Terraces of the Whitewater River Near Richmond, Indiana.

By Allen David Hole.

INTRODUCTION.

The terraces referred to in this paper constitute a small part of the complex series of terraces which characterize practically all the larger valleys in a considerable portion of the glaciated area of the United States. The terraces along the Whitewater River near Richmond have been recognized and referred to by a number of observers, but so far as the writer knows, there is no record of any systematic, detailed study of them prior to 1909. In that year Harold Chapman, then a student at Earlham College, studied carefully under the direction of the writer the terraces within the gorge from Richmond to a point about one and one-half miles south of the city. A continuation of this work for the three forks of the Whitewater above the city, extending four or five miles along each fork, was undertaken by Wendell H. Pitts, another student, and completed by him in 1911. The author has, by permission, used freely the data gathered in these two studies, which covered the areas indicated on the accompanying outline map, Fig. 1.

GEOLOGY.

The geologic formations involved include (1) thin-bedded limestone and intercalated shale of Upper Ordovician age, exposed in the gorge-like valley near the city of Richmond and for some distance above and below: (2) Middle Silurian limestone exposed scarcely at all within the limits here referred to, but forming the underlying bed rock in the northern (upper) parts of the area studied; (3) glacial drift of Pleistocene age, both unassorted (moraines), and assorted (valley trains, outwash plains, etc.); and (4) deposits of Recent age, mainly alluvial (flood-plains), but including also fans, material shifted by sheet wash, accumulations of talus, etc.

Structurally, the bed rock forms a part of the northernmost end of the Cincinnati anticline; the strata exposed are, however, practically hori-

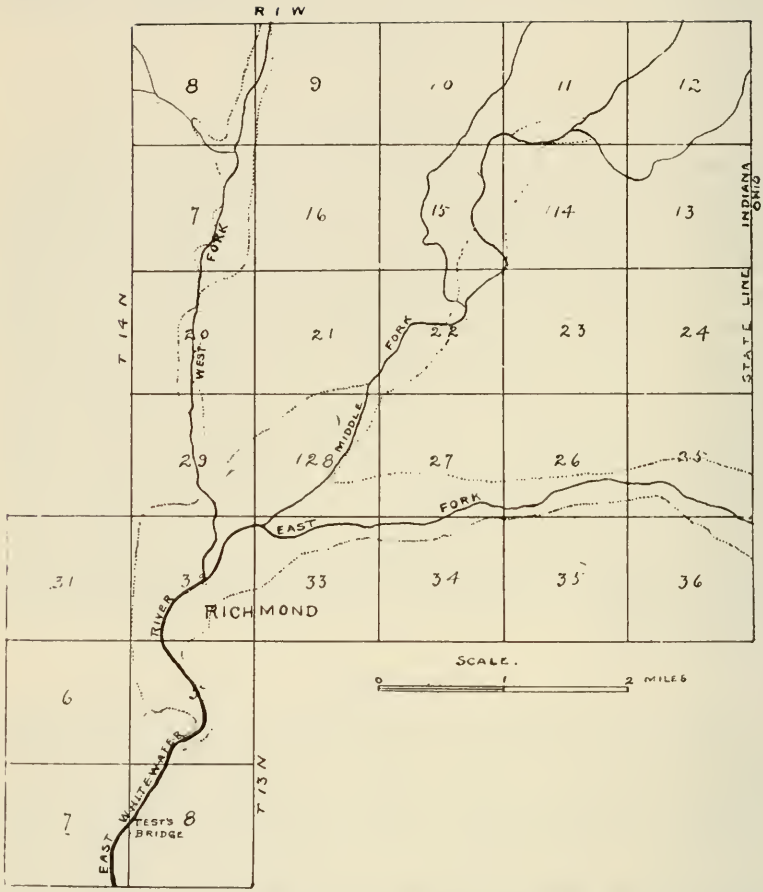

Fig. 1. Outline map of the region studied. Spaces included between dotted lines, or between one dotted line and the adjacent stream are approximately the areas within which terraces are found that is, a considerable part, though not all, of the included spaces are terraces.

zontal within the area observed, clinometer measurements indicating either no inclination at all or dips varying in amount up to about 1° in various directions, showing that the strata are either horizontal or departing from it to a very slight degree in such a way as to form an irregularly warped surface. Evidence of continued warping in the same direction of relatively recent date, considerable in total amount, yet occasioning dips too slight to be measured with a clinometer, will be presented in connection with the detailed discussion farther on.

No great systems of joints have been detected, and no faults except exceedingly diminutive ones.

GEOGRAPHY.

Whitewater River at Richmond is strictly East Whitewater River, the western branch crossing Wayne County near Cambridge City, and finally uniting with the eastern branch just below Brookville, in Franklin County, to form the Whitewater River proper; but in this paper, for the sake of brevity, the stream at Richmond will be referred to as the Whitewater River. This (East) Whitewater River is formed by the junction of three smaller streams just north of the city of Richmond, known as the West, the Middle, and the East Forks, respectively, of the Whitewater River. For the greater part of their course these three forks flow in valleys which are formed for the most part in glacial drift, bed rock being encountered at only a few points. Beginning a short distance north of Richmond, however, the valleys of these streams have cut into the underlying rock, which from this point on forms a large part of the slope of the sides of the valley; sometimes being exposed in steep, cliff-like faces, sometimes covered with a thin layer of soil, talus, or other rock waste.

From the vicinity of the junction of the three forks for a distance of over two miles southward, the valley is narrow, steep sided, and canyon-like, its width at the top being from 600 to 1,000 feet, and its depth 60 to 80 feet. A little farther down, the valley is somewhat deeper but proportionately much wider, with sides which, while still steep, are less precipitous, having cliff-like faces at relatively few points, and in general showing signs of greater topographic age.

THE TERRACES.

The region at and near the points of junction of the three forks marks the approximate location of a natural division separating the series of terraces along the valleys of the three forks above from those along the

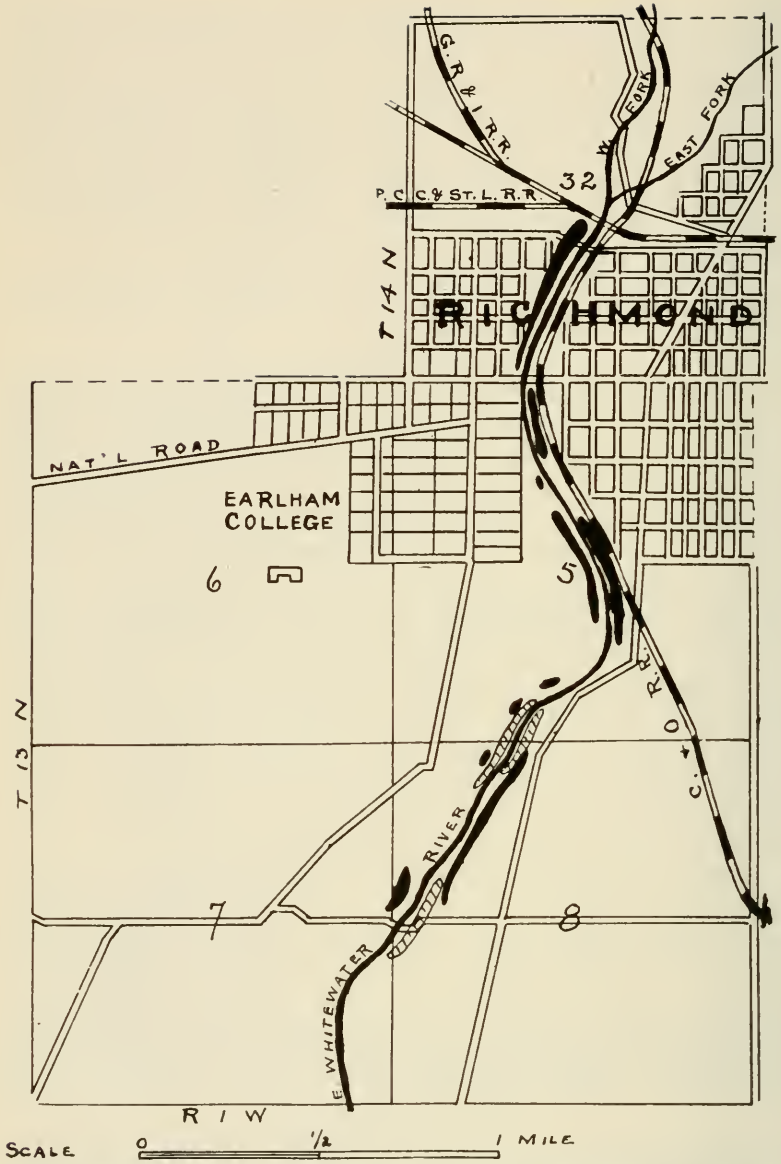

Fig. 2. Map of the gorge of the East Whitewater River and country adjacent, showing the approximate location of two levels of terraces within the gorge, viz: (A) a higher series, shown by solid black areas; and (B) a lower series, shown by obliquely-lined areas.

single, narrow, gorge-like valley below. The reasons for emphasizing this area as a division point will be clearer when the details of the different series are understood; but it may be worth while to note certain general differences just here between the terraces and valleys above the area near the junction and the corresponding phenomena below. The more obvious or the more important differences are:

1. Different materials; slopes mainly of outcropping bed rock below, mainly of glacial drift above.

2. Different number of terrace levels; four clearly marked below; seven above.

3. Different gradient of terraces; slope being upward in the downstream direction, or nearly horizontal below the junction area; level to a gradient about the same as the beds of the streams above the area.

Summary of Observations on Terraces Above the Gorge.

The different terraces along the three forks of the Whitewater can be referred to seven different series. For the West Fork these seven series are indicated in Fig. 3 by broken lines numbered from (1) to (7) inclusive. In nearly every case each series is made up of a number of disconnected terrace remnants. The total number of these remnants along the West Fork is 51; along Middle Fork, 26; along East Fork, 31; total, 108. From this total when deduction is made for terraces counted more than once near the junction of the streams, the net total is 103.

In size these remnants vary greatly. The largest forms the surface on which the principal part of West Richmond is built, and contains about 420 acres; its total length is more than 1½ miles, and its width from ⅛ to ½ mile. This terrace is a part of the fourth series and has an elevation above the stream at its south end of 82 feet; at its north end, of 45 feet. At its southern end bed rock is within a few feet of the surface; farther north the covering of drift, mostly assorted, becomes thicker.

At the other extreme of size are the very small patches forming flat-topped points or shoulders, in some cases having areas of only a few square feet. These exceedingly small patches, while sometimes of value in the field in correlating remnants of terraces, have not, however, been included in the count of terrace remnants given above. The smallest area included in the numbers as given contains about one-fifth of an acre; the average is, however, much larger, being for the 103 areas a little over 20 acres.

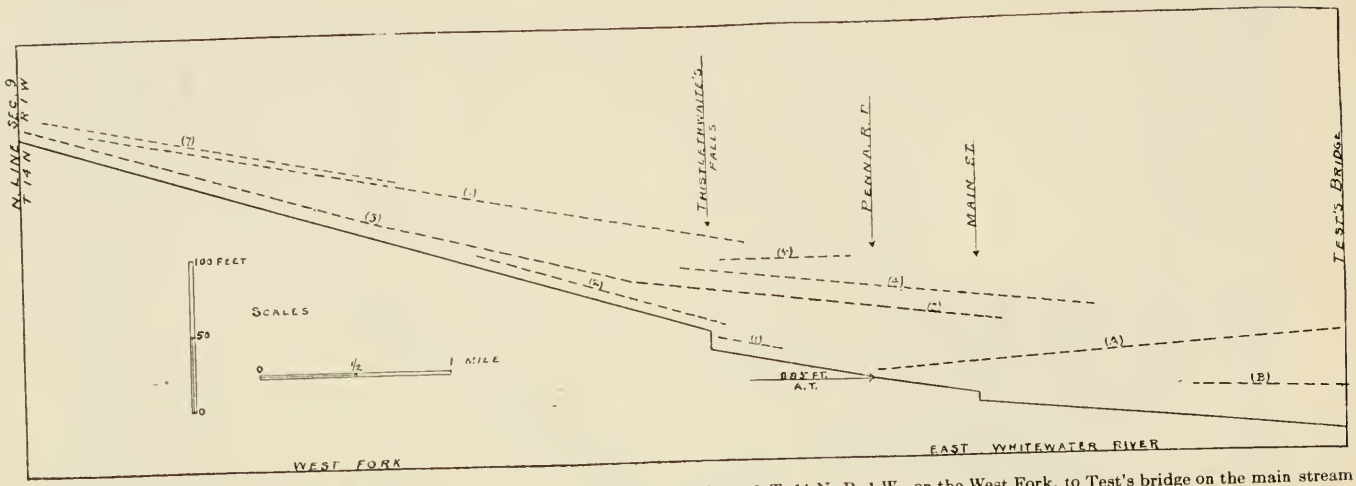

Fig. 3. Stream profile and approximate profiles of terraces from the north line of sec. 9 T. 14 N. R. 1 W., on the West Fork, to Test's bridge on the main stream (East Whitewater river).

Terrace profiles, broken lines; (terraces are in most cases not continuous).

Stream profile, unbroken line.

The gradients of the different series vary in about the same way on the three forks, though there is not perfect agreement. The general relations are shown by Fig. 3, viz.:

(1) The recent terraces above the point of junction of the forks agree quite closely in gradient with that of the stream to which they are adjacent.

(2) The older terraces have lower gradients than that of the adjacent stream.

One series, the fifth, has a surface almost horizontal so far as the West Fork is concerned; but its extent along this fork is limited to about three-fourths of a mile. When considered as a part of the corresponding series along Middle Fork with a total extent of nearly six miles, it agrees in general with the older terraces in having a distinct gradient, but less than that of the stream at present. The terrace profiles shown in Fig. 3 may suggest that the lower and upper parts of the third series do not belong together, since the degree of slope is so noticeably different. It cannot, of course, be considered as settled beyond question, yet the work in the field indicated so strongly that the two portions are part of the same series that the correlation was made as here given.

In most cases the remnants belonging to a given series are found part on one side, part on the other side of the stream. In only a few cases are remnants of the same series found on both sides of the stream at a given point.

An explanation of the profile of the West Fork it should perhaps be remarked that the Falls indicated are due to a diversion of the stream from a part of its natural channel for water-power purposes, which has forced it to abandon a part of its former course and re-enter its valley at a point where the slope is steep and formed of outcropping bed rock. The terraces of series (1) and (2) are, therefore, plainly not to be correlated, although the height of (2) above the stream bed above the Falls is about the same as that of (1) above the stream bed below.

Terraces Within the Gorge.

Within the part of the main valley which is canyon-like, extending from a little north of the city of Richmond to a point about two miles south, are two well marked terrace levels, an upper and a lower, indicated in profile on Fig. 3 by (A) and (B) respectively, and shown on Fig. 2 by solid black (upper), and obliquely lined (lower), areas. At neither level

are the terraces continuous for the whole distance indicated on the profiles, but consist of remnants, part on one side, part on the other side of the stream.

At the upper level, there is first a continuous terrace on the west side of the stream for about half a mile; next, in the down-stream direction, for about $\frac{1}{4}$ mile on the east side; below this for some distance not more than a trace on either side, succeeded by nearly continuous terraces on both sides for more than $\frac{1}{4}$ mile; again a distance of about $\frac{1}{3}$ mile with either no trace remaining or merely shoulder-like projections here and there; and finally at the south end of the canyon-like part of the valley, a terrace $\frac{1}{2}$ mile in length on the east side, with a remnant only a few rods in length on the west side.

At the lower level the terraces are likewise discontinuous in places and found only at times on both sides of the stream at the same point.

The width of these terraces is, at the maximum, about 60 feet; average, perhaps 20 to 30 feet; see Figs. 4 and 5. At both levels the terraces are chiefly rock cut, only a small amount of soil, talus, glacial debris, and rock waste being found upon their surfaces, and the rock in place rising in each case on the side away from the stream sometimes as a steep, wall-like slope until, at an elevation above the upper terrace nearly as great as the general level of the country, a considerable amount of glacial drift is found.

Perhaps the most interesting and significant feature about these terraces is their gradient as compared with the gradient of the stream, and with sea-level as a datum. The terraces of the upper level vary in height above the stream from 6 to 8 feet at the point farthest upstream where they are clearly marked, to 64 feet above the stream at the farthest down-stream point, a differential elevation of about 57 feet, rising higher and higher the farther downstream they are found. This suggested at first that there might be an error in correlating the separate remnants as parts of the same terrace; but it was observed that in each case where the terrace was continuous for about $\frac{1}{2}$ mile, there was this consistent rise in the downstream direction; in one case a rise of about 25 feet in a half-mile's distance; in another case a rise of 11 feet in a little less than $\frac{1}{2}$ mile. The shoulder-like points and projections and smaller terrace remnants where the terraces are discontinuous, have elevations agreeing closely with the general rise of the gradient in the downstream direction.

Fig 4. View along terrace (B) looking south from a point near the north end.

Fig. 5. View along terrace (A); looking north from a point about 40 rods north of Test's bridge.

Referred to sea level, the southern or downstream end of the upper terrace is about 20 feet higher than the northern, or upstream end. That is, in a distance of a little more than two miles the terrace level rises 20 feet higher above sea level, while the surface of the water in the stream has a fall of about 37 feet in the same distance, making a total differential level between the surface of the terrace and the surface of the water of about 57 feet.

The terraces of the lower level are from 25 to 35 feet lower than those of the upper level and are found only in the lower portion of the canyon-like part of the valley; their width is about the same as that of the upper terraces, averaging perhaps 25 or 30 feet, with a maximum of from 50 to 60 feet. The height of surface of this lower series above the stream also increases in the downstream direction, but at a much smaller rate than in the case of the upper terraces; in a total distance of about two-thirds of a mile the difference in elevation is about 6 feet. The fall of the stream is, in the same distance, a little more than 6 feet, which leaves the surface of the lower series of terraces with a very slight gradient in the downstream direction, when referred to sea level as datum.

Considering, then, the upper terrace level, the lower terrace level, and the present gradient of the stream in their relations to each other, the lower terrace level can be represented by a nearly horizontal line drawn a little lower than midway between two other straight lines which diverge in the downstream direction; the upper representing the surface of the upper terrace level, and the lower the present gradient of the stream.

CONCLUSIONS.

The causes which operated to make the conditions resulting in the terraces above described may, no doubt, be included for the most part in the following:

1. Variations in the amount of sediment carried by the streams.
2. Variations in the amount of water carried by the streams.
3. Variations in gradient due to—
   (a) Diastrophism;
   (b) Dams of ice and glacial debris more or less complete, resulting in ponds, river-lakes, etc.

While it is not possible to say positively just what share each of these causes may have had in the formation of each one of these terraces, the following partial explanations seem to be justified:

1. Terraces (A) and (B) in the gorge of the Whitewater River (mainly below the city of Richmond), were developed by the stream at periods, in each case, when its gradient was very much less than at present; a gradient sufficiently low to permit it to erode chiefly laterally.

2. In the case of the upper terrace, at least, this period of lateral erosion was interrupted by a relative elevation of the land (bed rock), which was not uniform, but increased southward from the city of Richmond to an undetermined distance. The total amount of the movement as indicated by terrace (A), is not less than 10 feet of elevation per mile in a general southward direction.

3. Since the terraces along each of the three forks are composed very largely of glacial material, it seems probable that temporary ponding of waters, and variation in amounts of water and sediment present, are largely responsible for their presence and for their relative positions. It seems probable also, however, that diastrophic movements may have had some part in producing the lack of parallelism in surface gradient of terraces of the different series.

The time relations involved can be stated clearly only in part. For example, the lowest terraces along the three forks, such as (1) along the West Fork, must be of date so recent as to fall within the category of present-day formations. Others, such as (A) in the gorge, must evidently be considered as belonging to a period sufficiently remote to allow for the erosion of a channel in bed rock 600 to 800 feet in width and 64 feet deep. Geologically this is still, however, quite recent, and this work may all have been accomplished since the final withdrawal of glacial ice from this latitude.

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