Art. XIII.—The Terraces of the Westfield River, Mass.; by W. M. Davis. (With Plate IV.)

1. The several theories of river terraces.—The river terraces that are so abundantly developed in the stratified drift of our New England valleys, receive scanty explanation in the textbooks to which reference is ordinarily made for accounts of such forms, and are, indeed, not exhaustively treated in essays of a more advanced character. Their most significant feature is an arrangement in the form of a flight of steps, of unequal tread and rise, and usually of unlike sequence on the two sides of a valley, but necessarily exhibiting a less cross-valley breadth between the terraces at the bottom of two opposite flights than between those at the top. It is generally agreed that each terrace plain is the remnant of a flood plain, that was formed during the process of valley-carving by the river that now flows on the flood plain or “interval” between the lowest terraces of the series; and that the terrace fronts or scarps have been carved by the wandering river as it swung laterally on its successive flood plains. The slope of the terrace plains down the valley and the pattern of the terrace scarps in curves concave towards the river, frequently uniting in cusps, give convincing proof of these conclusions. It follows that our terracing rivers habitually had a greater breadth of swinging on the flood plains at high levels, when beginning the work of sweeping the drift from their valleys, than at the low levels on which they are now flowing. The special point that needs to be accounted for is, therefore, the restriction of the belt over which the river swings to a less and less breadth in passing from the initial to the present stage of terrace development.

There are three theories which offer an explanation for this restriction. The first and most popular postulates a decrease
in river volume during and after the uplift of the region by which the erosion of the valley was prompted. The river is by this theory supposed to have been so large when terracing began that it needed a broad space on which to swing; now that the river has diminished in volume it is relatively enfeebled and is contented to swing over a narrower belt than formerly; so the later formed terraces do not undercut and destroy those of earlier date.

The second theory postulates successive uplifts of the region. The river, revived by each uplift, wears its channel beneath its previous flood plain and, on reaching grade, begins to swing laterally. It is then further postulated, sometimes tacitly, that the later uplifts have succeeded each other at shorter and shorter intervals, allowing less and less time for lateral swinging as the valley was worn deeper and deeper.

2. Miller's theory of river terraces.—The third theory, suggested in explanation of terraces in Scotland by Hugh Miller, the younger, in 1882,* recognizes slow regional uplift as the cause of valley erosion and then calls attention to the increase in the number of resistant obstacles—rock ledges, boulders, till—that the degrading river will encounter as it swings laterally while eroding the valley floor to lower and lower levels, and ascribes the decrease of interscarp breadth to this simple, effectual and observable cause.

As Miller's theory has not, to my knowledge, been quoted in this country, except in a brief note of my own,† a brief exposition of its merits may be made. I have found it very generally applicable to the terraced valleys of New England, and nowhere more so than in the valley of the Westfield river, between the eastern base of the Berkshire hills and the village of Westfield, Mass., a distance of about five miles, where I have repeatedly examined it. This district was the scene of an intercollegiate excursion in the autumn of 1901, in which Yale, Amherst, Williams, Wesleyan, Institute of Technology, and Harvard, together with six secondary schools, were represented by teachers and students to the number of forty-six; and it is not too much to say that at the end of the day's walk along the north side of the valley no doubt remained as to the competence of Miller's theory to explain the occurrence and the pattern of the terraces there seen. Decrease of volume and intermittent uplift seemed to be of altogether secondary importance, if indeed they had produced any recognizable effect.

The Westfield terraces.—The following pages give a brief account of the Westfield terraces, beginning with those on the

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† Bull. Geol. Soc. Amer., xii, 1900, 483–484.
north side of the valley near Westfield railroad station, thence going west about two miles to a little settlement known as Pochassic Street; and returning by the south side of the valley to the village again. The general pattern of the terraces is indicated in figure 6 (Plate IV), where the attempt is made to show them in bird's-eye view, as if looking northeast from a height of two or three thousand feet above a point about a mile south of Pochassic Street. The scale in the further part of the view is somewhat smaller than in the foreground. The vertical scale is significantly exaggerated. The Boston and Albany railroad is not so straight as it is here drawn through the valley; about a mile and a half of its length is shown. Defending ledges are drawn in black. Roads are dotted.

3. The open Westfield plain.—Just north of Westfield station, a good view is had from the terrace near Prospect Hill schoolhouse, A, figure 6, over a broad plain that the river has excavated east of the village. The plain is limited on the north by a single high terrace, B, rising at once from the marshy abandoned river channels at its base to the level of the highest drift plain of the district. On the opposite side the flood plain of the Westfield is confluent with that of (Westfield) Little river (not shown in fig. 6), limited on the south by a single high terrace, today undercut by Little river at two places. The low plain thus gains the unusual breadth of a mile or more for a distance of about two miles eastward from our point of view. The two rivers here show no incompetence whatever in the process of lateral swinging. Whatever loss of volume they may have suffered—and some loss since the disappearance of the ice sheet is highly probable—and however recent the last uplift of the region may have been, these two streams are here sweeping over a broader valley floor to-day than they have opened at any earlier time; for whatever earlier flood plains they have formed at intermediate levels, during the process of excavating their valleys, are now completely undercut and destroyed (except for a few low terraces) by the opening of the present broad plain. The prime reason for so striking an exhibition of competence on the part of the streams is believed to be the absence of rock ledges in this section of the valley. No ledges have here been discovered by the degrading streams; their high terrace scarps consist of clays, sands and gravels (the latter near the top), very easily eroded wherever the streams flow against their base, as may be seen where Little river is now swinging against the terrace scarp on the southern side of the plain. A secondary reason for the competence of the river to swing so broadly at the present level is probably to be found in the delay of further valley-deepening and in the resulting detention of the streams.
close to their present grade by the trap sheet which their
united current has come upon in the notch in the trap ridge
about two miles east of Westfield.

4. **Terrace diagrams.**—The single high terrace scarp, here
so well developed and typified in figure 1, is of more general
occurrence in the terraced valleys of New England than is
generally supposed to be the case. It may indeed be taken as
typical of many terraced valleys where no ledges have been
discovered to prevent the free swinging of the rivers. A few
lower terraces may still be unconsumed here and there, as in
figure 2; this arrangement of terraces also being of common
occurrence where ledges are wanting. The ordinary diagram of
a terraced valley, such as is here reproduced in figure 3, is there-
fore misleading in implying that the stepping terraces have
been carved in drift alone, without relation to the rock beneath.
These many-stepped flights of terraces need for their preserva-
tion a number of ledges, as in figure 4; but this figure is very
faulty in implying that ledges occur all along the base of the
terrace scarps. As a matter of fact, the ledges do not occupy
more than a small percentage of the terrace lengths, and far
from all lying on the line of a single cross section, as figure 4
implies, they are frequently distributed somewhat irregularly
up and down the valley sides. The true relation of ledges
and terraces is better shown in a block diagram, such as figure
5; and even here the area of the ledges exposed in the terrace
cusps is exaggerated over that commonly observed.

5. **The Westfield spur (Prospect hill).**—If the terrace by
Westfield station is now crossed to the west, it is soon found
to be a spur of a high, but not of the highest plain, extending
forward (southward on the north side of the valley) from the
broad plain in the background. It is known as Prospect hill.
The apex of the spur, E, figure 6, reaches the river; its
breadth, east and west, is about a quarter of a mile. From its
western side the valley floor again widens, making a recess or
re-entrant in the high plain on the north; but here four sub-
ordinate terraces are found beneath a stronger scarp that rises
to the highest level; they combine in a charming landscape,
when seen from the western scarp of Prospect hill. As the
river is thus found to have been competent to widen its valley
both east and west of the terrace spur, some reason for the pre-
servation of the spur should be looked for; and it is discovered
clearly enough on descending the western scarp, which is found
to be defended at various points along its bank by sandstone
ledges, C', C'', C'''. The sandstones are, to be sure, relatively
 friable; they are weak compared to the schists and gneisses of
the Berkshire hills to the west; so weak, indeed, that while
the Berkshires retain in the equable height of their uplands a
fair indication of the altitude to which the Cretaceous peneplain of this region has been raised, the Triassic sandstones in this part of the Westfield valley (part of the greater Connecticut valley lowland) have been reduced by later Tertiary erosion to a lowland of a second (or $n+1$) generation. Yet compared to the silts and gravels of the terraces, the sandstones are very strong; whenever the river has, in the process of sweeping the drift from its valley, swung against a sandstone ledge, previously buried, further lateral swinging has been peremptorily stopped and the terrace behind the ledge has been preserved.

It is evidently because of the abundant defending ledges here that the Westfield spur has not been destroyed. The stream has made a most determined effort to destroy the spur by scouring out a hollow, C, at its back, sweeping around in so great a curve that its normal eastward course was locally turned back to the southwest; but the ledge, C', on which the stream was caught, could not be removed, and hence the spur still stands there. The river seems to have been withdrawn from the deep recess, C, by taking a short-cut across a more axial part of the valley floor of that time, probably during a flood. When it again swung northward towards the recess, at a somewhat lower level than before, a lower part, D', of the same ledge was encountered a little farther forward than the point, C'; and a small lunate area, C, of the earlier sweep was therefore preserved back of the new terrace, D. On the third return of the river into the same locality at a still lower level, it was caught by a small ledge, D'', several hundred feet farther forward, and again by larger ledges, C'', C''', and hence a good stretch of the flood plain between D' and D'' was preserved in a terrace.

The Westfield river is at present making still another effort to remove the spur, and it is now for at least the fourth time stopped by a member of this group of ledges, for a strong reef of sandstone is seen in the river bank at E in the southern corner of the spur. The spur may in the distant future be somewhat sharpened by losing ground on its undefended south-east corner, should the river chance to swing that way; but such swinging will be for the present strongly resisted by the buttresses of two bridges and by artificial embankment where the Boston and Albany railroad follows the river; it will cost less to restrain the river than to remove the bridges and the tracks.

6. No local evidence of decrease of volume in the Westfield river.—Evidently the preservation of the spur of Prospect hill is not due to any incompetence or to any want of effort on the part of the river to remove the sands and gravels. The river has repeatedly and energetically attacked the spur; it has in
the most competent fashion swept away all the drift that could be reached. It was only upon encountering the stubborn resistance of an ambushed and impregnable ledge that the river first withdrew, and even then it withdrew only to renew the attack by returning bravely toward the spur on a later swing. Unfortunately for the reputation of the river, the ambushed ledges have been found entrenched farther and farther forward at every successive attack that has been made upon them; hence the river, losing ground at every advance, has come to be looked upon as a weakened and shrinking stream that voluntarily abandons its earlier enterprises and accepts a narrower limit for its conquests to-day than when in a youth of (imagined) greater vigor and aggression; but this is a most unjust interpretation of its behavior. The river is making a most determined and heroic effort to carry out its original plan of campaign. It is eminently successful in opening the valley east of Westfield, and if it is defeated at the spur, this is only because of the reinforcement of the unconsolidated drift by the invincible strength of the entrenched ledges. The river may be accused of want of foresight in not more carefully reconnoitering the ground that it originally proposed to excavate, but it is notorious that rivers are heedless of buried ledges, on which they often become inextricably superposed. The river may be thought headstrong to return to an attack, a forlorn hope, where defeat is inevitable. Headless and headstrong it may be, but it does not deserve the reproach of being looked upon as enfeebled. Even if its volume is now less than formerly, the river is as competent to-day as it ever was to open a wide flood plain in drift, and it does so wherever free opportunity is offered of carrying out its original enterprise.

7. **Relation of ledges, terraces and river swings.**—It should be noted that the ledges of the Westfield spur have not in any case determined the depth to which the river has cut its valley. The ledges here were not encountered in the river bed but in the river bank, and hence have controlled only the breadth of lateral swinging at the point where they were by chance discovered. The depth at which the ledges were encountered was dependent simply on the amount of valley excavation that had been accomplished by the graded river at the time that the discovery was made. It is also important to note that while a ledge thus encountered in the bank of a swinging river will defend and preserve that part of any flood plain previously formed at a higher level, above and back of the ledge, it is not at all necessary that every former flood plain of the river should be thus recorded. If the successive northward swings of an east-flowing river have by chance less and less ampli-
tude, successive terraces will remain, even without defense by ledges. There can be no question that some of our terraces are of this accidental kind. But the undefended lower terraces will be undercut and destroyed if the river swings more strongly north again. If the river again swings north until it strikes a ledge, the uppermost terrace may alone be preserved, and that only back of the defending ledge. It thus becomes evident that in order to discover the number of times that a river has swung across its valley, making laterally sloping flood plains at lower and lower altitudes at every swing, we must not trust to the chance preservation of flood plain remnants in terraces here and there, but must seek a flight of terraces, systematically grouped on a long sloping ledge, which may preserve a lateral remnant of every flood plain that has been formed, as in figure 5. It is certainly a striking fact that the number of steps in a flight of valley terraces always reaches a maximum in just such situations. The preservation of numerous terraces of moderate height on long sloping ledges—however few such ledges there may be in the valley and however few terraces occur elsewhere on the valley sides—goes far towards excluding the theory of successive uplifts and pauses as a cause of terracing. It goes far also towards supporting the theory that the wandering river has been swinging from side to side across its valley, always degrading its channel but always acting as a graded river, during the whole period of terracing, whatever may have been the cause that determined the excavation of the valley drift. If uplift were the cause, the uplift must have been slow and relatively uniform.

In illustration of this conclusion, we may return for a moment to the broad basin east of Westfield. No terraces at intermediate levels are found here to prove that the river did repeatedly swing laterally while degrading its valley floor in this part of its course; yet there can be no reasonable doubt that the river really did swing back and forth here, for the remnants of four flood plains at intermediate altitudes are found in the terraces on the west side of Prospect hill, only half a mile away. Farther up the valley one may find a flight of nine defended terraces, described below, whose subequal heights range from ten to fifteen feet; thus proving that even the four terraces on the Westfield spur preserve a very incomplete record of the river's activity. Evidently the maximum number of steps observed in any terrace flight gives only the minimum number of swings that the river may have made during the whole period of degradation.

8. Ledges outcrop on the up-valley side of terrace spurs.— In the terrace spur here called Prospect hill, as in many others, it is noteworthy that the up-valley side of the defending ledges
has been clean swept by a swinging curve of the attacking river. This may be explained as a result of the normal progress of a river meander down the valley, until it is stopped by coming on a ledge, or abandoned by withdrawal of the current to a short-cut or cut-off course. The fact of the down-valley progress of a meander does not seem to have received much attention from physiographers, judging by the silence of textbooks concerning it; but it must be a familiar matter to river engineers, so conspicuously is it exhibited on such maps as those prepared by the Mississippi River Commission. The cause of the down-valley progress is evidently to be found in the continued displacement of the thread of fastest current to the down-valley side of the channel on entering the tangent of inflexion between two meander curves.

9. Brown's spur.—On the other hand, a terrace may trail some distance down-valley from its defending ledge, unless the stream should by any chance swing in again and sweep it away. This chance has not happened in Prospect hill, the spur thus far considered; but it has in Brown's spur, F, half a mile farther west. This spur is well defended by a large sandstone ledge, at whose forward-reaching base the river is now flowing in a vain effort to widen its valley. Four terraces in the next up-valley reëntrant curve forward to the apex of the spur, and all agree in the most unanimous manner to sweep tangent to the slope of the defending ledge. The ledge is well exposed in the cuts made by the passing road and railroad. The scarp of the next higher terrace, G, is, however, pushed back a quarter of a mile farther north; evidently because when it was made the river was swinging at a slightly higher level than the summit of the defending ledges in the apex of Brown's spur. It seems undeniable, when one looks at these terraces on the ground, that the river would have pushed back the lower members of the series about as far as the higher member, if its lateral swinging had not been stopped by the ledge.

The peculiar feature of this spur is, however, the close trimming that it has suffered on its down-valley side. The river has at least three times swung northward so near the eastern side of the ledge as to narrow the spur into a sharp point. The normal down-valley progress of the meanders cannot be appealed to as a cause of this close trimming on the down-valley side of the ledge; some special cause must be looked for to direct the several northward swings of the river over so nearly the same course. It seems probable that some constraint has been exerted on the river further up its channel, whereby it has been repeatedly guided to the down-valley side of the ledge. A possible explanation of this peculiar feature will be suggested on a later page.
10. The flight of terraces by Pochassic Street.—The finest flight of terraces hereabouts is preserved a little east of a small settlement, known as Pochassic Street, on the southeastern slope of Pochassic hill, a drumlin, around whose base abundant ledges have been discovered. The settlement and drumlin are just to the left of the limit of figure 6. The highest terrace, $H$, shows waterworn cobbles and pebbles on its plain; the bouldery slope of Pochassic hill rises behind it. Terraces are usually counted upward from the valley floor in the reverse order from that of their production. It will be convenient here to follow the natural order and count downward, beginning with the plain and scarp of the highest terrace as number one. Thickets of small trees and bushes obscure many details here, and some of the terrace plains are inconveniently swampy near their back border, perhaps because of ledges farther forward by which the ground water is held up. Hence the correlation of some of the terraces in this locality is doubtful, as indicated by the blanks left in the figure. A flight of at least nine steps, $H-M$, may, however, be counted, all presenting characteristic concave fronts in what may be called the Pochassic reentrant, all curving forward at their down-valley ends to defending ledges, and all of similar height, roughly from eight to fifteen feet. A later terrace occasionally undercuts an earlier one, so that the two scarps are locally united in a slope of more than the average height; such being the case with the fifth—sixth scarp, along whose base lies a narrow country road in the middle of the reentrant; a little farther east and west the scarp is divided into two (or more) parts by a narrow terrace that comes forward at an intermediate level; thus what seem to be the fifth and sixth swings of the river may be identified.

The uppermost terrace may be followed along its scarped front through the second growth of bushes and trees past two defended cusps, $H$ and $H'$, beyond which it turns to the north-east and at a distance of half a mile or so seems to run tangent to another drumlin. The second terrace is not identified on the first ledge, $H$, but appears on the second, $H'$; it seems to fade away on the broad plain a quarter of a mile to the north-east. The third terrace is caught on both ledges, $H$ and $H'$; it then runs eastward half a mile and is undercut at $G$ by the large reentrant between Prospect hill (the Westfield spur) and Brown's spur. Shortly before it is cut away, a low terrace turns off northeastward from it and seems to continue some distance; hence what has just been called the third scarp might be taken to represent the fourth northward swing of the river.

It is important to note that the sharp curvature and large arc of the reentrants in the first and third scarps in connection with the ledges at $H$ and $H'$ are much more consistent with the
behavior of a river similar in volume to that of the present Westfield than with the behavior of a much larger river.

The fourth terrace in the Pochassic reentrant is caught on a ledge of loose-textured sandstone, J, that stands forward from the first small reentrant in the higher terraces. The ledge is not directly exposed, but abundant angular fragments of pebbly sandstone are found in the apex of the blunt cusp on the terrace front. This terrace is believed to be the one that runs forward in a long sweeping curve to the apex of Brown’s spur; but it has not been followed all through the bushes and some details of its form may not be shown in the figure.

The divergence between the eastward course of the third and fourth terraces, G and F, is highly significant. The third scarp was cut a quarter of a mile back of what is now the apex of Brown’s spur, because at the time of the third northward swing of the river, its channel had not been worn deep enough to catch upon the summit of the ledges in the spur. But at the time of the fourth northward swing the river had eroded its plain to a lower level, so that it was held by the topmost ledge. The fourth terrace, therefore, could not be cut so far back as the third; it makes a long sweep forward from the Pochassic reentrant to the apex of Brown’s spur and leaves a rather broad plain between its scarp and that of the third terrace. It is perfectly evident that this arrangement of the two terraces was not due to any decreasing strength on the part of the river, but to the constraint imposed upon its wandering by the ledge at F.

11. Perry’s spur.—Below the fourth terrace, J–F, come several others, which run forward to the rounded front of Perry’s spur, K, K’, where several blunt cusps are determined by ledges of very friable sandstone that would hardly be seen but for cuts made by the road and the railroad. This item is of importance, for it shows that certain ledges which are strong enough to defend a terrace are not always bold enough to keep themselves in sight. After having done their duty in fending off the river, they strategically weather under cover and thus ambush themselves again beneath a thin sheet of their own waste mixed with creeping drift from the terrace they have protected. It is possible that another example of this kind may be found in the well defined cusp, D’’, of a low terrace in the reentrant between Prospect hill and Brown’s spur; it seems at first to be only the free intersection of two curves, for there is no sign of a ledge at its base and there are no angular fragments of sandstone by which the presence of an ambushed ledge is sometimes revealed. A little digging or a boring with a soil auger would suffice to determine this point.

The indefiniteness of some of the terraces in the Pochassic reentrant may be due to the discovery there of till underlying
the stratified drift. Till is seldom well carved by a swinging river; its texture is significantly firmer than that of stratified sands and clays. A small stream coming out from the north cuts little trenches in the terrace fronts and spreads its gravel fans on their plains, thus further obscuring their forms.

The eighth and ninth members of the Pochassic flight are well defined, but instead of conforming to the concave pattern of the higher members of the series, they spring forward to a defended cusp, M, nearly opposite the middle of the reëntrant. Here as elsewhere it is perfectly evident that the failure of the river to cut back these lower terraces is not due in the least to any loss of its original strength, but to the increase of resistance offered by the ledges. The river has now swung away from the northward meander that it followed while carving the lowest terrace, N', to a correspondingly strong southward meander, T', which is now cutting a low terrace, T, on the south side of the valley. A broad flood plain, N, has thus been opened. It happens curiously enough that the down-valley progress of this southward meander has just now brought it to such a position that it is impinging against a large exposure of the sandstones at M. The normal down-valley advance of the meander, T', will soon carry it past the ledge, unless the caving bank at T is protected. For the present, the obstruction caused by the ledge in the normal flow of the river seems to have produced a slight bend in the channel a little farther upstream. When the meander is sufficiently advanced the river will impinge directly on the unprotected bank between M and L, and consume it rapidly, leaving a sharp cusp at M. It is probably in some such way that the sharpening of Brown’s spur, referred to above, has been accomplished. There has already been some undercutting of the low terrace east of M, for the main valley road was swept away by the northward swing of the river at L a few years ago. The road has been set back so as to cross Perry’s spur, K', north of the railroad, thus causing the desertion of several houses on the low plain, R, in front of the spur. The railroad itself is threatened by the river near L; the caving bank has been worn back dangerously near the track, and a quantity of coarse rock blocks has been thrown in there to stop the caving. But for this resistance the river would probably continue to swing northward until it encountered a low member of the group of ledges in the southwest base of Perry’s spur, K'.

West of Pochassic Street another large reëntrant has been swept out on the north side of its valley; its down-valley side is well defended by ledges in the southwest base of Pochassic hill.
The flight of nine terraces in the Pochassic reentrant, above described, constitutes the best series in the valley, as far as I have seen it. Closer study will probably increase the number of steps. The subequal height of the scarps suggests that these terraces record nearly every northward swing of the river in their locality. A similar number of swings has probably occurred elsewhere; the record of them is incomplete or wanting only because of the absence of defending ledges. It may therefore be concluded in general that it is only in localities well provided with ledges that one may expect to see preserved in terraces the lateral remnants of all the flood plains that were formed by the swinging river during the excavation of its valley; and that the maximum number of steps in a terrace flight is only the minimum number of lateral swings made by the river. All of these terraces testify to the graded condition of the degrading river at the time the terrace plains were made. The nine chance samples of river condition thus preserved may be fairly taken to show that the degrading river was meandering and swinging at grade during the whole period of terracing in this section of the valley. There is no indication that the individual terraces depend in any way whatever on individual uplifts.

12. Terraces south of the river.—The terraces on the south side of the valley may now be considered. No ledges are seen on this side of the river within the two-mile stretch included in figure 6. The first ledges are found half a mile further west; they defend the eastern or down-valley side of a strong reentrant a little west of the town farm. Correlated with the prevailing absence of ledges is the absence of upper terraces. The high plain is habitually bordered by a strong scarp of forty or more feet, beneath which there may be several low terraces; but in one case the low flood plain of the present river enters a strong reentrant, P, to the base of single scarp by which the whole descent is made from the high plain. Nowhere in this district is there a flight of low-scarped terraces from the top to the bottom level on the southern side of the valley. The reason for this contrast between the two sides of the valley may be with confidence ascribed to the general southward shifting of the belt within which the river swings, because of the southward slope of the ledges on the north side of the valley and the undefended condition of the terrace drift on the south side of the valley. It is a sort of monoclinal shifting of a river course. The several low terraces on the south might seem at first to contradict this explanation. They may, however, be reasonably explained as being not yet swept away. The river cannot attack the whole length of the southern side of the valley at once; it will swing against the southern
terraces only here and there, now and then; and hence the destruction of the lower southern terraces by the southward shifting of the belt of river-swinging can only be accomplished progressively. Thus viewed, it is no wonder that some of the lower southern terraces still remain. This corollary to the explanation above suggested receives much support when examination is made of the relation between the defended cusps of the terraces on the north and the concave reentrants of the terraces on the south, to which we now proceed.

13. Correlation of terraces on the two sides of the valley.—
It will be readily understood that, wherever a terrace scarp curves forward from a concave reentrant to a defended cusp, the river must have once flowed along the base of the scarp and must have continued the line of the terrace curve past the cusp toward the opposite side of the valley, there to recurve toward the general valley axis. The farther forward the defended cusp reaches toward the axis of the valley, the more likely it is to direct the departing river strongly against the terraces on the opposite side of the valley. Thus the curved scarps, $K', K'', K'''$, of the northern terraces, suggest that the river has formerly flowed on past the defending ledges of Perry's spur at these several levels and has thus entered the reversed curves of the southern scarps, $S', S'', S'''$. The levels of the terraces concerned seem to correspond by pairs, but they have not yet been accurately measured. Of the three northern scarps, the one leading to $K'$ has the strongest curvature, for the middle of its reentrant is cut farther back than the middle of the others. When the river flowed at the base of this scarp, its current must have departed from the defending ledge almost transversely to the general eastward course of the valley. Consequently the corresponding southern scarp, $S'$, makes a strong reentrant on the south side of the valley. The second scarp, $K''$, of the northern group was more gently curved; the third scarp, $K'''$, still more gently curved; and the same relation is seen in $S''$ and $S'''$. It is possible that even the higher southern reentrant, $S$, is indirectly related to the ledges of the northern valley-side about $K$; the general curvature of the river being determined by the ledges and a southward swing of the curving river there causing the excavation of the reentrant, $S$. It is proposed to make a careful measurement of all these terraces in order to test their correspondences.

Another example of this cross-valley relation is found farther west. The curved scarp of the lowest northern terrace, $N'$, that sweeps out to the defending ledges at $M$, is the northern member of a double curve whose southern member made the strong concave sweep, $P$, already mentioned, under the high southern terrace plain. The ledges at $M$ stand unusually
far forward toward the valley axis; this southern sweep is therefore the only one that has consumed all the southern terraces at intermediate and low levels. The abandoned channel of the sweep is still swampy and the enclosing scarp is still uneven with landslides, so lately has the river been withdrawn. It is natural enough that the river should not have swung so far south at higher levels, for the guiding ledge, M, is rather low; it was not encountered until the river had cut down its flood plain nearly to the present level.

Inasmuch as the southern sweeps, S' and P, seem to have been guided by the northern ledges, K' and M, it is natural to find the unconsumed remnant of the terrace between the two sweeps in the form of a cusp, Q. This cusp is about forty-five feet high. It is entirely undefended and might, therefore, at first sight be classed with free cusps, and regarded as the consequence of a chance intersection of successive meander sweeps on the valley side. But the dependence of the sweeps, P' and S', upon the defended spurs on the northern side of the valley shows that the strong southern cusp, Q, is not altogether accidental. It is in reality a natural, although an indirect and temporary, product of the northern ledges at M and K'. Unlike the defended northern spurs, which are relatively permanent features, the indirectly defended cusp, Q, will not endure. Its apex is already truncated by a chance swing of the river against it; it will be more and more consumed as such swings are continued and repeated. It is safe only so long as the river flows on curves determined by the ledges at M and K'.

The truncated free cusp, W, on the south side of the valley, is probably related to Brown's spur, F, in much the same way that the truncated spur, Q, is related to Perry's spur, K'.

Another southern cusp, T, is the remnant of a 15-foot terrace projecting far into the valley between the southern re-entrants, T' and P. A strong scarp, T'', with blunt salients rises to the high plain back of T. The sharp apex of the cusp points directly to the ledges at M, yet it is entirely undefended south of the river. It is probable that there was something of up-valley carving on the eastern side of the cusp; a relatively unusual process, for, as has been stated above, river meanders normally progress down-valley. But in this case, the down-valley progress of a northern meander was stopped by the ledge at M. The ledge probably acted as a sort of fulcrum as soon as the river impinged upon it; the deeper the northern reentrant, N', was cut, the more nearly the river must have turned square across the valley at M, and the more it must have been turned against the down-valley side of the spur, T. Something of the same kind probably occurred when the reentrants, S', S'', S''', were scoured out.
14. Development of future meanders.—The river is evidently tending to become more curved at its northward bend, L, and its southward bend, Q. It was formerly less curved; and it was probably then that it ran into the strongly concave reentrant, V'. No immediately local cause is found for the preservation of the low spur, V; for no defending ledge is to be seen at its apex; but one may be there, buried in the flood plain deposits; the sandstone outcrops in the little island near by and in the cusp F nearly opposite. It is possible that these ledges held the river in the channel between them (on the north side of the present island) while the river scoured out the sharply concave reentrant, V'; and that, as the river increased its curvature at L and Q, it withdrew from the curve of V'. Such a series of changes would not be inconsistent with what is known of the development of river meanders. Their greatest dimensions are attained only where the curves are well organized, and such organization requires time for its accomplishment. A limit is set to the size of the curves, less by an equilibrium between current and bank than by the abandonment of the curves when short cuts and cut-offs are made. The river course is thereby made nearly straight again, after which a new series of curves is gradually established. The Westfield river heretofore is comparatively straight to-day. Its course for several miles eastward from T must be much less curved now than when the concave terrace fronts were carved at various earlier dates. But a strong curve is seen to-day at T'; the curves at L and Q are increasing and their maximum curvature is not yet reached, and hence it may be expected that another period of organized meandering is approaching. The restraint of the ledges at M will soon be avoided by the down-valley progress of the meander T. The northward curving at L will be resisted by the railroad. The southward curving at Q may be delayed by the abundant fall of gravels from the truncated end of the spur; and indeed there are already some indications that the river may bend southward into the low flood plain west of the spur. A stronger northward turn toward F would thus be induced and a stronger southward turn might then follow farther eastward. The latter item in this series of changes would be made more probable if the swinging river would again pass the ledges at F on a southeastward course, as it did when carving the up-valley side of Brown's spur.

All these details are relatively trifling, yet they have a value in that they unite in showing the competence of ordinary processes, appropriate to a meandering, swinging and slowly degrading river, to produce even the most minute forms of our terraces. There is no demand for an ancient river of great
volume or for repeated movements of uplift in the terrace problem of the Westfield river.

15. Southern terraces at Westfield. — Nearer Westfield the complication of the southern terraces increases somewhat, and there is one member of the series at a higher level than elsewhere on the south side of the valley in this district. It may be therefore inferred that the river belt has hereabouts been shifting northward, and this would be confirmed by the high terrace of the opposite northern reentrant. Yet no ledges are found on the south side of the valley as a cause of this shifting. The only explanation that I have thought of for it is that Little river once entered the Westfield from the south near the present site of Westfield village, and thus slowly pushed the Westfield river northward from the course it had previously followed. Interference of one river with another in this way has been suspected in the eastern basin, beyond Westfield, and in several other localities in the Connecticut valley.

16. Conclusions. — The most manifest conclusion to be drawn from this study is the one already announced; namely, that Miller's theory of defending ledges gives a better explanation than any other for the terraces of our New England valleys. It is not desired to imply by this that all our terraces are defended, but that most of them are; and especially that all the many-stepped flights of terraces owe their preservation to defending ledges. Decrease of river volume and intermittent uplifts do not seem to have had any significant part to play in the restriction of the swinging rivers to narrower and narrower belts. Another conclusion is that the normal action of a meandering and swinging river suffices to account for practically all the details of terrace form; and hence that terraces, like other land forms, are susceptible of explanation, even down to their most minute elements. Following this there is a third conclusion, of interest to those who concern themselves especially with the study of land forms; namely, that in this division of the subject as well as elsewhere, observation is greatly aided by the discovery of a successful theory; for the essential facts are then quickly acquired by well directed search. It is also apparent that here as elsewhere description is greatly facilitated by explanation, for explanation enables the student to bring the local example into proper relation to the generalized type. There may seldom be necessity of giving minute description of forms so small and so ephemeral as drift terraces; but when that necessity arises it will be met better by characterizing terraces in terms explanatory of their origin than by an attempt at absolute or empirical description;
the defended and the free cusps, the high scarps without outcropping ledges, the flights of advancing terrace steps in association with groups of outcropping ledges, the correlations of the terraces on the opposite sides of a valley, all these items are best told by explaining them.

Finally it may be noted that even the geologist who is concerned only with the underlying rocks may well afford to give some heed to the pattern of drift terraces; for he will be most quickly guided to his desired outcrops if he examines the points and the up-valley sides of the terrace cusps.

Cambridge, Mass., June, 1902.
Figure 6.
Sketch of the Terraces of Westfield river, in bird's eye perspective, looking northeast.