100 feet beyond the fall-scarp.

At the Lake Street, or 4-mile, stage the rate of recession appears to have been slower than at the 2-mile stage. An upper rapids extended back over 300 feet, indicating time for erosion of the upper limestone. The caving off from the front of the fallscarp was evidently slow. The blocks, which cover the terrace below the fall, are almost exclusively from the lower limestone, testifying that the upper limestone was all eroded preceding the falling of blocks. The recession of the fall involved evidently first the complete removal of the close-jointed upper limestone; second, the caving down of the lower limestone in blocks, because of water entering its joints and undermining the sandstone; and next the great blocks forming a lower rapids were slowly undermined, sinking to the bed of the river. This manner of recession at the Lake Street stage appears to have continued to the Tenth Avenue bridge, or 8-mile stage, where the falls entered the Nicollet Island rapids.

In its last stage the falls entered the Nicollet Island rapids and made doubtless a greatly accelerated retreat, because the upper limestone was

¹⁵ Sixty feet high at Riverside park includes 4 feet above the top of the second limestone.

wanting, as already described. The rate at this stage is the one which Winchell very nicely calculated. He believed that the same rate applied to the making of the entire gorge, which it evidently does not.

Very possibly the falls were only entering the Nicollet Island rapids at the time when Hennepin and Carver saw them, and the upper limestone was not all gone from the fallscarp. Winchell calculated the recession of the falls from the time when Hennepin saw them, A. D. 1680, to that of Carver, 1766, to be 412 feet, or 4.79 feet per year, and from 1766 to 1856 to be 606 feet, or 6.73 feet per year. The increase of 40 per cent in the rate of the second period over the first indicates, I think, that the falls were in transition stage. In that case also the first must be an increased rate over that of stages preceding the entrance of the falls into the Nicollet Island rapids. Since 5 feet, or one-third, is lacking from the upper limestone at Tenth Avenue bridge, it seems probable that the same was only half eroded away at the time of Father Hennepin's visit. We may therefore assume four periods of accelerated recession, of which the two just cited as calculated by Winchell are the last. If we accordingly discount the rate of the third, 4.79 feet per year, by 40 per cent twice, we may find the probable rate of recession (2.44 feet per year) previous to the entrance of the falls into the Nicollet Island rapids.

While the rate of recession of the falls as taken by Winchell is twice too great, the length of recession which he takes for the time since the falling of the river Warren and ending of the ice-barrier in the north is twice too long. At the time of that event he supposed the falls to have begun at Fort Snelling, while most probably they were half way along in retreat, or at the Lake Street stage. From there to Tenth avenue the recession was fairly uniform. Taking, then, one-half the rate and one-half the length, the number of years, as calculated by Winchell for the event of the reduction of the river Warren, is not necessarily changed. Eight or ten thousand years may have elapsed while the last 4 miles of the gorge were making.

Probably no less an interval elapsed while the preceding 4 miles were making from above Fort Snelling to Lake street, though in this case the rate was not evidently uniform, and calculation of years from distance divided by a supposed rate would be very uncertain. The recession was at first comparatively rapid, but the falls during that interval were increasing in height, tending toward slower recession. The volume of the stream may have been reduced much below that which it was later, and this would tend toward slow recession. Here, also, for a part of the distance, perhaps a mile, as said, the limestone was augmented by crystalline limestone and shales. Of the effect of all this we have no good record

for a distance of over 2 miles. The fall possibly approached the cascade type, as seen in the Minnehaha falls now, where the limestone stands in an overhanging ledge from which the stream makes a clear leap to the bottom of the gorge. The recession of Minnehaha falls depends on the weathering down of the shaly contact between the Saint Peter sandstone and the limestone. The limestone then scales off in small pieces, from the base upward, and the sandstone washes slowly away, so that a ledge remains upon which a pony can be ridden under the falls.

The gorge from Saint Paul to Fort Snelling is still more uncertain. In a more general comparison it may be said that we have represented in these gorges three periods or units. From Saint Paul (representing locally the beginning of ice-retreat) to the Soldier gorge above Fort Snelling is one unit; from the Soldier gorge (representing the time of the glaciers' retreat from the head of the Mississippi) to the Lake Street stage is a second unit; from Lake street (representing the time of falling off of lake Agassiz and river Warren) to the present is a third unit. If the last is 10,000 years, the other two may be each no less, giving 20,000 years as the duration of the river Warren and 30,000 years as the lapse of time since the glaciers decamped from Fort Snelling.

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Beginning and recession of Saint Anthony Falls

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Notes

