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The Lower Rapids of the Mississippi River

Frank Leverett

Number.	FORMATION.	Thickness.	Depth.
40-44	St. Peter	145	1100
36-39	Upper Oneota	250	1350
32-35	New Richmond	60	1410
30-31	Lower Oneota	22	1432
5-29	St. Croix	968	2400
3-4	Sioux Quartzite (?)	10	2410
1-2	Primitive (?)	20	2430

In the discussion of this paper Mr. Leverett called attention to the need of careful examination of the suposed Sioux quartzite drillings, especially since a well at the neighboring town of Aledo, Ill , reached a depth of 3,100 feet without touching the quartzite.

THE LOWER RAPIDS OF THE MISSISSIPPI RIVER.*

BY FRANK LEVERETT.

INTRODUCTORY.

In the early days of navigation on the Mississippi, two important rapids were found to interrupt the passage of vessels at low water stages; one, about fifteen miles in length, being above the city of Rock Island, Ill., and the other, about eleven miles in length, above the city of Keokuk, Iowa. These became known, respectively, as the upper and lower rapids. The latter are also called the Des Moines rapids because of the situation above the mouth of the Des Moines river.

In both rapids the obstructions consist of rock ledges, yet the form of arrangement of the ledges is not the same. The upper rapids consist of a succession of rock barriers called "chains," each usually but a fraction of a mile in breadth, which pass across the river channel and are separated by pools or stretches of slack water. The lower rapids are more uniform, there being a nearly continuous descent across them. The rate of descent, however, varies, as shown below. In open-

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ing the upper rapids to navigation it was necessary only to cut channels across the barriers, while in the lower rapids a canal has been constructed.*

The precise length of the lower rapids is 11.1 miles, the head being at Montrose island and the foot a short distance above the river bridge at Keokuk. The total descent is 22.17 feet, or very nearly two feet per mile. The rate of descent is greatest in the lower part, there being a fall of about four and one-half feet in the lower mile and nearly eight feet in the lower two miles.† Above this part the fall, though not uniform, is less definitely broken into rapids and pools than in the upper rapids. Indeed, there appears to be a rock floor forming the river bed throughout the entire length of the lower rapids.

Immediately above the head of the lower rapids a deep, preglacial channel appears, whose floor, as shown by several borings, is 125 to 135 feet below the low water level of the river. This is filled mainly with blue bowlder clay up to about the level of the river bed. Sand, however, in places, extends to a depth of nearly sixty feet below the surface of the river at low water, as shown by the bridge soundings at Ft. Madison and Burlington. A pool extends from the head of the rapids up to the vicinity of Ft. Madison—nine miles. The depth of the pool in places exceeds twenty feet at low water stage, thus extending to about that distance below the level of the rock surface in the river bed at the head of the rapids.

Below the rapids the river for four miles is in a narrow valley in which the depth of the drift filling is not known. It there enters a broad, preglacial valley, which has been found to constitute the continuation of that occupied by the river above the rapids, and which no doubt was excavated to a corresponding depth, though as yet no borings have been made

*This consists of a channel blasted out of the rock for a distance of three and one-quarter miles from the head of the rapids, below which a retaining embankment is built on the river bed along the Iowa side to the foot of the rapids at Keokuk.

†From Greenleaf's report on "Water Power of the Mississippi and Tributaries," tenth census of United States, 1880, Vol. XVII, p. 60, the following data are obtained. "In the first 4,800 feet from the lower lock there is a rise of 4 21 feet, then 2 22 feet in the next 3,600 feet, and 1 67 feet in the succeeding 3,600 feet to the middle lock, making the fall in ordinary low water, from a point opposite the middle lock to the foot of the rapids, 8.1 feet."

which reach its rock floor. The comparative size of the valley of the Mississippi, in its new channel across the lower rapids, and the partially abandoned preglacial valley, is shown in cross section in figure 6, of Vol. III of the Iowa Geological Survey. The depth of the new channel is but little more than half, and the width scarcely one-fifth, that of the preglacial channel. In size it is, therefore, scarcely one-tenth as large as the preglacial valley.

The small size of the Mississippi valley at the lower rapids, compared with its size above and below, was noted by Worthen more than forty years ago, and interpreted to be an evidence that the greater valley is preglacial, while the portion of the valley across the rapids is postglacial.*

Again, in his first volume of the Geology of Illinois, published in 1866, Worthen remarks (page 9) that the present river has shown, by the work done in the upper and lower rapids, how inadequate its erosive power would be to excavate in postglacial time the entire valley which it now but partially occupies.

A few years later Gen. G. K. Warren discovered the abandoned section of the preglacial valley which crosses Lee county, Iowa, a few miles west of the lower rapids, and connects the portion occupied by the stream above the rapids with that below. In his report in 1878 he presented a discussion illustrated by a map setting forth the position of the old channel.†

General Warren based his interpretations upon the absence of rock outcrops in the valleys which traverse the old course

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*In his report to Hall, made in 1856, the following statement is found in the discussion of Lee county. (Geol. of Iowa, Vol. I, 1858, p. 188):

"The valley thus scooped out of the solid rocks extends from Montrose to the mouth of Skunk river, and is from six to eight miles in width. The eastern portion of this ancient basin, except the bluffs on the river above Ft. Madison, is now covered by the alluvial deposits before mentioned, while the western part is occupied by deposits of drift material from 100 to 185 feet in thickness That this valley was formed by ancient currents, previous to the drift period, is proved by the fact that a considerable portion of it is now occupied by deposits of that age, and which must have been formed after those currents ceased to act."

†Report of the U. S. Army Engineers for 1878-9, Vol IV, part 2, pp. 916-917, Diagram E, also Diagram 1, sheet 4.

of the river, there being no borings that extended to the rock bottom. A few years later a boring at Mont Clare, Iowa, was sunk in the old valley and brought confirmation to General Warren's interpretation.* The accompanying sketch map, figure 2, sets forth the position of the old valley and its relation to the one across the rapids.

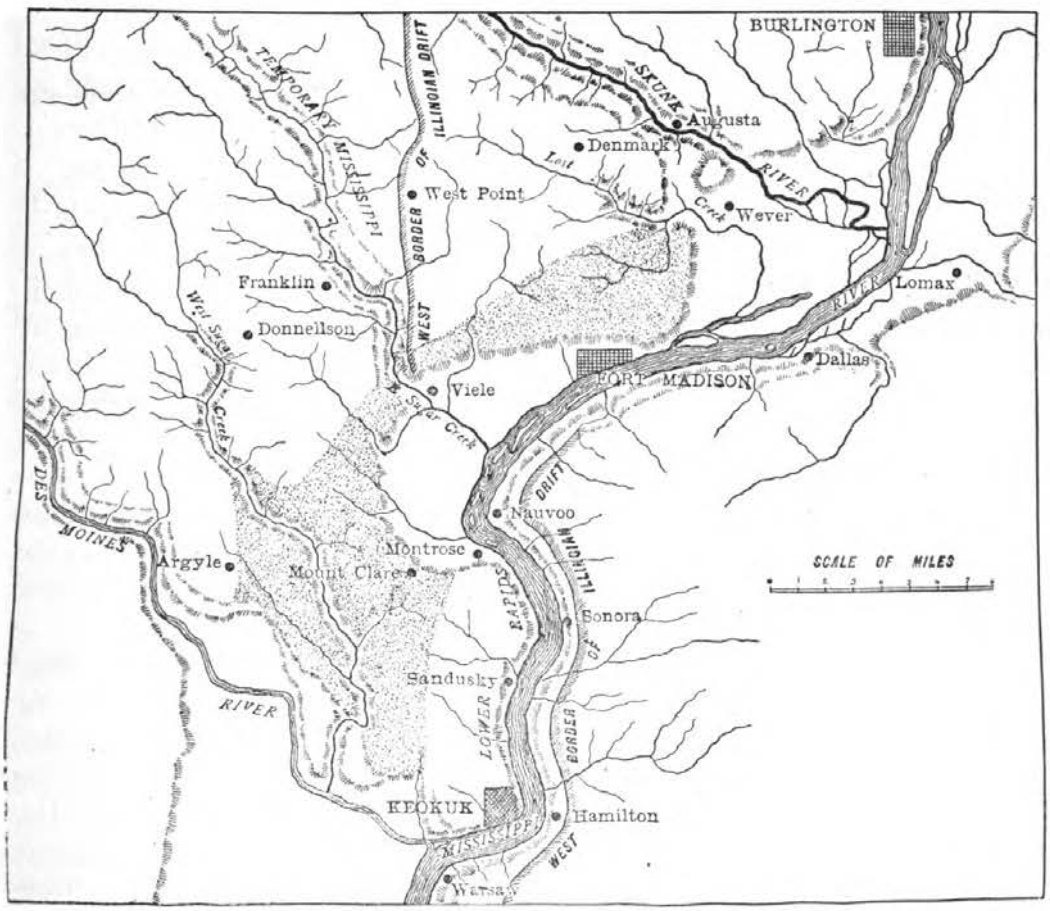

Figure 1. Sketch map of region discussed, showing course of old channels.

NOTE OF EXPLANATION.—The abandoned portion of the pre-glacial channel of the Mississippi is shaded. Hachures are used to indicate valley borders both below and above high terraces and along the temporary Mississippi channel, opened at the Illinoian stage of glaciation. The extent of the high terrace in Missouri has not been determined.

It should not be inferred that this broad, preglacial valley was necessarily a line of discharge for the whole of the present drainage basin of the upper Mississippi. The available evidence concerning the preglacial drainage, though imperfect, is thought to indicate that a large part of the region

*Buried River Channels in Southwestern Iowa, by C. H. Gordon, Iowa Geol. Surv. Report for 1893, pp. 236-255. Figs. 5, 6 and 7. Published in 1895 as Vol. III of the present survey

above the upper rapids may have trained southeastward through the Green river basin to the Illinois. Hirshey has suggested a northward discharge for the headwater portion of the basin,* a suggestion that awaits adequate investigation. The preglacial valley, which passes the lower rapids on the west, is nearly coincident with the present Mississippi, from the head of these rapids up to Muscatine, but its position farther north has not been ascertained, nor has the size of its drainage basin been even approximately determined. It is probable, however, that much of eastern Iowa was tributary to this preglacial line.

DATE OF THE DEFLECTION ACROSS THE LOWER RAPIDS.

In previous years attention has been called, both by Mr. Fultz and myself, to evidence that the region around the lower rapids presents a complicated glacial history.† It has been shown that one ice field extended southward from Kewatin, in the Dominion of Canada, across Manitoba, Minnesota and Iowa into Missouri and that it spread eastward beyond the valley of the Mississippi, from near the southern end of the driftless area of the upper Mississippi, to the vicinity of Hannibal, Mo. Two invasions may have been made by that ice field with an intervening deglaciation interval of some length, as indicated by Bain‡. The later, and probably the more extensive, advance is referred to the Kansan stage of glaciation.

It has also been shown that subsequent to the Kansan stage of glaciation an ice field extended from Labrador and the heights south of Hudson bay southwestward across Michigan, the Lake Michigan basin and Illinois into southeastern Iowa.

The Kewatin ice field not only covered the preglacial valley near the lower rapids, but also the district which the stream traverses in passing the rapids. It was thus liable to have displaced the stream to a much greater extent than the deflection past the rapids, as indicated below. The invasion from Labrador, on the other hand, appears to have barely reached to the rapids, and may not have interfered seriously with drainage across them, though it greatly disturbed the course

* American Geologist, Vol. XX, 1897, pp. 246-263.

† F. M. Fultz, Proc. Iowa Acad. of Sciences for 1895, Vol. II, pp. 209-212.
Ibid. 1896, Vol. III, pp. 60-62.
Frank Leverett, Science, Jan. 10, 1896.
American Geologist, Feb., 1896.
Bull., No. 2, Chi. Acad. Sci., May, 1897.
Proc. Iowa Acad. Sci., 1897, Vol. V, pp. 71-74.

‡ Proc. Iowa Acad. Sci. for 1897, Vol. V, pp. 86-101.

of the Mississippi above the rapids. It did not reach the section of the preglacial valley west of the rapids. The inflection from the preglacial channel must, therefore, be due to the Kewatin ice field.

But, since the Kewatin ice field may have twice invaded this region, it is necessary to inquire into the probable effect of each of its two invasions. If it be found that the earlier invasion extended beyond the line of the preglacial valley, and deposited sufficient material to prevent the re-establishment of the river along the preglacial line, a deflection at this early date must have occurred. The deflection, however, need not necessarily have thrown the stream into its present course across the rapids. That course may have been taken as a result of the later invasion of the Kewatin ice field, if not as a result of the still later encroachment of the Labrador ice field. It is reasonable to suppose that the deflection caused by the Kewatin ice field might give the stream a course farther to the east than the lower rapids, since the region across which the rapids have been opened appears to have been entirely covered by the Kewatin ice field at each of its invasions. It will be necessary, therefore, to determine whether the Kewatin field did not establish the Mississippi in a course east of the rapids, and whether that course was not held by the Mississippi until the Labrador ice field forced it westward into its present course across the lower rapids.

Turning now to the question of the influence of the supposed earlier invasion of the Kewatin ice field, a few remarks seem necessary concerning the deposits made by that ice field. The lowest conspicuous member of the drift series in eastern Iowa is a sheet of dark blue till, often nearly black, which is thickly set with fragments of wood and coal. This is overlain by a sheet of blue-gray till which differs from the blue black till in texture and rock constituents as well as in color. It shows a decided tendency to break into rectangular blocks, and often presents vertical fissures extending to a depth of many feet, which are filled with sand or deeply oxidized clay. The blue-black till is very friable, and seldom shows a tendency to break into rectangular blocks, while the few fissures which it contains traverse it in oblique, rather than vertical, lines. The blue-gray till carries much less vegetal material and coal fragments than the blue-black till. It differs also from the blue-black till in containing a larger percentage

of greenstone rocks. These differences have naturally led to the suspicion that two quite distinct sheets of till are present and this suspicion is confirmed by the occasional occurrence of a black soil at the surface of the blue-black till. Such exposures are rare compared with those of the Yarmouth soil found between the Kansan and Illinoian till sheets,* but their rare occurrence may not demonstrate that the interval of deglaciation is of minor importance. From conversations with Calvin, Norton and Bain, I am led to think that a large part of the buried soils reported by McGee, from eastern Iowa,† occupy a horizon corresponding to the junction of the blue-gray and blue-black tills of southeastern Iowa. This being true, the interval of deglaciation between the blue-gray and blue-black tills becomes of much importance.

The sheet of blue-black till has been found to occur at points farther east than the lower rapids. It occurs in the Mississippi valley in the vicinity of Ft. Madison, Iowa, and in Hancock and Adams counties, Illinois, east and southeast of the rapids. There is little doubt, therefore, that during the deposition of this till the Kewatin ice field was *sufficiently extensive* to force the Mississippi out of the preglacial channel which passes west of the lower rapids.

It is not certain, however, that the *amount of filling* in that valley was sufficient to prevent the return of the stream to its preglacial course in the interval between the deposition of the blue-black till and the blue-gray till. The blue-black till in the vicinity of Ft. Madison is found to rise to a height of only sixty to seventy-five feet above the present stream, or nearly seventy-five feet less than would probably have been necessary to throw the stream from the preglacial channel into its present course across the rapids. This may possibly have been sufficient to throw the drainage of the portion above the lower rapids eastward into the Illinois, either by way of the Green river basin or by some line farther south that is now completely concealed by the later sheets of drift. But it seems quite as probable that the stream returned to its preglacial course,

The blue-gray till seems to be fully as extensive a sheet as the underlying blue-black till. It extends eastward into

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*See Proc. Iowa Acad. Sci., Vol. V, 1897, pp. 81-86.

†Eleventh Annual Report U. S. Geol. Surv., 1889-90, pp. 232, 233, 485, 496, 541, 569.

Illinois beneath the Illinoian till sheet an undetermined distance. The tendency to break into rectangular blocks often serves to distinguish it from the overlying Illinoian till, as well as from the underlying blue-black till, though the Illinoian, in places, takes on this phase of fracture. Probably the most extensive of the exposures of the blue-gray Kansan till are found in the vicinity of Ft. Madison. It there constitutes, for several miles, the upper 100 feet of the Mississippi bluff, except a thin coating of loess.

The filling produced by the blue-gray till was sufficient to prevent the return of the stream to its preglacial course, for the altitude of the surface, along the part of the preglacial channel west of the lower rapids, is as great as in border districts. In this case, therefore, it is only necessary to decide whether the stream assumed its present course across the lower rapids at the time the Kewatin ice field made its final withdrawal from that region, or whether it drained eastward to the Illinois until it was forced from that course by the advance of the Labrador ice field at the Illinoian stage of glaciation. Concerning this question it is thought that evidence of some value has been collected, as appears below:

EROSION PRECEDING THE ILLINOIAN STAGE OF GLACIATION.

The Mississippi valley, for about fifty miles below the lower rapids, was greatly filled by the drift from the Kewatin ice field. Immediately below the rapids the filling on the borders of the valley reached a level about 150 feet above the present stream. It seems not improbable that there was a filling to nearly this height in the middle of the valley, for the abandoned section just above was filled in its middle part to as great height as on its borders. Upon passing down the valley the height of filling gradually decreases to the limits of the Kewatin drift near Hannibal. From the filling of tributaries near Hannibal, it is estimated that the Mississippi valley could not have been filled to a height greater than seventy-five feet above the present stream. Below Hannibal the filling was produced by stream action, rather than by glacial deposition, and appears to have reached but little, if any, above the sand terraces of the valley—say fifty feet above the river. Now, if this filling suffered but little erosion before the Illinoian stage of glaciation, it can reasonably be inferred that the drainage of the upper Mississippi did not pass across the lower rapids

and through this part of the valley until forced westward by the advance of the Labrador ice field. But if a great erosion took place in this part of the valley prior to the Illinoian stage of glaciation, there would seem good grounds for supposing that the stream assumed its present course soon after the Kewatin ice field made its final withdrawal.

Examining into this question, it is found that after this drift was deposited by the Kewatin ice field an erosion so great took place that it was removed, throughout the greater part of the width of the valley, down to a level scarcely fifty feet above the present stream at the mouth of the Des Moines, and to an equally low level at Hannibal. The depth of cutting appears, therefore, to have been about 100 feet at the mouth of the Des Moines and perhaps twenty-five feet at Hannibal. It seems safe to assume an average depth of fifty feet for the entire section and a width of five or six miles, making an erosion of nearly three cubic miles of drift in the fifty miles below the mouth of the Des Moines river. It is scarcely necessary to raise the question whether this erosion could have been accomplished by the Des Moines and other tributaries of the Mississippi below the rapids, for it is evidently out of proportion to the work which these small streams would be able to accomplish since the Kansan stage of glaciation. It seems certain that the Mississippi river is responsible for the principal part of the erosion. This makes necessary the opening of the new channel across the rapids, since the old channel west of the rapids was not utilized by the river after the Kansan stage of glaciation, and no other line of drainage could have been adopted by the river that would pass through the portion of the valley below the rapids.

Evidence is found within the new channel, of an erosion such as the interpretation just given demands. In the south part of Keokuk, between the foot of Main street and the mouth of Soap creek, the rock bluff rises but fifty to sixty feet above low water and is capped by a bed of bowlders about twenty feet in depth. Attention was called to this bed some thirty years ago by Mr. S. J. Wallace of Keokuk,* and the view expressed that it is "old river shingle." Mr. Wallace stated that Dr. George Kellogg, of Keokuk, regarded it as an indication of an ancient fall at this place, but that he did not so regard it.

* Proc. A. A. A. S., Vol. XVII, 1869, p. 344.

This bed has been discussed at some length by Mr. Gordon in the Geology of Iowa,* and three interpretations for its origin are presented.

First.—That it was formed by river action alone, *i. e.*, as an alluvial bar.

Second.—That it is due to the cutting down of a till sheet, the coarse material being left as a residue.

Third.—That it is a bowldery moraine dropped at the edge of the ice sheet at the Illinoian stage of glaciation.

Of the three interpretations the second seems to Mr. Gordon, as well as to the present writer, the most applicable. Dr. Kellogg's suggestion of a fall as the cause seems, at best, to be poorly sustained. A similar bowlder bed occurs near Warsaw, Ill. It there forms a capping for an eroded till surface and bears clear evidence of removal of the fine material by a stream, with the retention of the bowlders as a residue. A bowlder bed is also found along the face of the west bluff of the rapids near Sandusky, about six miles above Keokuk, at a level forty to sixty feet above the stream, that probably was derived from the erosion of a sheet of till, though the exposure is scarcely extensive enough to show clearly the relationship. It seems referable to the period of erosion that produced the beds at Keokuk and Warsaw.

The amount of erosion effected is so great that the beginning of this new channel seems to date from near the close of the Kansan stage of glaciation. This becomes more evident as we study into the later stages of the history of the river. Even if the river had been forced into a channel farther east than the lower rapids, it seems scarcely probable that it remained long in that course. It apparently began its work of opening the course across the rapids long before the Labrador ice field had reached the region.

FILLING AT THE ILLINOIAN STAGE OF GLACIATION.

Following this great erosion there came a partial filling of the part of the valley immediately outside the limits of the Illinoian drift sheet. It is well displayed below the rapids, and some remnants are to be seen along the borders of the rapids. This filling appears to have occurred at the Illinoian stage of glaciation: Evidence of this relationship is to be found in the connection, or close association, of this filling

*Geology of Iowa, Vol. III, 1893, pp. 252-255. See also Pl. XV.

with the opening of a temporary course for the Mississippi across southeastern Iowa, which occurred at the time the Mississippi valley above the rapids was covered by the Labrador ice field.

The drainage line referred to leaves the present Mississippi at the mouth of the Maquoketa, passes southward along that valley (reversed) to Goose Lake channel, and thence to the Wapsipinicon valley, coming to that valley a few miles above its present mouth. It follows up the Wapsipinicon a few miles to the mouth of Mud creek, a southern tributary, which, together with a small tributary of Cedar river also called Mud creek, furnishes the line of continuation for the old valley to the Cedar river near the great bend at Moscow. The valley continues southwest to the Iowa river along the course now followed by the Cedar river in its lower twenty-five miles. It then passes southward from Columbus Junction to Winfield and thence westward to Skunk river at Coppock, opening in its westward course two lines, one of which is now utilized by Crooked creek. From Coppock the old drainage line follows the course of Skunk river southward to Rome, and Cedar creek (reversed) to Salem. It there turns southeastward, being known as "Grand valley" in northern Lee county, and joins the Mississippi about six miles west of Ft. Madison, nearly opposite the head of the rapids. Its continuation was evidently across the rapids into the broad valley below Keokuk.

The altitude of the bottom of this old valley, near the head of the rapids, is fully 100 feet above the present stream, but connects well with the surface of the valley filling in and below the rapids. It is nearly 100 feet lower than at the point where it leaves the Iowa valley, seventy-five miles to the north. The portion above the point where the Iowa valley is crossed has been so modified since the Illinoian stage of glaciation that very little is known concerning its condition at the close of that glacial stage, but the portion south from the Iowa valley has been only slightly modified.

Very little material was deposited on the bed of the temporary channel of the Mississippi in the seventy-five miles from the Iowa valley to the head of the rapids, but a great filling occurred in the broad valley below the rapids, and some filling along the rapids, especially at their lower end. The valley, which, at the foot of the rapids, had been cut down

to a level scarcely fifty feet above the present stream, was built up to eighty or ninety feet above the river at that point. The depth of filling is found to increase upon passing down the valley, and becomes scarcely noticeable at Hannibal. It is, therefore, much like a delta, formed where a rapid stream emerges into a sluggish, lake-like body of water. It consists mainly of fine material, sand or silt, with few pebbles greater than one-fourth inch in diameter. A fine gravel, however, appears at an exposure called "Yellow Banks," near the mouth of the Des Moines river. The bowlder bed in Keokuk, described above, received at this time a capping of sand fifteen or twenty feet in depth. Sand deposits are also found at a corresponding level in Hamilton, Ill., near the foot of the rapids, capping a low part of the rock bluff. Another possible remnant of the sand filling is found at Sandusky, Iowa, six miles above Keokuk, immediately back of the bowlder-strewn slope, noted above. It there rises about eighty feet above the river, or to within twenty-five feet of the level of the bottom of the channel of the temporary Mississippi, ten miles to the north. No remnants of the filling have been noted in this interval of ten miles and it is thought probable that the rate of fall was so great above Sandusky that but little lodgment of material occurred.

In the portion of the Mississippi valley covered by the Labrador ice field at the Illinoian stage of glaciation, there appears to be no such sand filling as is found below the rapids, although it has nearly as low a gradient. This feature confirms the above interpretation, that the sand filling occurred during this stage of glaciation.

In explanation of the small amount of material deposited in the bed of the temporary Mississippi, Professor Chamberlin has suggested to me that the ground in which this channel was excavated may have been frozen at the time of excavation, its situation being on the immediate borders of the ice sheet, and that this frozen condition of the ground may have prevented the stream from eroding more material than it could readily transport

The time involved in the valley filling is a question of much interest, but one on which an estimate is very difficult to make. The filling of any given section is not a measure of the full work of the stream, but simply an index to the excess of material above the limits of transportation by the stream.

To properly estimate the work in a stage of filling it is necessary to compute the amount of material carried through the channel, as well as that deposited in it. It is doubtful if present methods of study are sufficiently refined to enable one to make even an approximate calculation of the time involved. It may safely be affirmed, however, that the filling under discussion progressed slowly, and that the time involved was sufficiently long to affect materially the chronology of the lower rapids.

EROSION CONDITIONS DURING THE SANGAMON INTERGLACIAL STAGE.

Between the Illinoian stage of glaciation and the deposition of loess, which accompanied the Iowan stage of glaciation, there was a long interval of time during which the surface of the Illinoian drift sheet was subjected to leaching, and weathering, and the formation of a soil. The name Sangamon has been applied by the present writer to the soil and weathered zone formed at this time, and may properly be made to denote the time interval.* Although the degree of weathering and leaching makes it evident that the interval was protracted, the valley excavation appears to have been comparatively slight, so far as depth is concerned. This is true not only in the region about the lower rapids, but throughout the entire exposed portion of the Illinoian drift sheet.

The erosion on the lower rapids appears to have been scarcely sufficient to remove the sand filling which occurred during the Illinoian stage of glaciation. It could have amounted to scarcely twenty feet in depth and was mainly in loose material. The limits of the erosion are determined by the level down to which the loess extends. That deposit appears nowhere *in situ* at a lower level than sixty-five to seventy-five feet above the head of the rapids. Its lower limits, in the portion of the valley above the rapids, are also as great as seventy feet above the present stream.

A study of tributary valleys in this region has shown that the streams meandered widely and performed a large amount of work, notwithstanding the shallow depth of erosion. For example, Skunk river, in southeastern Iowa, at that time meandered over a width of about two miles (see figure 2),

* Proc. Iowa Acad. Sci., Vol. V, for 1897, pp. 70-80. Journal of Geology, Vol. VI, 1898, pp. 171-181

whereas it is now confined to an inner valley scarcely one-half mile in average width. It should be noted, however, that the erosion of fifteen or twenty feet over a width of two miles, by a stream with sluggish current, may involve more time than is required for the cutting of the inner valley, which has an average depth of nearly 100 feet and a width of about one-half mile.

In this interval, as in the interval of filling which preceded it, the rapids suffered but little modification, yet the time involved was sufficiently long to affect materially the estimates of the duration of the stream in its present course.

THE LOESS FILLING ACCOMPANYING THE IOWAN STAGE OF GLACIATION.

The period of low gradient and slack drainage, just discussed, was followed by even less favorable conditions for the opening of a channel During the Iowan stage of glaciation, as long since pointed out by McGee* and elaborated by Calvin and others,† the deposition of a sheet of silt occurred, not only along the main valleys, but over much of the low country in the interior of the Mississippi basin. This silt is the problematical loess. Its mode of deposition is still a matter of dispute, the deposit being thought by some glacialists to be largely aqueous, while by others it is thought to be chiefly æolian.

In the region under discussion the valleys, as previously indicated, were opened only to shallow depths, hence but slight accumulation of the silt was necessary to fill them or to cause the streams to spread over the bordering plains. The depth of the silt in the vicinity of the lower rapids seldom reaches thirty feet and probably averages not more than fifteen feet. Its bulk, therefore, does not, so far as the valleys are concerned, greatly exceed that of the filling which occurred below the rapids during the Illinoian stage of glaciation. If, however, the deposits on the bordering plains are taken into consideration, the amount of material deposited is very much greater, for the plains were covered to a depth of six to ten feet by this silt.

*The Drainage System and Distribution of the Loess of Eastern Iowa, by W. J. McGee, Bull. Wash. Phil. Soc'y, Vol. VI, 1883, pp. 93-97. Also see discussion in Eleventh Ann. Rep't U. S. Geol. Survey, 1890, pp. 435-471.

†Geology of Jones County, by S. Calvin, Iowa Geol. Survey, Vol. V, 1895, pp. 63-69. Geology of Johnson County, by S. Calvin, Iowa Geol. Survey, Vol. VII, 1896, pp. 39-45, 86-89. Geology of Linn County, by W. H. Norton, Iowa Geol. Survey, Vol. IV, 1894. pp. 168-184. Geology of Marshall County, by S. W. Beyer, Iowa Geol. Survey Vol. VII, 1896, pp. 234-238. Geology of Plymouth County, by H. F. Bain, Iowa Geol. Survey, Vol. VIII, 1897, pp. 335-351.

Whether the deposition took place by water or by wind, there seems to have been a suspension of erosion on the lower rapids, and the length of this suspension must certainly be sufficient to affect materially their duration. An estimate of the time involved seems at present impossible, there being fewer data for an estimate than in the filling which occurred at the Illinoian stage.

EROSION FOLLOWING THE LOESS FILLING.

After the deposition of the loess, the valleys throughout much of the Mississippi basin experienced a marked deepening, which brought their bottoms to a lower level than before the loess filling. In the portion of the Mississippi valley which lies within and near the rapids the deepening seems to have proceeded continuously to a level nearly as low as the present stream, or fifty to seventy-five feet below the excavation which occurred in the interval following the Kansan glaciation. This excavation, in the section embraced within the rapids, was mainly rock, for the loess and alluvium had built up the channel scarcely thirty feet above the rock floor of the post-Kansan erosion. But for some distance, both above and below these rapids, the excavation was largely in till. The channel across the rapids was opened to a width but little greater than the stream, or about one mile. Elsewhere the channel is three to six times the width of the stream.

This erosion seems to have continued until the early part of the Wisconsin glacial stage, when, as indicated below, another filling occurred. The extent and depth of the erosion which took place prior to the Wisconsin filling, is well shown in the broad portion of the valley above the rapids. Numerous wells indicate that the till had been removed nearly to present river level, over the greater part of the width of the valley, before that filling set in.

The amount of erosion in the Mississippi valley seems to have been nearly as great in this interval as in the post-Kansan interval of erosion. It is doubtful, however, if the time involved was so great as in that interval, for the gradient appears to have been higher. To properly estimate the time involved, it is necessary also to know the volume of water discharged through the valley at each interval, a matter concerning which very little is yet known.

FILLING AT THE WISCONSIN STAGE OF GLACIATION.

At the Wisconsin stage of glaciation the Mississippi and several of its tributaries, which flowed away from the ice sheet, became so burdened by glacial detritus that they were unable to completely transport their load, much less to continue the erosion of their valleys. The Mississippi headed in the ice sheet near St. Paul, Minn., while the Chippewa and Wisconsin rivers brought material from the Chippewa and Green bay lobes of Wisconsin. Rock river, also, brought material from the Green bay lobe and through its tributaries, Kishwaukee and Green rivers, from the Lake Michigan lobe. Just above St. Louis the Illinois river contributed a large amount of material, derived from the Lake Michigan lobe. These streams discharged such large quantities of sand into the Mississippi that its valley was greatly filled as far down as the head of the broad valley of the lower Mississippi at Cairo. Throughout much of the interval between St. Paul and Cairo the valley was filled to a height of fifty to seventy-five feet above the present stream. In the vicinity of the rapids it reached nearly fifty feet above the level of erosion in the preceding stage of deglaciation.

The filling probably began during the early part of the Wisconsin stage of glaciation, but the great bulk of it appears to have been contributed during the part of the Wisconsin stage of glaciation represented by the Kettle-morainic system. The transportation of sand down the valley no doubt continued for a long time after the ice sheet had ceased to contribute material to the headwaters of the present Mississippi. The filling may, therefore, have occupied a longer time than that involved in the formation of all the moraines which cross the headwaters of the Mississippi.

The greater part of this filling consists of sand of medium coarseness. This, however, is interbedded with thin deposits of very fine gravel, and pebbles are also scattered through the sand. The pebbles seldom exceed one-half inch in diameter and are usually one-fourth inch or less. They have been noted by the writer as far down the valley as the vicinity of Quincy, Ill. They are a conspicuous feature above Rock Island, Ill. Upon following up the tributaries of the Mississippi toward the head of these valley trains, the material becomes markedly coarser, as is to be expected, on the theory of their derivation from the ice sheet.

It scarcely needs to be stated that so great a filling has greatly interrupted the removal of the rock barriers of the Mississippi at each of the rapids. A stream, with the present volume of the Mississippi, and its comparatively low gradient of about six inches per mile, can scarcely do more than remove the material brought in by its tributaries, to say nothing of removing the great amount of material deposited at the Wisconsin stage of glaciation. There appears, however, to have been a long period succeeding this sand deposition in which the volume of the Mississippi was much greater than at present, and this matter will next receive our attention.

EROSION ACCOMPLISHED BY THE LAKE AGASSIZ OUTLET.

Following this period of sand deposition the Mississippi valley afforded a line for the discharge of a large area now tributary to Hudson's bay, an area which was occupied by the glacial lake, Agassiz. The area of this glacial lake, and of the country tributary to it, is estimated by Upham to have been from 350,000 to 500,000 square miles.* This great drainage area has been reduced to about 12,000 square miles† now tributary to the Mississippi through the Minnesota river. The present drainage area of the Mississippi, above the lower rapids, does not exceed 125,000 square miles, or about one-third the minimum estimate of Upham for the area of Lake Agassiz and its tributaries. Although this great reduction has been in the arid portion of the old drainage basin, it must greatly affect the volume of the river. The present run-off of that region can scarcely furnish a full index, since the ice sheet was also a great contributor of water to the glacial lake.‡

It can scarcely be questioned that at the height of the discharge from Lake Agassiz the volume of water was fully four times that of the present Mississippi. This view is sustained, both by the amount of erosion which took place, and by the low gradient reached by the stream. The sand which was deposited as a glacial outwash, while the ice sheet occupied the headwaters of the present Mississippi, was largely

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*"The Glacial Lake Agassiz," by Warren Upham, Monograph XXV, U. S. Geol. Survey, 1895, pp. 50-64.

†Warren's Report Bridging Mississippi River, Chief of Engineers U. S. Army, 1878-79, Vol. IV, p. 924.

‡In addition to the change of drainage area involved in the Glacial Lake Agassiz, it is necessary to take into consideration the influx of water from the glacial lake which occupied the western end of the Lake Superior basin, and also a small glacial lake at the head of Green Bay in Wisconsin.

removed by the Lake Agassiz outlet throughout the entire distance from St. Paul to Cairo. It is estimated that the average width of the channel formed by this outlet is three miles, or about four times the breadth of the present steam.

The depth of erosion seems to have been such as to give portions of the stream a lower level and lower gradient than that of the present river. This is especially noticeable in the portion above the upper rapids, as indicated by General Warren.* Lake Pepin, an expansion of the Mississippi, situated just above the mouth of the Chippewa river, has a depth of about sixty feet. It was General Warren's opinion that when the flow of water from the great northern basin ceased there would no longer be the volume of water necessary to remove the deposits brought in by the Chippewa river. In consequence of this change the Mississippi has been lifted to a level about sixty feet above its former bed. Evidence of a similar filling, produced by the Mississippi at the mouth of the Minnesota, is cited by General Warren. He also noted evidence of the marked shoaling of the Mississippi at the mouth of the Wisconsin. He further expressed the opinion that the entire cutting now in progress on the Mississippi may be confined to short sections in the vicinity of the rapids.

It is of interest to note what a slight change is required to stop the cutting at these places. A filling of only twenty-five feet at the mouth of the Des Moines, or of Rock river, is necessary to cause the neighboring rapids to become protected from erosion. It is not probable, however, that either of these tributaries will, for some time, begin the filling of the valley at the foot of the rapids, for the fall of the Mississippi, in passing each of the rapids, is greater than that of the lower course of the Rock or the Des Moines. Furthermore, the main stream has the advantage of much greater volume than these tributaries, in consequence of which the fall across the rapids must be reduced below that of the tributaries before filling can begin at their mouths.

CONTOURS OF THE BLUFFS ALONG THE LOWER RAPIDS.

The great length of time involved in the development of a channel across the rapids is shown by the contours of the bluffs. Except at a few points, where the river in rounding a curve has recently encroached upon its bluff, there is not an

*Op. cit. pp. 911-916.

abrupt face. A large part of the slope is so gradual that it has been brought under cultivation. When it is considered that the bluff is composed mainly of a firm limestone, the height of the rock portion ranging from fifty up to 150 feet, with an average height of nearly 100 feet, the prevalence of a moderate slope must indicate a long period of excavation.

But little is yet known concerning the manner in which the rock barrier has been cut away, whether by the recession of a fall or by the present process of slow cutting across its whole breadth. The fact that the old valley below the rapids was filled with drift about to the height of the highest part of the rock barrier, lends support to the view that there has been a slow cutting down of the entire width of the barrier, rather than the recession of a fall. It seems scarcely probable that the till beneath the stream was scooped out to a much greater degree below the rock barrier, in the early stages of excavation, than at the present day.

COMPARISON WITH THE UPPER RAPIDS.

The work performed in cutting away the rock barrier, at the lower rapids, appears to be several times as great as at the upper rapids. In the latter the rock excavation has not been sufficient to remove the prominent parts of the barrier. It scarcely amounts to an average cutting ten feet in depth. In the rapids under discussion the barrier is estimated to have suffered a rock excavation to a depth of nearly 100 feet, or about one fourth of a cubic mile. This difference in amount of work accomplished is readily accounted for by the earlier date at which the lower rapids began excavation. The excavation, as shown above, appears to have begun soon after the Kansan stage of glaciation, while the excavation at the upper rapids appears to have set in after the Illinoian and to have been mainly accomplished since the Iowan stage of glaciation.

THE LOWER RAPIDS AS A CHRONOMETER.

When this investigation was entered upon by the writer, hopes were entertained that the channel across the lower rapids would furnish a valuable chronometer for determining the time since the Kansan stage of glaciation. But from what has been shown it is evident that the determination of the time is at present very difficult, if not impracticable. It may be thought that this channel will furnish a chronometer for

the relative dates of the Kansan, Illinoian, Iowan and Wisconsin glaciations. But on this question scarcely more than a very rude approximation is likely to be reached. As indicated above, the work involved in filling is especially difficult to determine. These difficulties, however, are no greater than those involved in the estimates of the changes of drainage area which the Mississippi has experienced. The object of the present paper is accomplished if the complexity of the history has been adequately presented. The chronological determinations must be deferred to a time when more refined methods of investigation are instituted than are now at command.

OBSERVATIONS ON THE GEOLOGY OF STEAMBOAT SPRINGS, COLORADO.

BY F. M. WITTER.

In the year 1873, a division of geologists under the management of Dr. F. V. Hayden, made a survey of the region from Willow Creek pass, between North and Middle Parks, across the park range down the Yuma or Bear river to the White river, around to Eagle river and up the Grand, of which Willow creek, in Middle Park, is a tributary. In this report, very brief mention is made of Steamboat Springs, although the trail on their map does not pass nearer than twenty-five or thirty miles to the Springs.

Steamboat Springs is now not far from 100 miles by wagon road from a railway. Rawlins, on the Union Pacific in Wyoming, is probably the nearest railroad point on the north, and Glenwood Springs, on the Denver & Rio Grande, is the nearest on the south. Last July our party left North Park in its extreme southwest corner at Rabbit Ear peak. This mountain is the most conspicuous in the park range, immediately west of North Park. From near Pinkhampton, in the northeast corner of North Park, Rabbit Ear is plainly visible, a distance of sixty miles or more. This peak is capped by two immense vertical rocks about 100 feet apart. These rocks have suggested the name for the peak. By means of a spruce-tree ladder we climbed to the top of one of these huge "ears." We