nal History of the Driftless Are

Trowbridge

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THE EROSIONAL HISTORY OF THE DRIFTLESS AREA

by

ARTHUR C. TROWBRIDGE

PUBLISHED BY THE UNIVERSITY, IOWA CITY

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PART I

MULTIPLE EROSION CYCLES IN PRINCIPLE

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PART I

MULTIPLE EROSION CYCLES IN PRINCIPLE

INTRODUCTORY SKETCH

First steps in the interpretation of the erosional histories of regions were taken when (1) the processes of land degradation by streams were worked out, (2) the limits of change were recognized, and (3) the stages of reduction, expressed in the terms *youth, maturity,* and *old age* were described.

Second steps were taken by Dutton[1] who conceived that the Arizona plateau had been degraded to low levels and then had been uplifted in such a way as to start new cycles of erosion. Following the lead of Dutton but bringing to bear upon their studies critical and analytical methods Willis[2], Hayes and Campbell[3], Davis[4] and others wrote histories of parts of the Appalachian mountains, not only presenting and explaining evidences of more than one cycle of erosion, but working out evidences of more than two cycles, describing the degree of completeness of reduction reached in each cycle, giving the geologic dates of each event in the erosional history of the region, interpreting the number, character and dates of uplift, etc. But, by its very thoroughness and accuracy, this work has led unfortunately to confusion. Later the principles so well used in the Appalachian region were applied, with little consideration, to regions where their application was doubtful. Complex series of events were thus assigned to regions whose histories were simple, and there came to be more raised peneplains in literature than in the field. The care-

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[1] Dutton, C. E., "Tertiary History of the Grand Canyon District," *U. S. Geol. Surv.*, Monograph No. 2, 1882.

[2] Willis, Bailey, *The Northern Appalachians, Physiography of United States*, 1895, pp. 169-202.

[3] Hayes, Willard C., and Campbell, M. R., "Geomorphology of the Southern Appalachians," *Nat'l Geog. Mag.*, Vol. VI (1894), pp. 63-126.

[4] Davis, W. M., "Rivers and Valleys of Pennsylvania," *Nat'l Geog. Mag.*, Vol. I (1889), pp. 183-253.

lessness of physiographic interpretation during this time was followed by a period of reaction ushered in by the criticism of Tarr[1] who seems to have been the first to sound a note of warning and present the idea that not all flattish surfaces above streams are old peneplains.

But now Tarr's argument in turn seems to have been carried beyond the point intended by its author, for many geologists having convinced themselves and others that some physiographic features which have been described as raised peneplains are not old erosion surfaces, have proceeded to the extreme conclusion that there are no such things as raised peneplains and consider no evidence either in favor of or against the peneplain theory in working out the histories of regions in the field. The conclusion that because some upland flats are not old peneplains there is no such thing as raised peneplains is as unwarranted and as great a detriment in the search for truth as was the conclusion of the older physiographers that because some upland surfaces were old peneplains, all such surfaces could be identically interpreted.

The extreme reaction against the peneplain theory seems to be giving way at present to a revival of interest in the subject, as shown in the spirited discussion among Umpleby[2], Atwood[3], Blackwelder[4], and Rich[5], all of whom assume the existence of a raised peneplain and differ among themselves only in regard to the age of the plain. R. T. Chamberlin[6] also clearly believes in the peneplain theory, as evidenced in one of his latest productions. Physiographers seem still to be about evenly divided into two groups, the members of one of which disregard the peneplain theory en-

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[1] Tarr, Ralph S., "The Peneplain," *Am. Geol.* Vol. XXI (1898), pp. 351-371.

[2] Umpleby, Joseph B., "An Old Erosion Surface in Idaho—Its Age and Value as a Datum Plane," *Jour. Geol.*, Vol. XX, No. 2, pp. 139-147; "An Old Erosion Surface in Eastern Utah—Its Age and Value in Time Determination," Abstract, *Wash. Acad. Sci. Jour.*, Vol. 2, pp. 109-110, 1912; "The Old Erosion Surface in Idaho," *Jour. Geol.*, Vol. XXI, pp. 224 et seq, 1913.

[3] Atwood, Wallace W., "The Physiographic Conditions at Butte, Montana and Bingham Canyon, Utah When the Copper Ores in These Districts were Enriched," *Econ. Geol.*, Vol. XI, pp. 687-740, 1916; "Physiographic Conditions and Copper Enrichment," *Econ. Geol.*, Vol. XII, pp. 545-547, 1917.

[4] Blackwelder, E., "Physiographic Conditions and Copper Enrichment," *Econ. Geol.*, Vol. XII, pp. 541-545, 1917.

[5] Rich, John L., "An Old Erosion Surface in Idaho: Is it Eocene," *Econ. Geol.*, Vol. XIII, No. 2, March, 1918.

[6] Chamberlin, R. T., "The Building of the Colorado Rockies," *Jour. Geol.*, Vol. XXVII, pp. 145-251.

tirely in field work, while those of the other group believe that raised peneplains exist, but are doing little constructive thinking or writing in substantiation of the theory itself.

It now seems appropriate to bring together all the methods which have been used in the interpretation of erosional histories, to analyze each method, to discuss its uses and abuses, and to attempt to assign to each its proper value. These are the purposes of this paper.

Both in the analysis of the principles and in the construction of the paper, the writer has been greatly assisted by Professors R. D. Salisbury, M. M. Leighton, and Leroy Patton, of whom all were so kind as to read the first draft and to make helpful suggestions for incorporation in the final paper.

MORE THAN ONE CYCLE OF EROSION

Theoretic Considerations

The rate of land degradation by streams has been estimated at 1 foot in 9000 years, under conditions which exist in the United States[1]. If the average altitude of the land today be taken as 2300 feet it would take more than 20,000,000 years for streams to reduce the land to sea level. But the process of degradation becomes slower as the lands are reduced. This progressively decreasing rate of reduction carried through from youth to the ideal baselevelled condition would involve an amount of time approaching infinity. Indeed, it seems doubtful if geologic time has been as long as a *complete* cycle of erosion would be. But, though it be uncertain that lands were ever reduced to base level, they have been reduced to low levels; that is, *perfect baselevel plains* are probably not formed, but *peneplains* may be. There is no theoretic reason for believing that extensive areas have not been peneplained again and again.

If the history of land surfaces were merely a matter of formation and subsequent degradation, most lands should to-day be in the condition of peneplains. The fact that

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[1] Water Supply Paper No. 234, U. S. Geological Survey, pp. 78-83.

high lands exist demonstrates that there are forces which give lands high altitudes and that these forces, on the average, at least balance the processes of degradation. These renewing forces are diastrophic.

There is not perfect agreement among geologists concerning some of the phases of diastrophism, but the principles involved in land formation are fairly well agreed upon. Lands are due to lithospheric contraction. As the lithosphere shrinks, the ocean basins settle more than the continental platforms, the capacity of the ocean basins increases, the water withdraws from the continental platforms, and lands are increased in area or height or both. If lands have been reduced to low levels and the lithosphere shrinks, these lands are left higher by the withdrawal of the sea and a new cycle of erosion is inaugurated.

If diastrophism were a continuous process, land would be reduced slowly if general degradation exceeded uplift, it would remain at a generally constant level if degradation and uplift were equal, and it would become slowly higher if uplift took place more rapidly than degradation. The height of land would depend upon a balance between diastrophic uplift and degradation by all agents of which running water is chief.

Pronounced diastrophism manifests itself periodically rather than continuously. Degradation goes on uninterruptedly between periods of diastrophism, but sooner or later the uplift comes, degradation is renewed and new cycles of erosion are inaugurated.

The relative duration of erosion cycles and diastrophic periods now becomes important. If the diastrophic period is longer than the erosional cycle, land is totally destroyed and then formed again. If the periodic uplifts come so frequently and the land is uplifted each time so high that the land added by each uplift is not entirely destroyed before the next uplift, the history is one of land increase, partial degradation, further increase, partial degradation, and so on. Neither the cycle of erosion nor the diastrophic period is of determinate duration, and therefore there can be no invariable rule in their relative values, but a study of geologic history leads to the conclusion that the *complete* erosion cycle is in most cases at least longer than the diastrophic period. This being the case most cycles of erosion are interrupted by uplift and few if any cycles of erosion have been complete. Doubtless there have been cases in which lands have been so reduced by all the agencies at work on their surfaces and by deposition in the sea that the sea spread over them, but probably there has never been a time when whole continents have been so destroyed. In any case the present paper deals only with those surfaces which have not been reduced to the condition of submergence.

The question now arises as to what stage of degradation is reached by the average surface before the cycle is interrupted. Tarr[1] has argued that because there are few if any low level plains to-day which have been developed by streams, there never have been any and that pleneplains have never existed. This conclusion is hardly warranted, for the present day may be one closely following an uplift.

The writer would agree that probably no continent-wide and perfectly flat erosional plains have been developed in the past, but he cannot agree that smaller areas have not been brought to an earlier stage of reduction which might be defined by the term peneplain.

It seems unavoidable to suppose that erosion cycles might be interrupted either in youth, maturity, or old age. But interruption in old age should theoretically be most common, for degradation takes place most rapidly in youth and maturity, and is much slower in old age. Land is reduced rather quickly to the peneplain stage but further reduction to complete base level is almost infinitely slow. That is, in a complete cycle the stage of old age would be longer than youth and maturity.

If a region reached old age in the first cycle and has gone only to maturity of the second, some of the characteristics of the first cycle will have held over into the second, and the history should be ascertainable. If on the other hand, a region is in youth of the first cycle when the interruption

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[1] Tarr, R. S., "The Peneplain," *Am. Geol.*, Vol. 21, pp. 351-370..

occurs, and it is in youth of the second cycle at the time of observation, it would be almost impossible to determine that it had entered upon a second cycle. It would be still more difficult to interpret the history of a region in which a cycle of erosion had gone so nearly to completeness that all evidences of a former cycle had been obliterated. Indeed, satisfactory determination seems to be almost limited to cases where each cycle of erosion is less nearly complete than those which preceded.

Evidences of More Than One Cycle of Erosion

Several different physiographic features have been used as criteria for more than one cycle of erosion in the history of land surfaces. If their relative values are to be fixed, it is necessary that each of these features be analyzed.

Interrupted Profile

Streams which have reached grade, normally have concave profiles with progressively decreasing gradients from source to debouchure. (abc Fig. 1). If such a profile be developed in old age of a first cycle of erosion and if the region then be uplifted so that a steep bordering slope is formed, rejuvenating the stream, degradation will be renewed first near the mouth of the stream, where a new valley and a new profile will be developed. As this new valley, with its profile, is extended headward, there will come a time when there is a double or interrupted profile (abe Fig. 1) in which the upper portion was made in the

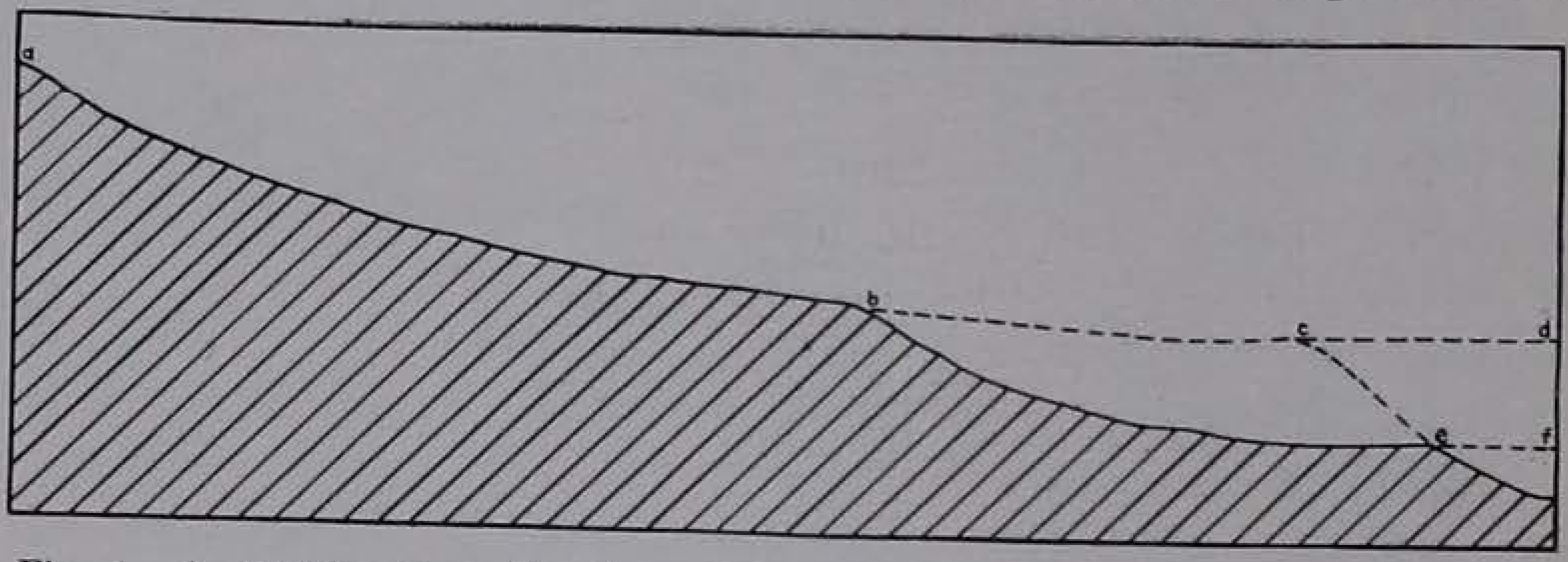

Fig. 1. A diagram in explanation of interrupted profile due to rejuvenation of a stream. abc is the profile of the stream in old age of the first cycle when sea level was cd. abe is the profile after sea level has taken the position ef and the rejuvenated stream has worked headward to be.

first cycle and the lower portion in the second cycle of erosion.

There are, however, distinct limitations to the use of interrupted profiles as criteria of rejuvenated streams. Any stream which flows across resistant to non-resistant rock, and which has not yet brought the resistant rock to grade, may develop an interrupted profile in a single cycle of erosion. (Fig. 2). If a relatively flat surface emerged from the sea and came to stand distinctly above its surroundings, as in the case of a plateau, water would run down the gently sloping summit surface and down the steep bordering slope and would acquire an interrupted profile which would last until the lower portion of the stream had worked headward to the very source of drainage. Any region therefore having unequally resistant rock or any flattish surface bordered by a distinct descent, may have streams with interrupted profiles.

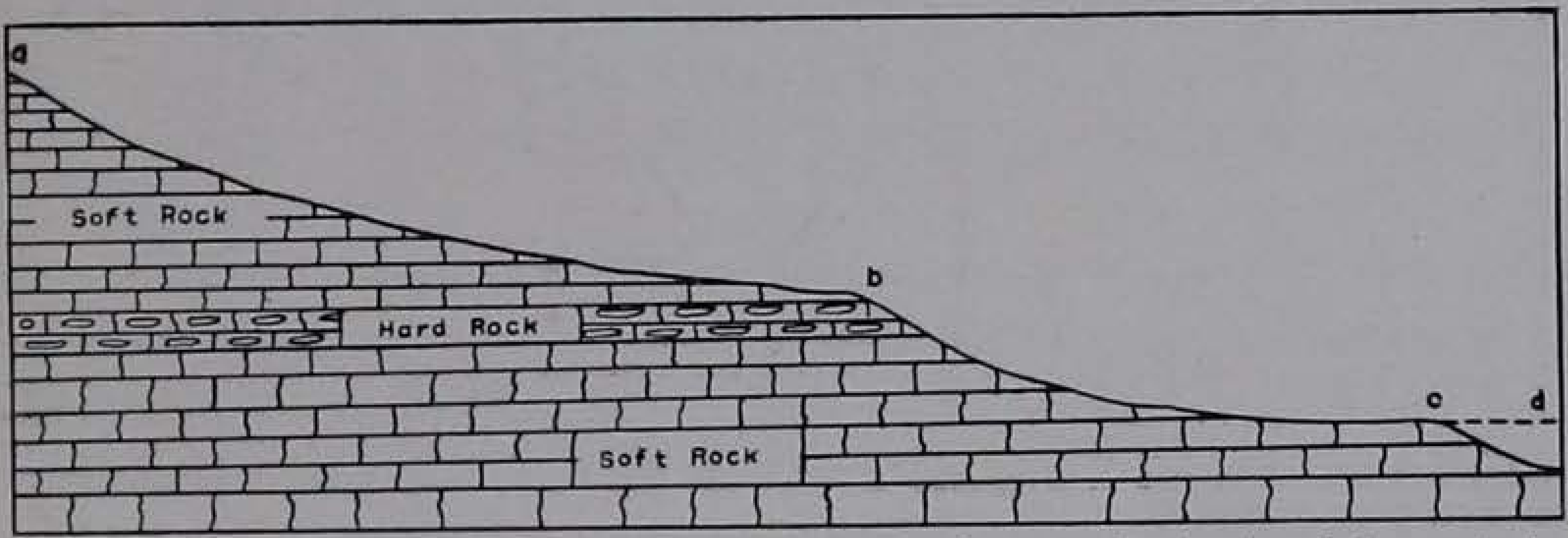

Fig. 2. Diagram showing how interrupted profile abc may be developed in a single cycle of erosion with reference to sea level cd, due to inequalities in the hardness of the rock formations.

In the abstract, interrupted profiles in the streams of a region merely suggest that the region may be in the second cycle; they do not furnish strong evidence, much less proof, of a second cycle. They amount to strong evidence, only after all other possible interpretations have been eliminated by careful study in the field.

Stream Terraces

The uplift of a surface in which a stream has previously reduced its bed to grade and developed a valley flat causes the stream to intrench itself in the flood plain and form terraces. (Fig. 3). Terraces so formed involve more than one cycle of erosion.

However, stream terraces are formed in a single cycle of erosion (1) by unequal widening at the levels of unequally resistant horizontal strata, (2) by the partial removal of glacial or fluvio-glacial fills in valleys, (3) by the recession of falls through temporarily graded valley bottoms, (4) by the removal of dams, such as landslides, lava flows, sand dunes, etc., (5) by renewed erosion of a valley flat, due to increased volume in a pirate stream, (6) by the intrenchment of graded valley bottoms as a stream acquires greater length and more and longer tributaries and comes to drain a larger area, and increases in volume, (7) by a graded stream receiving less load from its head as gradients are lowered, and intrenching itself, (8) by a stream picking up much fine material from its flood plain and dropping less coarse material in its place, (9) by the shifting of meander belts down stream, etc. These are common processes and all the events in the history of many stream terraces take place in a single erosion cycle.

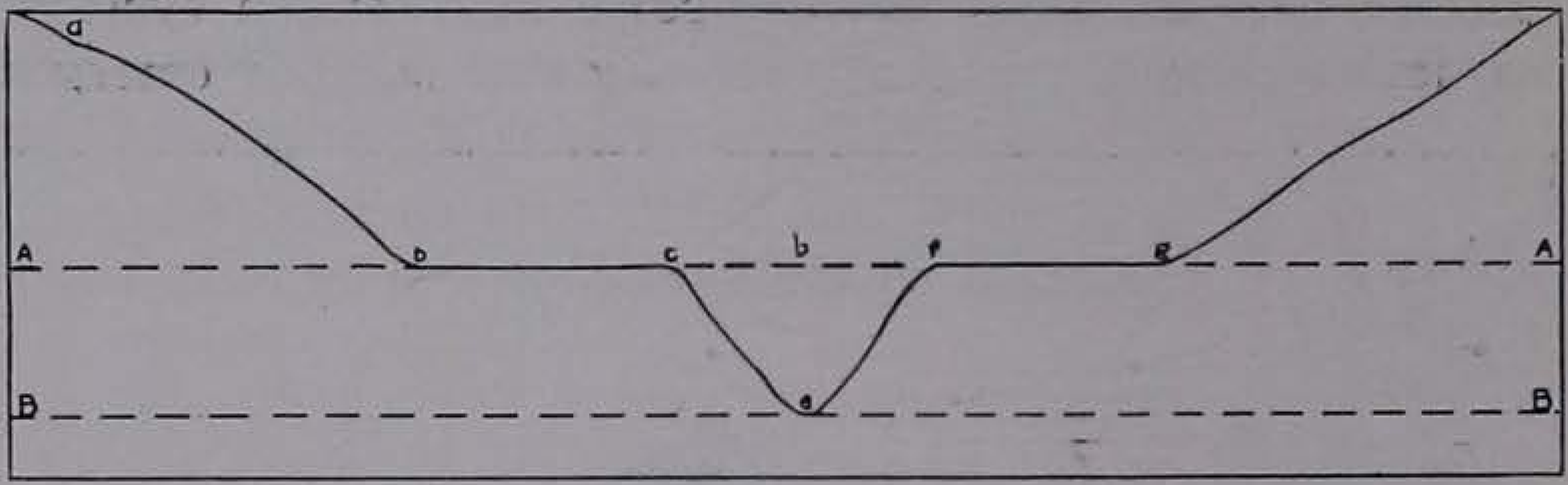

Fig. 3. Diagram showing how stream terraces may be formed by uplift of the surface after a stream has developed a valley flat. The profile abcdfgh is the cross section of the valley after grade level AA has been reached. By uplift a new level was established at BB, the rejuvenated stream cut the new valley cef, and terraces bc and fg were formed.

From the above, it is clear that terraces along the streams of a region can seldom be used as adequate evidence of more than one cycle of erosion. On the other hand, if stream terraces can be analyzed and all possibilities can be eliminated except the one involving more than one cycle of erosion, they might be considered to be more than merely suggestive of a second cycle, especially if there are other evidences which corroborate the conclusion.

Intrenched Meanders

Meandering streams in young valleys have long been used as evidence of second cycles of erosion in regions. By some they have been used as proof, even in regions which afford practically no other evidence of more than one cycle of erosion[1]. As commonly interpreted, the history of intrenched meanders is somewhat as follows: (1) in a first cycle of erosion a stream reaches grade, becomes sluggish, and develops a broad valley flat and broad meanders; (2) the surface is uplifted relative to sea, the stream is rejuvenated, and intrenches itself without changing its meandering course.

The value of intrenched meanders as evidences of more than one cycle depends upon the definition of meanders, and the accuracy with which they may be distinguished from other crooks in streams. During all stages of their history all streams are more or less crooked. The first water which flows over a newly formed land surface concentrates in crooked courses, (1) where there are original depressions irregularly distributed, (2) where unequally resistant materials are not arranged in orderly fashion, or (3) where there are differences in the amount of water supply. If in this stage the streams are flowing over a low, almost flat surface, they are easily deflected and curves are developed which are identical in principle with meanders developed on valley flats by streams at grade. In this first stage of its history such a stream is said to be consequent and its curves might be called *consequent crooks*. Continuing their histories, such streams lengthen by headward erosion, their heads being extended up the steepest slopes, through the least resistant material, and toward the greatest water supply. Inasmuch as these determining conditions are irregularly distributed on most surfaces, this stage of stream adjustment involves the development of a second set of crooks which are also consequent. As the cycle of valley development and the cycle of land reduction continue, a third stage is reached in which stream piracy takes place,

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[1] Gannett, Henry, "Physiographic Types," Folio No. 1, *U. S. Geol. Surv.* Fourth map and page 2.

streams are diverted and beheaded, drainage is reversed in direction, and still other crooks are developed. During any one of these first stages in stream adjustment, streams may reach *temporary grade,* on the upstream sides of resistant rock or upstream from glacial dams, blocking lava flows, landslides, or artificial dams, and develop meanders. Finally, when the stream has developed its valley to old age, has large tributaries and large volume, and has reached a still later stage of adjustment, the stream is sluggish, is likely to be depositing, is easily turned from side to side, and stream meanders, as the term is commonly applied, are formed. The crooks developed in the first three stages as outlined above, may be formed and intrenched in a single cycle of erosion. It would require an uplift and a second cycle of erosion for the intrenchment of the meanders developed in the fourth stage. If meanders be defined as the curves acquired by a stream in the late stages of valley development, intrenched meanders would be proof of a second cycle of erosion. But a difficulty lies in distinguishing such meanders from crooks developed during earlier stages.

The writer does not see any means of distinguishing crooks developed in youth on a flat surface (Fig. 4, AA and BB) nor meanders formed on temporary flood plains upstream from obstructions, from meanders developed in old age (Fig. 4 DD and EE). It seems even difficult, and in many cases impossible to distinguish the meanders of old age from ordinary crooks due to topography, irregularities of resistance, or stream piracy (Fig. 4 CC).

It has been said that meanders differ from other crooks, (1) in being more symmetrical, (2) in being so arranged that every portion of the stream course is a part of two meanders, and (3) in having a ratio of distance across the necks of meanders to distance around the meanders of about 1 to 7. A study of the courses of the Missouri and Sioux rivers on the Elk Point, S. D. topographic sheet, the Missouri and Platte rivers on the Leavenworth, Kas. sheet, Mississippi river on the Baton Rouge, La. sheet, Missouri river on the Marshall, Mo. sheet, the Wabash, White and Patoka rivers on the Princeton, Ind. sheet, the Wabash and Little

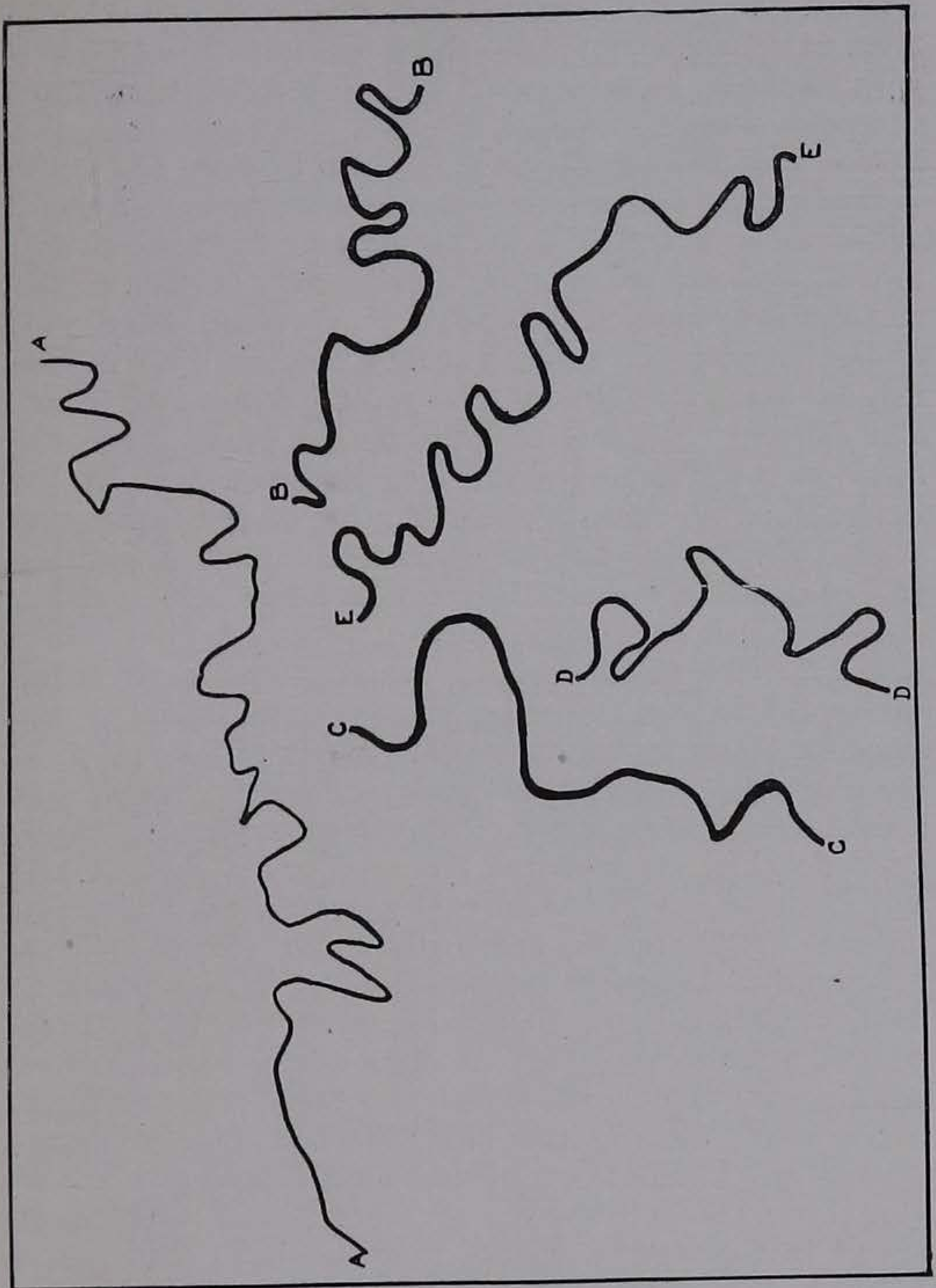

Fig. 4. A series of plats of stream courses of different histories.
AA is a part of the course of Maple river taken from the Casselton, No. Dak. topographic sheet. It has a consequent course in youth of its first cycle. Curves developed on low, flat land.
BB Rock river, Waterloo, Wis. sheet. A consequent stream on the surface of glacial drift.
CC Deerfield river, Wilmington, Vt. sheet. A stream in harmony with rock hardness and topography.
DD Platte river, Leavenworth, Kas. sheet. Meanders developed in old age.
EE Big Sioux river, Elkpoint, So. Dak. sheet. Meanders developed in old age.

Wabash rivers on the New Haven, Ills. sheet, and Nemaha river on the Falls City, Nebr. sheet, all of which are streams with meanders formed in old age, shows that these three characteristics of meanders are more imaginary than real. Few if any distinguishable differences between the meanders of old age and crooks made in other ways are brought out by the comparison of the meandering streams referred to with typical crooked streams not in old age, such as Red and Buffalo rivers on the Fargo, N. D. sheet, Otter creek on the Brandon, Vt. sheet, Deerfield river on the Wilmington, Vt. sheet, Des Moines river on the Boone, Iowa sheet, San Joaquin river on the Westley, Cal. sheet, Tuolumne river on the Westport, Cal. sheet, Canadian river on the Brilliant, N. M. sheet, Stanislaus river on the Ripon, Cal. sheet. There being no distinguishable differences between the meandering streams referred to above and ordinary streams which have never reached old age, it follows that it is impossible to tell from the maps, after a study of the curves themselves, whether intrenched meanders of the second cycle of erosion or ordinary crooks of the first cycle are illustrated in the Brazos river on the Palo Pinto, Texas sheet, Monongahela river on the Brownsville, Pa. sheet, Canondoquinet creek on the Harrisburg, Pa. sheet, Grant and Platte rivers on the Lancaster, Wis. sheet, and Osage river on the Tuscumbia and Forsyth, Mo. (Fig. 5) sheets.

Intrenched meanders might, however, in some cases at least, be distinguished from consequent crooks by the presence of outer valley walls. If the meander belt is located within outer valley walls and the stream is intrenched, the curves would seem to have been inherited from the meanders of an old age stage of valley development in a previous cycle. With this exception, which would rarely apply except in the early stages of a second cycle following a cycle which was interrupted before the valley walls became indistinct, intrenched meanders as evidence of more than one cycle in the erosional history of a surface would seem to have little if any value. Only in combination with other and more decisive evidences would they rise in other cases above the rank of mere suggestion.

Associated Sets of Straight and Crooked Streams

Although it seems impossible to distinguish intrenched meanders from other stream curves by a study of the curves themselves, comparison of a stream and its own tributaries will, in some cases at least, determine whether or not a crooked stream is in its second cycle. When a stream is old it meanders and has only a few tributaries which also meander. After rejuvenation, many other tributaries are developed, which do not meander. The early stages of a second cycle then would exhibit two sets of streams, one of which includes only a few large, conspicuously crooked streams, and the other set a large number of small, relatively straight streams. If all the streams of a region were formed in the same cycle under the same conditions, they should all show the same general character and degree of crookedness. If one set is curved and the other set straight, both cannot have been developed in the same cycle. (Fig. 6)

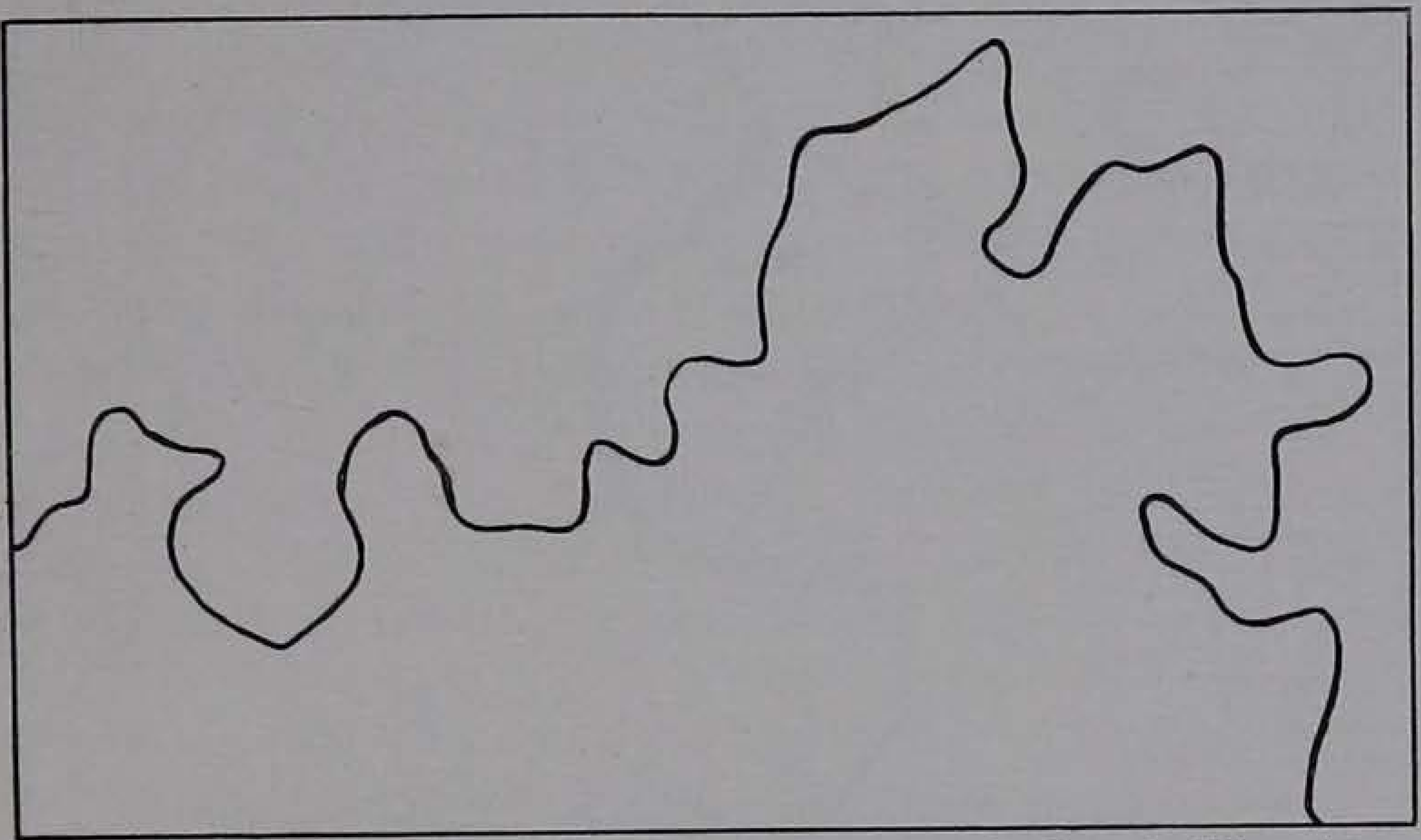

Fig. 5. A plat of the course of White river taken from the Forsyth, Missouri topagraphic map. The stream flows in a young valley, and its course has been interpreted to be a series of intrenched meanders. Reference to Figure 4 brings out the danger in such interpretations. So far as the curves themselves are concerned, they might not be intrenched meanders, as that term is commonly applied, and the surface might have suffered only one cycle of erosion.

It seems, therefore, that this association of one set of streams which meander and a second set the members of which are conspicuously more nearly straight affords strong evidence that the surface on which the two sets are thus associated is not in its first cycle of erosion.

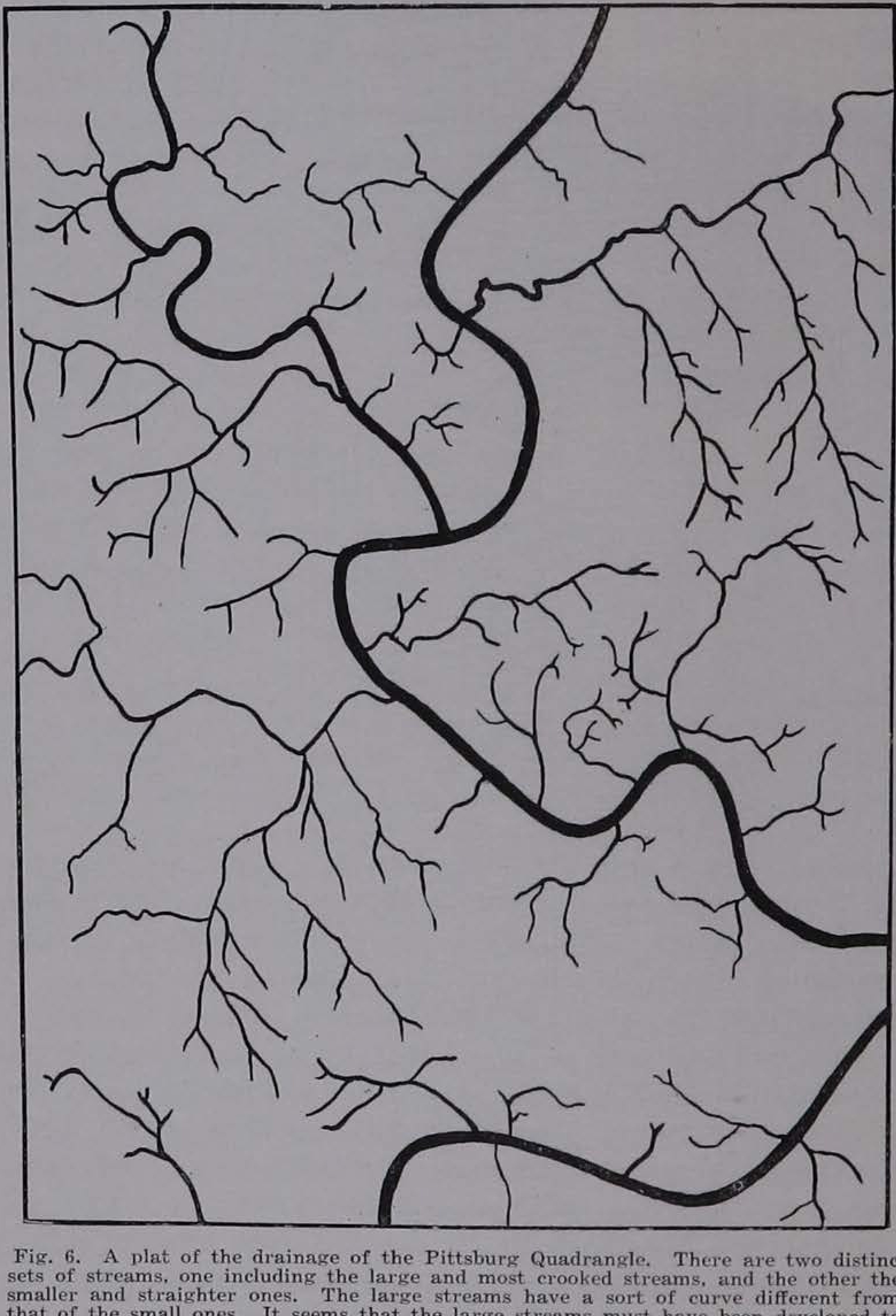

Fig. 6. A plat of the drainage of the Pittsburg Quadrangle. There are two distinct sets of streams, one including the large and most crooked streams, and the other the smaller and straighter ones. The large streams have a sort of curve different from that of the small ones. It seems that the large streams must have been developed to something like their present sizes and must have had their present courses before the small streams were started. The interpretation seems warranted that the courses of the large streams were established in old age of the first cycle of erosion and the small streams in the second cycle.

Antecedent Streams

The value of antecedent streams as evidences of more than one cycle of erosion in a region depends upon the definition of the term antecedent. The term was originally applied by Powell[1] to streams which hold previously established courses as their beds are warped, folded, or faulted. The streams were supposed to degrade their beds as rapidly as the beds were warped up. Such a history does not necessarily involve more than one cycle of erosion, except in the places where up-warping occurs.

Later the definition of antecedent streams was greatly broadened by Davis, Willis, and Hayes and Campbell, who applied the term to the Potomac, Susquehanna and other rivers of the Appalachian mountains. This whole region was folded and then peneplained, the rivers acquired their present courses on the peneplain, and then uplift of the whole surface took place and the streams intrenched themselves in their old courses. According to this definition antecedent streams are those which develop courses independent of rock structures in old age of an erosion cycle and hold those courses after uplift. Such streams are important evidences of more than one cycle.

In a folded region, such as the Appalachian mountains at the end of the Paleozoic era, streams adjust their courses in several distinct stages during the first cycle of erosion. In stage I, the main streams flow parallel with the strike of the strata in the axes of the synclines and the tributaries flow down the limbs of the anticlines parallel with the dip and at right angles to the main streams. In this first stage the slope of the land controls the courses of the streams. In stage II, those streams acquire an advantage, which first penetrate resistant layers and come to flow on non-resistant layers parallel with the strike. In this stage the main drainage lines shift to the limbs or axes of the anticlines. (Fig. 7). Now it is the resistance of the rock and the rock structures which control the courses of the streams. Finally when old age has been reached and all or most of the rocks

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[1] Powell, J. W., "*Explorations of the Colorado River of the West and Its Tributaries*," p. 163. 1875.

have been reduced to grade, those streams which flow the shortest distance to the sea will have higher gradients than others and will therefore gradually absorb these other streams. The result is a drainage system in which the main streams flow the shortest distances to the sea irrespective of rock structure or hardness, and even the tributaries flow into the mains by the shortest routes (Stage III, Fig 8). Near the divides where the streams are not at grade, tributaries may still be flowing parallel with the strike, controlled by the structure. In this third and final stage of adjustment the courses of the streams are again controlled by the topography, but the topography is not the same as it was in the first stage. Roughly, Stage I would correspond with youth of the cycle of erosion, Stage II with maturity, and Stage III with old age.

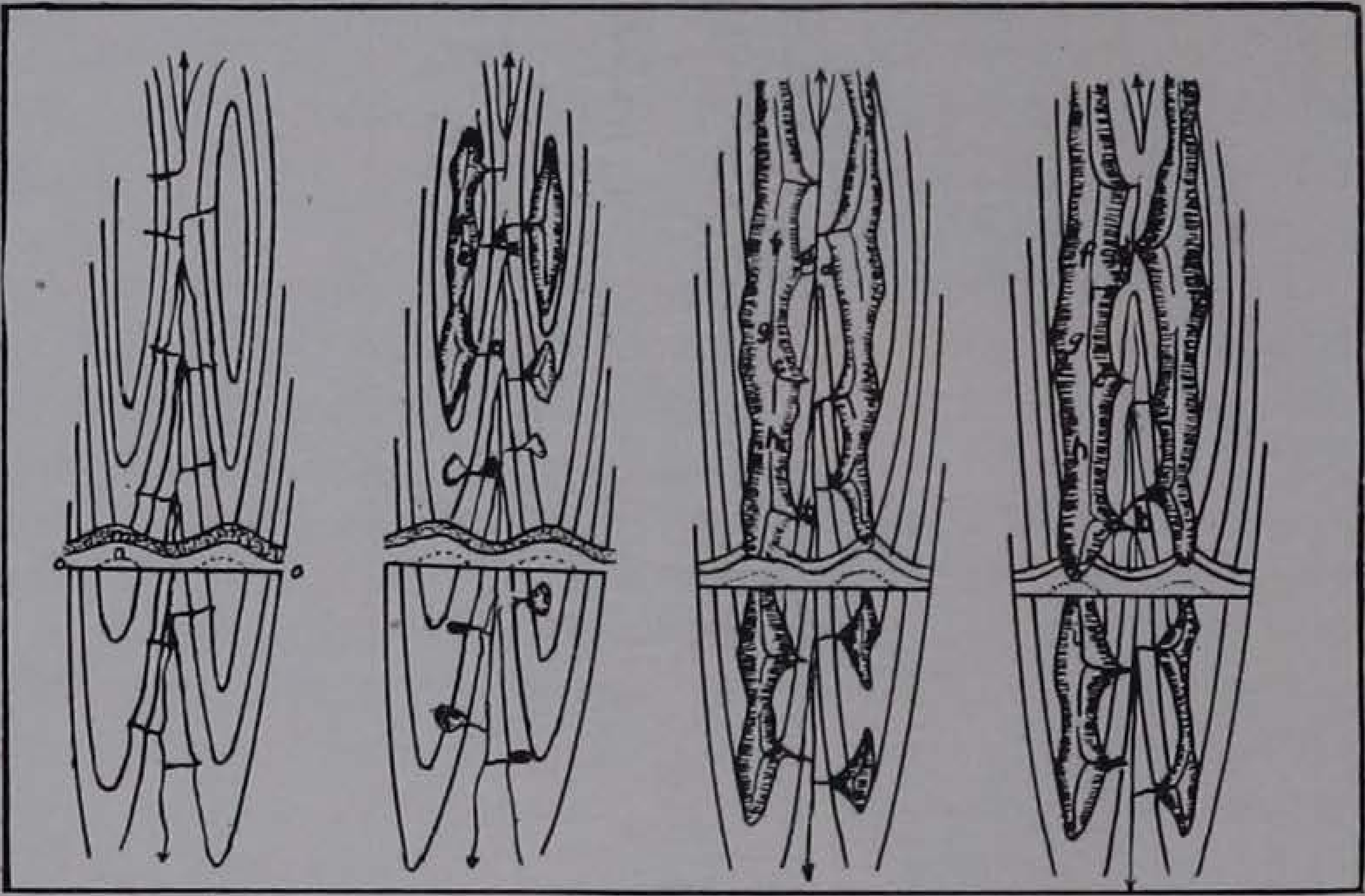

Fig. 7. Diagram to illustrate the change from Stage I to Stage II of stream adjustment in regions of folded strata. (After Davis).

If a region in which the streams have gone through the three stages of adjustment, be uplifted relative to the sea and the streams hold their courses during and after uplift, the streams in the second cycle would be antecedent according to the more recent use of the term. In a region of folded strata *during maturity,* streams which have courses parallel or oblique to the dip and flow the shortest distance to the sea, afford good evidence that the region has suffered more than one cycle of erosion.

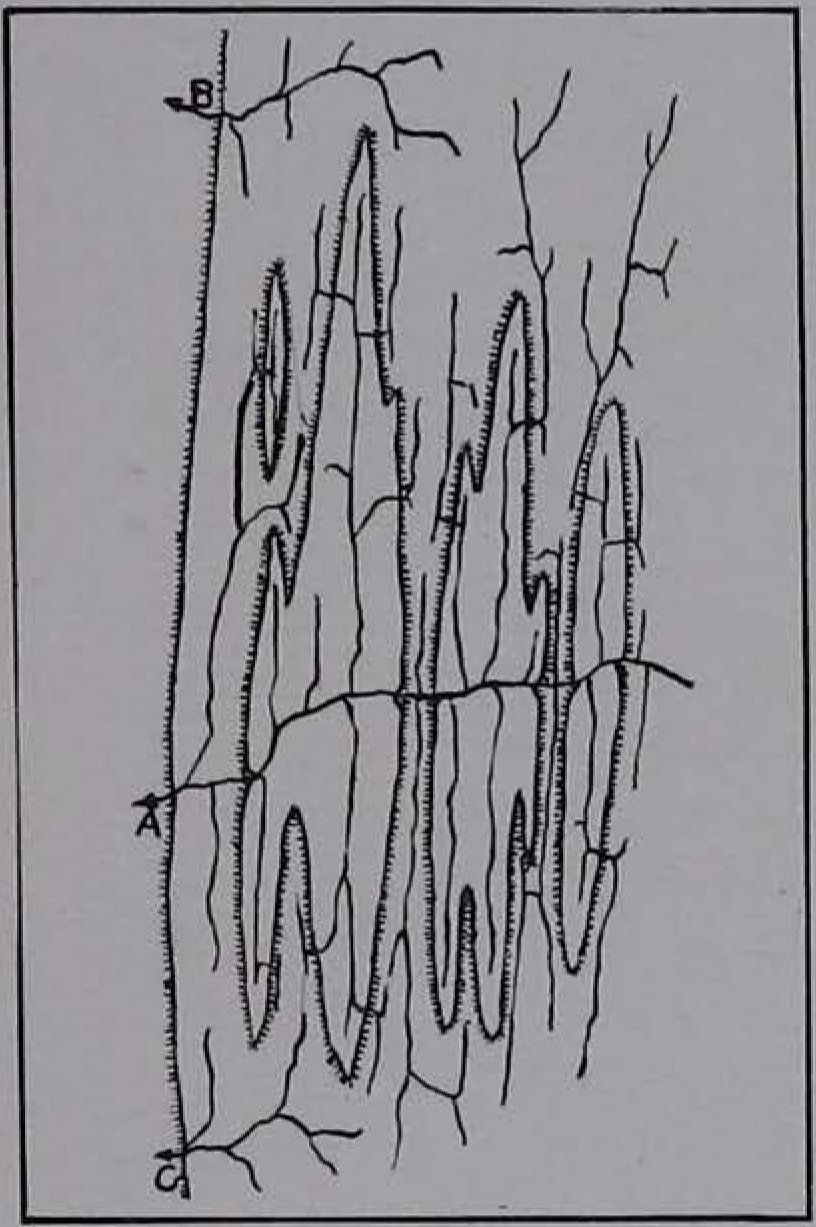

Fig. 8. Diagram illustrating Stage III of stream adjustment. (After Davis).

In case a region under investigation is not one of folded structures, the same general methods as outlined above may be applied. The stages of adjustment can be worked out and the corresponding stage of reduction. If the stage of reduction and stage of adjustment do not harmonize, the stream courses furnish evidence of more than one cycle of erosion.

It must be recognized that by extremes in slope streams might work headward through hard rocks and that by extremes in non-resistance, they might extend headward through topographic elevations so as to flow through watergaps, all in the first cycle. It is not probable, however, that anything but the smaller streams of a region would in this way develop courses which would appear to be out of harmony with rock resistance and existing topography in a single cycle of erosion.

Another case of antecedent streams involves *superimposition.* Streams which develop courses on newly formed surfaces, such as lava plains, emerging sea bottoms, or surfaces of glacial drift, may cut through superficial deposits and become superimposed upon previously existing, irregular, buried surfaces. Such streams may have courses entirely out of harmony with the resistance, structure and topography of the old surfaces. Superimposed streams are antecedent but they do not indicate that the youngest surface degraded has been reduced in more than one cycle of erosion.

From the foregoing, it is seen that certain antecedent streams are significant of more than one cycle of erosion. If the main streams of a region show evidence of having reached a late stage of stream adjustment but if they are not in a late stage of erosion in the present cycle, they offer valuable and almost indisputable evidence of more than one cycle. The Susquehanna river shown in Fig. 9 practically proves that the region in which it has its course is not in its first cycle of erosion, if local warping under the stream and superimposition can be eliminated.

Windgaps

It has long been the prevalent opinion that most, if not all, windgaps are the result of diversions by piracy of streams flowing in narrows or watergaps across hard ridges, leaving the watergaps without water. If this is the origin of windgaps, they have some value as evidences of more than one cycle of erosion in the region in which they are found. Let a region of folded strata go to old age of a cycle of erosion and let the streams attain a final stage of adjustment following the shortest routes to the sea parallel or oblique with the dip of the strata. After uplift of the surface, new streams will be started which will adjust parallel with the strike on the less resistant formations. These streams under the new conditions will have the advantage of the antecedent streams oblique to the strike and will behead the antecedent streams. This leaves windgaps where the antecedent streams flowed across hard formations, provided these streams intrenched themselves in their old courses before piracy took place.

Fig. 9. Part of the Harrisburg, Pa. topographic map, showing the antecedent course of the Susquehanna river. Such a relation between stream course, topography, and rock structure proves that the surface has suffered more than one cycle of erosion.

In regions of folded strata there is possibility of piracy and the formation of windgaps in the first cycle of erosion. In passing from Stage I to Stage II of adjustment the main streams are diverted from courses on the synclines to courses on the limbs or axes of the anticlines, giving rise to drainage systems some portions of which are parallel with the strike and other portions parallel with the dip. This stage is reached before the streams have reached their depth limits, and piracy may occur. Indeed, the change from Stage I to Stage II is not accomplished without piracy. In such cases streams parallel with the strike have the advantage of streams flowing across the strike and windgaps are formed which might be indistinguishable from those due to piracy in the second cycle.

Windgaps are not conspicuous in regions of horizontal strata nor in regions of massive rock, a fact which practically limits the application of windgaps to regions of folded or tilted strata.

Another limitation in the use of windgaps as criteria for more than one cycle of erosion has recently been emphasized by Miller[1] who explains that windgaps may be formed by two streams working headward from opposite sides of the same divide, developing a permanent divide between their heads and forming a col. Such a col could hardly be distinguished from gaps which had once been occupied by streams and then abandoned. A study of the relative sizes and gradients of the streams on either side of the divide might aid in determining the histories of such gaps.

So difficult is it to distinguish wind gaps resulting from piracy in the second cycle from those developed during ordinary adjustment or in the establishment of permanent divides in the first cycle that it is doubtful if they would ever, even under the most favorable circumstances afford important evidence of more than one cycle, taken alone.

Even-crested Summit Areas

Perhaps the fact that the uppermost surfaces of some regions approximate planeness and that the summit divides all come up to a nearly uniform level, has been more generally used as a criterion of more than one cycle of erosion than has any other evidence. But the principle has been abused. Various terms have been used in connection with this point, such as "even-crested hogbacks," "even-crested ridges," "upland plains," "accordant summit levels," "even-

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[1] Miller, A. M., "Windgaps," *Science*, Vol. 42 (1915), pp. 571-573.

crested divides," "even-crested uplands," and "even-crested skylines." The term "even-crested summit areas" seems to include every phase of the subject and to exclude *intermediate plains,* which might be included under some of the other terms and which constitutes a separate point.

Study of the principles involved in the formation of topographies in which the highest elevations are flat-topped and have about the same altitude, shows that such even-crested summit areas constitute better evidence of more than one cycle if the rocks involved are folded or tilted or massive, than if they are horizontal or nearly horizontal strata.

In Regions of Folded Strata: A plain which bevels folded strata might be interpreted as recording the following events: (1) the folding of the strata, forming a topography of high relief with anticlinal ridges and synclinal troughs; (2) erosion of the surface until a large part is brought to grade, leaving the surface relatively flat; (3) uplift of the land relative to sea, renewed degradation by streams and the relatively rapid removal of the non-resistant materials, leaving the outcrops of the harder formations as ridges or hogbacks, the tops of which are remnants of the peneplain developed in the first cycle.

It seems difficult to the writer to assign any other history than that outlined above to topographies illustrating even-crested summit areas in regions of folded strata. Other possible interpretations may be mentioned. Tarr[1] has objected to the idea that the more or less even-crested ridges of the Appalachian region represent an ancient peneplain and points out (1) that they are by no means of a common level and (2) that elevations made of about equally resistant rock, starting with their summits above timberline, would be eroded rapidly and about equally to timberline, and then acquire more or less uniform levels, all in a single erosional cycle. It should be noted that these even-crests are not at timberline. Other investigators[2] have proven,

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[1] Tarr, R. S., *Am. Geol.*, Vol. 21, pp. 351-370.

[2] Davis, W. M., *Am. Jour. Sci.*, 1889, Vol. 37, p. 430; Willis, Bailey, *Physiography of the United States*, pp. 169-202; Hayes and Campbell, *Nat'l Geog. Mag.*, Vol. 6, pp. 65-126.

by the application of a combination of other evidences, that the Appalachian mountains have been eroded in more than one cycle and that at the accordant summits of the ridges there are remnants of a surface formed in a cycle previous to the present one.

It has also been argued that mountain ridges can maintain only a certain elevation because the surrounding area is not able to support the greater pressure which would operate if the ridges were higher. This is a part of the theory of *isostasy*. No discussion of this theory is in place here. It need only be said that the structure of the rocks in most areas where there are accordant summit levels is such as to prove that the elevations were once much higher than they now are and that they have been reduced by streams.

It is also possible to assume, until proven otherwise, that accordant summit levels in a folded region are remnants of a plain of marine denudation. The criteria for distinguishing remnants of such a plain and remnants of a true peneplain are clear. If the sea cut its way on the land for any considerable distance, portions of the wave-cut terrace would become sites of marine deposition and when the sea-denuded plain became land, it would be covered with marine sediments, which of course might be removed later. Also the border of an old plain of marine denudation would be a shoreline and erosion remnants on its surface would have the contour of islands. It has never been proven that plains of wide extent are made by this method, especially if the plain be inland, and no even-crested summit areas have ever been proven to be remnants of plains of marine denudation.

It should not be said that even-crested summit areas in regions of folded strata considered alone, prove more than one cycle of erosion, but they afford strong corroborative evidence to that effect.

In Regions of horizontal or nearly horizontal strata: Accordant summit levels, where strata are horizontal or nearly so, afford possibilities of interpretation not applicable in regions of folded strata. In a previous article by the writer[1] an upland plain in northwestern Illinois was conceived to be (1) an original marine plain of deposition; (2) a marine plain of erosion; (3) a structural plain; or (4) a true peneplain. Only in case such upland plains can be proven to be true peneplains do they constitute proof of more than one cycle in the erosional history of a region. For the detailed discussion of the characterizing features of plains formed in the four ways outlined above, readers are referred to the article cited. A plain of marine deposition should be parallel with the rock strata and should not have on its surface deposits of any sort younger than the marine formations which underlie it. A plain of marine erosion should be bordered by higher land and separated from this land by a shoreline. It should bevel the edges of rock formations; its surface should contain marine deposits younger than the formations which the plain bevels and any remnants which stand above it should be isle-like. A structural plain would be located on a resistant formation and would be parallel with the dip of that formation. If upland flats are remnants of a true peneplain, the surface represented by them when reconstructed should not, except in unusual cases, be parallel with rock structure, should be more or less uneven, have dendritic erosion remnants above it, and have fluvial deposits on its surface. There might be cases in which it would be impossible to determine the correct one of these four origins of upland plains, but if they be studied carefully enough and over sufficiently wide areas, correct interpretation should be possible.

Recently, Martin[2] has expressed the opinion that features of the topography of the Driftless Area of Wisconsin, which have been most generally interpreted as even-crested summit areas representing an old peneplain, can better be explained by assuming that the topography is due to the unequal erosion in a single cycle of series of unequally resistant rock formations having a slight monoclinal dip. After defining a *cuesta* as "an upland with a short steep descent,

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[1] Trowbridge, A. C., *Jour. Geol.*, Vol. 21, pp. 731-738.

[2] Martin, Lawrence, Bull. No. 36, *Wis. Geol. and Nat'l Hist. Surv.*, pp. 63-70.

or escarpment, on one side and a long, gentle slope on the other," and stating that "the gentle slope usually corresponds to the inclination or dip of slightly inclined sedimentary rocks[1]," he contends that the upland plains in the Driftless Area are simply the gently sloping surfaces of cuestas. If this is the correct interpretation of such upland surfaces, (1) the slope of any individual patch of summit area should correspond in direction and amount with the dip of the rock formations, (2) each upland area should be formed by resistant rocks, and (3) the altitude of the summit of any given cuesta should depend upon the resistance of the rocks forming it and the length of time it had been exposed to erosion after the removal by streams of all overlying rock formations.

Any considerable areas of summit flats now poorly drained and forming broad divides between present streams would hardly be formed in this way in a single cycle of erosion. If individual summit areas were found to bevel the edges of layers or formations, if these areas are large and far from present streams, if some of the rock formations bevelled by the surfaces are non-resistant, and especially if a surface reconstructed by filling the lowlands to the summit areas is found to have a uniform slope in direction and amount, if this slope be uniformly greater or less than the dip of the beds, and if irregularities in rock structure and rock resistance do not influence this surface, the even-crested summit areas could hardly be considered to be merely a series of cuestas.

In Regions of Igneous Rocks: If massive igneous rocks solidified below the surface of the lithosphere be eroded in such a way as to leave flat-topped and accordant elevations, it seems that at least two cycles must have been involved in the history of the topography, except in cases where the massive rock had a flat surface to begin with. In the normal case it would require a cycle of erosion to remove overlying rocks and flatten the surface of the igneous rocks, and

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[1] *Op. Cit.*, p. 42.

a second cycle to degrade some of the land further and leave the previous surface represented by the flat summit areas. It seems that accordant summit levels would be as strong evidence of more than one cycle in regions of massive igneous rocks as in regions of folded strata.

Extrusive lava sheets and intruded sills might form flat-topped hills, when eroded, without offering more than a bare suggestion of more than one cycle of erosion.

In any case there is an unanswerable question as to how flat upland surfaces must be and how nearly to a common level their remnants must come before weight is given to them as evidences of more than one cycle of erosion. Even in the regions which have suffered more than one cycle there are several causes of irregularity in the topography of the upland plain. In the first place most peneplains at the close of the first cycles are not flat. A total relief of several hundred feet would not be incompatible with the term peneplain, provided large portions of the surface had been brought to grade. Secondly, the surface might be warped, folded, tilted, or faulted as it is uplifted. Finally, erosion might roughen the upland surface after rejuvenation of the streams, without entirely destroying its former characters. The larger and flatter summit areas are, and the more nearly accordant they are, the more definitely can the term "even-crested summit areas" be applied to them, and the more certainly can the erosional histories of regions be read from them. The failure of accordance in the uplands of a region could under no circumstances be taken as proof that the region had not been eroded in more than one cycle.

Even-crested summit areas should be used as evidence of more than one cycle of erosion only after complete and careful study.

Intermediate Plains

The term *intermediate plain* has not been used before as an evidence of more than one cycle, but the principle involved has been used extensively and to good advantage, without previously having been named. In the present connection an intermediate plain may be defined as one having a position intermediate between the summits of the highest elevations and the bottoms of the deepest valleys (Fig. 10). Or intermediate plains might be defined as plains

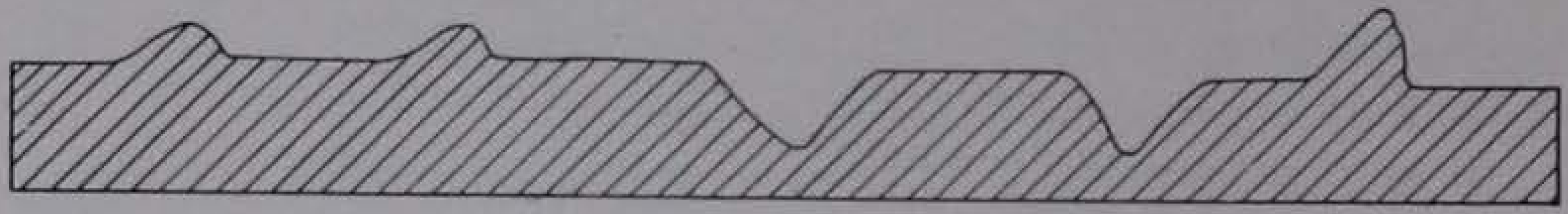

Fig. 10. Diagrammatic section illustrating an ideal intermediate plain.

above which stand erosion remnants and below which are valleys. The erosional history of such a region as is shown in Fig. 10, would seem to involve two cycles of erosion and to be somewhat as follows: (1) the formation of a land surface at levels at or above the present summits, (2) the reduction of the region and the formation of a peneplain, (3) the uplift of the region, rejuvenating the streams, and (4) the development of the valleys. This sort of topography seems to be and is strong evidence of more than one cycle of erosion, although it hardly amounts to proof.

Plains having similar relations to erosion remnants and valleys might be structural. It is conceivable that streams might cut through soft surficial material, to a thick, hard formation of rock, then find further degradation retarded to such an extent that by processes of widening, the soft material might be removed over wide areas before the hard formation is cut through, leaving only a few remnants above the level of the top of the resistant formation. The surface in this stage might resemble a peneplain. Finally, the streams might sink themselves below the hard formation and develop valleys at levels below the structural plain. However, it seems difficult to conceive that, even under the most favorable circumstances, intermediate plains of wide extent could be formed in this way. Rock terraces might be so formed, but hardly plains which spread across divides from valley to valley. Such structural plains, also, should be parallel with rock structure and everywhere located on rocks more resistant than their surroundings.

Intermediate plains might be remnants of a plain of marine erosion, but the erosion remnants above it should be isle-like and its surface should contain marine deposits. Obviously no intermediate plain of great extent could be an original marine plain of deposition. Neither is it clear that the remnants of an intermediate plain could be the surface of a series of cuestas formed in a single cycle. If a rough topography were developed by streams and then the lowlands were filled, but not to the level of the summit areas, by glacial material or lava flows having a flat surface, streams might so dissect the glacial or volcanic fill as to leave remnants of an intermediate plain which would not record more than one cycle of erosion, in the usual sense at least.

Fluvial Deposits on Uplands

Where stream deposits are found occupying topographic positions distinctly above present stream beds, whether they lie on summit areas or areas of intermediate plain, on divides or on slopes above drainage, there is evidence that streams which once deposited, ceased depositing and began to degrade. As old streams most commonly aggrade and young streams degrade their beds, there is suggestion in such relations of deposits to stream beds, that the streams were once old and deposited and became young again, carving out the valleys below the levels of the deposits. That is, such a relationship suggests that the land was uplifted after some portions at least had been brought to grade and that more than one erosion cycle was involved in the history of the topography in which such relationship exists.

In case of upland or intermediate plains due to structure, streams flowing from soft material to the hard rock which forms the plain may be held at temporary grade on the soft material while degradation of the hard rock is in progress, and might deposit on the upstream side of the hard rock. Later in the same erosion cycle, when the hard formation has been cut through, the streams might cut down, leaving the deposits on the structural plain. It is hardly conceivable, however, that deposits which have had such histories would be found widely spread over upland surfaces.

It is possible for a stream not at grade to deposit, to shift its course slightly, and to sink its channel deeper, leaving its deposits in small areas as pockets or patches on upper slopes. Small patches of fluvial gravel or sand found on slopes above present drainage might be explained in this way, but thick fluvial deposits spread widely over upland flats could not be so explained.

The application of this point is also limited by the difficulty in distinguishing fluvial deposits from marine or eolian or glacial or lacustrine deposits, especially after long exposure.

Undoubted fluvial deposits spread widely over upland surfaces would disprove that those surfaces represent plains of marine deposition or of marine erosion or are merely the tops of cuestas. They would almost or quite disprove the structural hypothesis for the origin of the upland plain on which they lie. Therefore, they constitute strong evidence of more than one cycle of erosion.

Combinations

If the analysis of each of the evidences of more than one cycle of erosion has been followed up to this point, it is clear that no one of these evidences, in the abstract and taken alone, can be said to prove more than one cycle in the erosional history of a region. However, the study of concrete cases of individual points may yield such proof. Some of the evidences usually assigned merely suggest more than one cycle of erosion if taken abstractly, but become strong evidence when properly restricted by the elimination of other possible interpretations. Others are strong evidence in the abstract, and amount to proof if properly applied and limited. The relative values of these evidences are summed up in the accompanying table.

Interrupted profile and stream terraces could hardly amount to more than a suggestion of more than one cycle of erosion unless all other possible interpretations had been eliminated by careful study in the field.

So nearly impossible is it to distinguish the meanders of old age from other crooks in streams that intrenched meanders afford no more than a suggestion of more than one cycle. Associated sets of straight and crooked streams, on the other hand, are strong evidence of more than one cycle.

TABLE SHOWING THE RELATIVE VALUES OF THE VARIOUS EVIDENCES OF MORE THAN ONE CYCLE OF EROSION IN REGIONS

No.	Name	Proof	Strong Evidence	Mere Suggestion
1	Interrupted Profile		X?	X
2	Stream Terraces		X?	X
3	Intrenched Meanders			X
4	Associated Sets of Straight and Crooked Streams		X	
5	Antecedent Streams	X?	X	X?
6	Windgaps		X?	X
7	Even-crested Summit Areas		X	X
8	Intermediate Plains	X?	X	
9	Fluvial Deposits on Uplands	X?	X	

Those antecedent streams which can be proven to have gone to the final stage of stream adjustment and are not now in adjustment prove more than one cycle of erosion; any antecedent stream, except one in which warping has followed establishment of the stream course or one which is due to superimposition, is strong evidence of more than one cycle. Windgaps made by the abandonment of watergaps in the changing of streams from antecedent to adjusted courses form strong evidence and other windgaps merely suggest more than one cycle. Especially even-crested summit areas in regions of folded strata, are good evidences of more than one cycle of erosion, but from these ideal conditions the value deteriorates almost to zero in regions of horizontal strata or where accordance of summit areas is more imaginary than real. It is believed that carefully investigated intermediate plains may prove more than one cycle and that any intermediate plain of wide extent is strong evidence. Fluvial deposits either on intermediate plains or on summit areas might prove more than one cycle under certain conditions and would be valuable evidence in any case. It is to be noted that most of the abstract evidences have more weight in regions of folded strata than where strata are horizontal.

But the investigator must depend upon certain *combinations* of the various evidences, rather than upon single points, if he is to prove or disprove that given regions have suffered more than one cycle of erosion. It is unlikely that a surface which has been peneplained and then uplifted relative to the sea would show only one of the evidences of having had such a history. The sequence of events which involves two erosion cycles, and which gives rise to one of these lines of evidence, may give rise to all. If a region shows only one of these evidences the value of that one should be discounted because none of the others is shown. On the other hand a combination of several of these evidences in a region furnishes a progression toward definite conclusions which is geometrical rather than arithmetical.

Referring again to the table above, Nos. 5, 8 and 9, all found together in a region, even without special analysis, would come near to proving more than one erosion cycle in the history of the surface, and if properly analyzed the combination might prove such a history beyond the possibility of a doubt. Similarly, proof might be obtained through the combinations of Nos. 4, 7 and 9; or Nos. 5, 6 and 8; or Nos. 4, 5 and 7; or perhaps by a combination of 8 and 9, or 5 and 7. Combinations of 4 and 8, 7 and 9, 4 and 6, or 1, 4 and 7 might under certain topographic conditions afford strong evidence or even proof. Even Nos. 1 and 2 combined might under certain circumstances be strong evidence of more than one cycle.

It therefore seems clear that by distinguishing these various features in the topographies of regions, by the proper analysis of their possibilities and limitations under existing conditions, and by certain combinations, it is possible to determine that (1) regions have *certainly* suffered more than one cycle of erosion, or that (2) they have *probably* suffered more than one cycle, or that (3) they have *possibly* suffered more than one cycle. If careful study of a topography reveals no one of these evidences, or if it reveals only one or two whose origin after analysis is found not to involve more than one cycle, it could be concluded that (4) the surface has *probably not* been eroded in more than one cycle. There would be cases where it would be entirely impossible to demonstrate that (5) the surface had *certainly not* been eroded in more than one cycle.

If the deposits laid in a near-by sea during the erosional history of a land surface are available for study, evidence of more than one cycle of erosion on the land might be found in them. If a series of formations graded upward from conglomerate at the base through sandstone, shale, and limestone to another conglomerate, it would seem that the lower series including coarse, medium, and fine materials would correspond respectively with youth, maturity and old age of an erosion cycle on the land and that the upper conglomerate would record an uplift of the land and the inauguration of a youthful stage of a second cycle.

However, such gradations in marine sediments might be due to gradually changing climates, changing depth of water without affecting land and sea relations, or slightly migrating shorelines which do not materially effect the height of land relative to sea.

Alternation of sediments might be used to good advantage in some cases to check the topographic evidences of erosion cycles. For instance, the Cretaceous and Tertiary deposits of the Atlantic Coastal Plain should and do, at least roughly, check in this way the erosional history of the Appalachian mountains as stated by Willis, Hayes and Campbell, and Davis. Similarly it is believed that the Tertiary and Quaternary deposits of the Gulf Coastal Plain of Texas will help in interpreting the erosional history of the Cordillera.

MORE THAN TWO CYCLES

When it has been demonstrated that the erosional history of a given surface has involved more than one cycle, the question of the number of cycles arises. Theoretically the number of erosion cycles in a region is limited only by the length of time during which the surface has been subjected to fluvial processes and the frequency of positive diastrophic movements during that time. So far as geologic time and the frequency of land-forming diastrophic movements may be conjectured, there is no known limit to the number of cycles which might have effected a topography. Such regions as the Piedmont Plateau or portions of the Laurentian Shield, which are thought to have been land since the beginning of the Cambrain period, have probably been peneplained and uplifted many times, although the detection of so large a number of cycles would be extremely difficult, if not impossible. On the other extreme, surfaces fashioned by the Wisconsin ice sheet have probably nowhere been eroded in more than one cycle, so short has been the time since the retreat of the ice.

The number of cycles of erosion which has affected a given region is to be determined by the number of *sets* of evidences of more than one cycle. For instance, in the Appalachian mountains, even-crested summit areas, antecedent streams, windgaps, intrenched meanders, associated sets of straight and crooked streams, intermediate plains and fluvial deposits on uplands, all are in evidence, and the combination proves more than one cycle of erosion in the history of the region. Obviously, even-crested summit areas which are the remnants of an old peneplain, and an intermediate plain representing an old peneplain, cannot belong to the same set of evidences if they both occur in the same region. Most of the antecedent streams and some of the windgaps of the Appalachian region belong with the set of evidences represented by the even-crested summit areas, and most of the intrenched meanders and associated sets of straight and crooked streams, and all of the fluvial deposits are clearly correlated with the intermediate plain. There seem to be two sets of intrenched meanders and two sets of antecedent streams, one set of each related to the upper plain and the other set to the intermediate plain. Thus, the older set of evidences includes even-crested summit areas, antecedent streams, windgaps and intrenched meanders, and the younger set consists of intermediate plain, fluvial deposits on divides, intrenched meanders, associated sets of straight and crooked streams, antecedent streams and windgaps. Each of these sets includes the proper combination of evidences to prove more than one cycle, hence it is concluded that the region is now in its third cycle, the first set of evidences being proof of the first cycle, the second set proving that there was a second cycle carried to a late stage. The evidence of the beginning of the third and present cycle is found in the fact that the second set of evidences is related to a surface distinctly above the present streams. There are certain terrace-like features between the summit areas and the intermediate plain which suggest an additional cycle between the first and second, but as these benches have been proven to be structural and as there are no other evidences in the set, it is concluded that the mountains are in the third, rather than the fourth cycle.

The method of procedure then, in determining the number of distinguishable cycles which have been involved in the erosional history of a region is as follows: (1) Determine how many of the evidences of more than one cycle of erosion the topography exhibits; (2) sort these evidences into the proper number of sets; (3) conclude that the *total number of distinguishable cycles is the number of sets of evidences plus one.* The degree of certainty with which the number of cycles is determined depends upon the certainty with which the various sets of evidences record the individual cycles.

THE DETERMINATION OF DIASTROPHIC EVENTS

Because diastrophism is involved in the formation and renewal of lands, the interpretation of the history of land surfaces includes also the diastrophic history.

The Number of Movements

In regions in which the land surfaces were originally formed by diastrophism the number of positive diastrophic movements is the same as the number of cycles of erosion. For instance, the Appalachian mountains were formed first by folding; this is movement No. 1. Movement No. 2 interrupted the first erosion cycle and inaugurated the second cycle; movement No. 3 started the third cycle. The region has suffered parts of three erosion cycles and there have been three upward diastrophic movements.

Some surfaces, such as those formed by glaciation, by lava flows, or by the draining of lakes, have no genetic relation with diastrophism. On such surfaces the number of diastrophic movements is one less than the total number of cycles.

The Nature of Movements

Not only the number but the nature of diastrophic movements should be determinable in an interpretation of the erosional history of a region. There are several possible cases: (1) uniform uplift of the whole surface; (2) uplift with tilting; (3) uplift with warping; (4) uplift with faulting; (5) subsidence of the surface, with the four possible phases as outlined for uplift.

Uniform Uplift: If a peneplain were formed and then uplifted uniformly, there would be a change in altitude but not in attitude. If the general slope of an old erosion surface, be its remnants on the summits or at intermediate levels in a topography, is approximately the same in direction and amount as the slopes of other graded erosional surfaces in the region, the inference would be that the uplift had been uniform. The difficulty with this point lies in the fact that no old erosion surface is perfectly flat, and it is difficult to determine whether consecutive graded surfaces are parallel. Also a graded plain might be uplifted uniformly and yet not be parallel with a younger peneplain if the streams had higher or lower gradients at the close of the second cycle than at the close of the first.

However, if a peneplain represented by even-crested summit areas is practically parallel with an intermediate plain, and with present valley flats on which streams are at grade, the conclusion would be warranted that both the uplift which inaugurated the second cycle and the uplift starting the third cycle were practically uniform.

Uplift with Tilting: If a raised and partly dissected surface which was once a peneplain has a generally uniform slope throughout a given region, but is not parallel with an intermediate peneplain or with graded streams below it, either because its angle or direction of slope is different, the conditions suggest that the uplift which inaugurated the dissection of the upper plain was accompanied by tilting. If an upland peneplain and an intermediate peneplain are essentially parallel, but are not parallel with an existing and undissected peneplain, the uplift which started the second cycle was probably uniform and the movement starting the third cycle was a tilting movement. The best evidence of tilting in the renewal of lands by diastrophism is a lack of parallelism between uniformly-sloping, consecutive, graded, erosion surfaces.

As in most rules, there are limitations in the application of this one. Lack of parallelism between consecutive erosion surfaces, provided it is a matter of amount rather than direction of slope, may be due to difference in the gradients of final grades of the drainage system under different conditions at different times. At the close of a first cycle the streams may have been small and carrying heavy loads, with resulting high gradients and a relatively steeply sloping peneplain. The uplift may have been uniform, but in the second cycle larger streams carrying lighter loads may have developed gradients lower than those of the first cycle, and the two erosion surfaces would diverge upstream. By the reversal of the sequence, two peneplains might be caused to converge upstream, without tilting.

Even differences in the direction of slope of two peneplains in a region might be obtained without tilting, if conditions of structure, proximity to the sea or climate were so changed, during uplift, as to cause reversal or diversion of drainage in the second cycle.

It is probable that these exceptions might lead to conclusions that tilting has taken place where it has not in some cases, and that tilting has not taken place where it has in others. Perhaps only the more pronounced cases of tilting can be distinguished by this method.

Uplift with Warping: Warping during uplift of a plane erosion surface would result in an irregular obliquity between this surface and lower peneplains. The two erosion surfaces would converge and diverge in many directions and at many angles. In a region where such obliquity exists between a summit plain and an intermediate plain, but with the intermediate plain parallel with an undissected peneplain or with graded streams, the first recorded movement seems to have involved warping and the second uplift was uniform. If the upper plain and the intermediate plain are parallel, but with irregular obliquity related to present graded streams, the first movement was uniform and the second one was accompanied by warping.

This method of interpretation lacks much of being decisive. In the first place the warping or folding of an erosion surface destroys accordance of levels and makes it extremely difficult to decide whether the surface was once smooth and has been warped, or whether it was never smooth. In the latter case there would be little evidence that there has ever been more than one erosion cycle. The warping of a surface is likely to destroy evidence that there has been any moveemnt at all. There would have to be some evidence beyond the accordance of levels to prove that the surface actually was a peneplain. However, such evidence might consist in fluvial deposits on remnants of the warped surface, or in antecedent streams cutting across the folds of the surface.

Another difficulty with the interpretation of warping movements grows out of the fact that no erosion surfaces are altogether flat and that there is therefore an irregular obliquity between two consecutive surfaces whether warping has taken place or not. However, departures from parallelism due to erosional irregularities in the surface would show themselves in topographic details and those due to warping would be more general; that is, they would be differences between averages rather than between specific points. Careful study of the valleys cut in the old erosion surface during the next cycle should also aid in determining whether the irregular lack of parallelism is due to warping or to erosional irregularities. If the valleys vary in depth or width or stage of development from point to point warping could be called in to explain such variations.

After all probably the best evidence of warping of peneplains is found when it is determined that the individual peneplain reconstructed varies in altitude above sea, that it has on its surface stream deposits distributed without reference to the variations in altitude, that the variations are due to flexures rather than to erosional irregularities, and that streams have antecedent courses at right angles or oblique to the flexures.

Warping may have occurred in regions where there is no evidence of movement of any kind. There may also be suggestions of warping where uplift was uniform. There are doubtless regions, however, such as the Appalachian mountains, where warping movements have taken place and where, by application of the principles outlined above, such movements can be proven to have taken place. These principles, therefore, are usable, but their use is attended with difficulty and may result in uncertainty.

Uplift with Faulting: One of the best known illustrations of a cycle of erosion having been interrupted by faulting is found in the mountains and valleys of eastern California. Here an ancient erosion surface which is characterized by mid-Tertiary stream gravels which lie on the remnants of the old surface in many places, slopes up from low levels on the west flanks of the Sierras and reaches altitudes of more than 14,000 feet at the crest of the range where it is broken by the great fault whose scarp forms the east slope of the mountains. East of this line the surface seems to be buried under the late Tertiary and Pleistocene sediments of Owens Valley below altitudes of 2,000 feet. The surface and its gravel deposits appear again in the Inyo mountains east of Owens Valley, reaching altitudes close to 10,000 feet, where the surface is broken by another fault on the east side of these mountains. The evidence of faulting in this case is a series of tilted blocks, each one of the series being sharply set off from the adjacent one by a fault scarp.

It seems that cases of uplift with faulting could be certainly interpreted only where the old erosion surface is distinguishable in spite of great relief within short distances, where the separate blocks are distinct and where differences in altitude of the surface are too abrupt to be accounted for on the basis of warping.

Subsidence: It is a quibble whether or not the subsidence of a surface starts a new cycle of erosion. However, the study of the erosion cycles in a region may yield evidence of subsidence. If it can be proven that all the graded streams of a region have their beds at levels far above beds which they previously occupied, it seems most likely that the surface of the region has subsided. If the establishment of grades below previous grades indicates uplift, the establishment of new flood plains above previous erosional surfaces is an equally strong indication of subsidence. If uplift raises a previously graded surface above grade, subsidence lowers valley bottoms below the level of grade.

This principle seems to be illustrated in the upper Mississippi valley region, where the Mississippi river and its main tributaries are at grade 100 feet or more above the bedrock beneath. The fills in this region consist of glacial and fluvio-glacial drift. It seems likely that the surface subsided after the deep valleys were cut.

Another possible interpretation is that the streams were not so heavily loaded before the filling as now, or were larger then than now, and consequently were able to reduce their valleys to a lower depth limit in relation to the Gulf of Mexico than is possible now.

By the application of the principles outlined above for uplift, it might be determined whether subsidence was uniform or was accompanied by tilting, warping or faulting.

The Amount of Movement

The interpretation of erosional histories furnishes some basis for determination of the amount of each diastrophic movement. Streams which have reached their depth limits in a first cycle of erosion may degrade their beds below these old graded levels in the second cycle by approximately the amount of the uplift which rejuvenated them. The difference in altitude between two consecutive graded surfaces, therefore, is roughly the measure of the amount of the uplift which interrupted the one cycle and started the other. In a region in which there is a summit peneplain at 2,000 feet, an intermediate peneplain at 1,000 feet and graded flats at 500 feet, it could be inferred that there had been an uplift of approximately 1,000 feet, and a second one of about 500 feet.

This method of interpretation seems simple enough but its application to field conditions involves possibilities of error. Differences in altitude between remnants of consecutive graded plains vary from point to point in any region, (1) if uplift was accompanied by tilting, warping, or faulting, (2) if either surface was irregular, (3) if final grades differed because of changes in volume or load of the streams. These being common conditions, it seems possible to get accurate figures on the amount of uplift for individual districts only, and even this is subject to error. For whole regions, only approximate averages are possible.

THE DETERMINATION OF DATES

The complete history of a surface involves dates as well as events and sequences. Various criteria have been used for the determination of the geologic dates of the various events in the histories of land surfaces. Some of these criteria are readily applicable and accurate if properly applied. Others are not so valuable. The problem involves the ages of old erosion surfaces, the dates of diastrophic movements, the duration of time involved in erosion cycles, etc.

The Age of Old Erosion Surfaces

It has been customary in designating the ages of raised peneplains to refer to the date at which the plain was completed and still intact rather than the whole time during which it was in process of formation. For instance, the Kittatinney peneplain in the northern Appalachians is referred to as the Cretaceous plain, not because its formation was accomplished during the Cretaceous period only, but because it was believed to have been completed during that period. The cycle during which it was formed was probably inaugurated long before the Cretaceous. Although this departs in a way from the usage of time terms in relation to rock formations, with this statement, the writer considers it best to continue the custom.

Various methods may be used in determining the periods or epochs to which certain raised peneplains belong, the method used depending upon the conditions existing in the region under investigation. Some of these methods are here mentioned: (1) Any graded erosion surface is younger than the youngest formation which it cuts, and (2) younger than any structure it bevels. The youngest system forming the oldest peneplain surface in the Appalachian mountains is the Pennsylvanian, and the folds and faults across which the surface is developed took place in the Permian. The peneplain is therefore not only post-Pennsylvanian, but is post-Permian. (3) An old erosion surface is younger than any formation of which there are distinguishable fragments or fossils in fluvial deposits on the surface. This is illustrated in the Driftless Area where stream gravels containing chert pebbles and fossils of Niagaran age lie on divides where the uppermost rock is pre-Niagaran; the divides must be remnants of a surface which is at least younger than mid-Silurian. (4) Peneplains are contemporaneous with fluvial deposits which lie on them, (5) contemporaneous with or older than other terrestrial deposits lying on them, and (6) older than marine formations lying on them. Peneplains are (7) older than valleys which have been cut below them. An old peneplain is (8) younger than rocks forming erosion remnants above the plain and (9) older than deposits in valleys below it. A peneplain is (10) younger than any adjacent peneplain which stands at a higher level and (11) older than any lower adjacent graded plain. In the case where subsidence has taken place and streams have been caused to develop grades at levels higher than was possible before subsidence occurred, points (10) and (11) would be reversed. The higher of two graded surfaces in this case would be the younger. The lower one would be buried and would only in the rarest case be distinguishable. (12) If an erosion surface has been uplifted by tilting, warping, folding or faulting, and there are deposits which have not been disturbed, the surface is older than those deposits. (13) A less accurate method has been used in determining the ages of old erosion surfaces. It has been concluded that a given peneplain is Cretaceous because it is known to be post-Triassic, and because its formation is assumed to have required all the Jurassic, Comanchean, and Cretaceous periods. Or it might be stated that a peneplain is of Eocene age because Pliocene deposits lie in valleys below it and it would have taken the Oligocene and Miocene periods to cut the valleys. The inaccuracy in such criteria is due to the varying rates of degradation by streams under varying conditions and to a general lack of knowledge of the duration of the various geologic periods.

Not all of the above-mentioned means of determining the ages of raised peneplains are likely to be applicable in any one region, but it seems that among so large a number of possible criteria, enough would be usable to lead to conclusions giving at least the approximate age of an old erosion surface.

Once the age of an upland plain is established it may become a valuable horizon marker by which the ages of associated topographies and deposits and structures may be determined. If a peneplain known to be of mid-Eocene age is uplifted uniformly and partly dissected, all topographies and deposits which lie above it are early Eocene or pre-Eocene and all topographies and deposits lying stratigraphically below it are late Eocene or post-Eocene. Similarly, structures which the plain bevels are pre-Eocene and structures in which the surface of the plain itself is involved are late Eocene or post-Eocene.

The extreme care with which all these points should be used and the difficulties in the way of accurate interpretation are emphasized in the discussion among Umpleby, Atwood, Blackwelder and Rich, references to which were given on page 8.

The Dates of Movement

The dates of diastrophic movements in the erosional histories of surfaces can be determined in a general way at least from the ages of the different erosional surfaces. For instance, if it has been proven that an upland peneplain in a given district is Cretaceous in age and there is an intermediate plain below it which is Eocene, it is a short and simple step to the conclusion that the uplift of the upper plain took place at or near the close of the Cretaceous period. But if two consecutive erosion surfaces are more widely different in age, as late Cretaceous and early Pleistocene, the uplift of the Cretaceous plain may have taken place at any time between the two periods; that is at the end of the Cretaceous, or during or at the end of the Eocene, Oligocene, Miocene or Pliocene.

In such cases as the last the student is likely to fall back on an estimate of the amount of time it must have taken to produce the second plain after the uplift of the first. If it seems that it would have required the Miocene and Pliocene periods to produce the lower plain, it might be assumed that the uplift took place at the end of the Oligocene, but this assumption would not be without possibility of serious error. If the conclusion was reached that the uplift of the older plain did take place at the close of the Oligocene, this plain would probably thereafter be called the Oligocene rather than the Cretaceous plain, for the period name given it would be that designating the latest period at which the plain is believed to have been intact.

The conclusion arrived at is that the dates of diastrophic movement can be told in a general way from the ages of consecutive erosion surfaces, but that the closer together the surfaces are in age the more accurately can the date of the diastrophism be determined.

Duration of Geologic Time

A rough estimate of the duration of certain geologic periods might be made if the ages of consecutive erosion surfaces and the dates of uplift are known. For instance, if an upland plain with remnants at an average altitude of 2,000 feet is of Miocene age and is known to have been uplifted at the end of the Miocene period, and if in the same district there is an intermediate plain of early Pleistocene age at an average altitude of 1,000 feet, the conclusion is warranted that the land was degraded 1,000 feet during the Pliocene period. If it be assumed that all this degradation took place at a rate which is average for all lands through all times and that this average rate is 1 foot in 9,000 years, the duration of the Pliocene period would be estimated at 9,000,000 years. The estimate, of course, would be subject to large error in each of the two points of the assumption. However, this method of estimating the duration of geologic time, duly considered and qualified, might be as accurate as estimates based on the rate of accumulation of sediments, the rate of increase of salinity in the sea, the rate of life evolution, or the rate of radio-active changes.

CONCLUSION

From the foregoing discussions it seems clear that there are many rules for determination of the various events in the erosional histories of regions, that all of them are open to exception and some of them to serious and frequent exceptions, that the full interpretation of erosional history is attended with great difficulty, that such interpretation is safe only after wide areas have been studied closely, and with all criteria and limitations in mind, but that on the whole fairly accurate conclusions may be drawn by the student of diligence, persistence and analytic mind.

PART II

MESOZOIC AND CENOZOIC HISTORY OF THE DRIFTLESS AREA

CONTENTS

PART II

MESOZOIC AND CENOZOIC HISTORY OF THE DRIFTLESS AREA

In Part I the various principles involved in the erosional histories of regions were outlined and each principle was analyzed, without special reference to any given region. In Part II it seems possible to summarize and emphasize the principles discussed in Part I and at the same time to contribute something to the history of a region in which much work has been done, on which much has been written, but concerning which there has been some difference of opinion.

All who have worked in the Driftless Area within recent years have noticed that many of the divides within small districts are roughly accordant in level. Most students of the region have concluded that the even-topped divides are remnants of raised peneplains and that more than one cycle was involved in the erosional history of the surface[1]. There

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[1] Bain, H. F., "Zinc and Lead Deposits of Northwestern Illinois," *Bull. U. S. Geol. Surv.*, No. 246, pp. 13-16.
Calvin, Samuel, "Geology of Allamakee County," *Ia. Geol. Surv.*, Vol. IV, pp. 41-44.
Grant, U. S. and Burchard, E. F., *Lancaster-Mineral Point Folio, U. S. Geol. Surv.*, pp. 1 and 2.
Hershey, O. H., "The Physiographic Development of the Upper Mississippi Valley," *Am. Geol.*, Vol. 20, pp. 246-268.
Howell, J. V., "The Occurrence and Origin of the Iron Ores of Iron Hill, near Waukon, Iowa," *Ia. Geol. Surv.*, Vol. XXV, pp. 54-62.
Hughes, U. B., "A Correlation of the Peneplains of the Driftless Area," *Proc. Ia. Acad. Sci.*, Vol. 23, pp. 125-132.
Leonard, A. G., "Geology of Clayton County," *Ia. Geol. Surv.*, Vol. XVI, pp. 220-233.
MacClintock, Paul, *The Wisconsin River Valley Below Prairie du Sac*, Unpublished paper.
Salisbury, R. D., "Preglacial Gravels on the Quartzite Range near Baraboo, Wisconsin," *Jour. Geol.*, Vol. III, pp. 655-667.
Salisbury, R. D. and Atwood, W. W., "The Geography of the Region about Devils Lake and the Dalles of Wisconsin," Bull. No. 5. *Wis. Geol. and Nat'l Surv.*, pp. 60-64.
Shaw, E. W. and Trowbridge, A. C., "Galena-Elizabeth Folio," *U. S. Geol. Surv.*, pp. 9 and 10.
Shipton, W. D., "The Geology of the Sparta Quadrangle, Wisconsin," Master's Thesis, Univ. of Iowa, unpublished.
Trowbridge, A. C., "Some Partly Dissected Plains in Jo Daviess County, Illinois," *Jour. Geol.*, Vol. XXI, pp. 731-742.
"Preliminary Report on Geological Work in Northeastern Iowa," *Proc. of the Ia. Acad. Sci.*, Vol. 21, pp. 205-209.
"Physiographic Studies in the Driftless Area," Abstract, *Bull. Geol. Soc. Am.*, Vol. 26, p. 76.
"The History of Devil's Lake, Wisconsin," *Jour. Geol.*, Vol. XXV, pp. 344-372.
Trowbridge, A. C. and Shaw, E. W., "Geology and Geography of the Galena and Elizabeth Quadrangles," Bull. No. 26. *Ill. Geol. Surv.*, pp. 126-146.
Williams, A. J., "Physiographic Studies in and around Dubuque, Iowa," Master's Thesis, University of Iowa, unpublished.

has, however, been disagreement concerning the number of cycles, and the dates of historical events. Recently, doubt has been expressed that these upland surfaces represent old peneplains, and the belief advanced that all the features of the topography have been formed in a single erosional cycle[1]. Most of the papers so far published on this subject are the results of work done in small and isolated districts within the general region. Therefore it is not strange that agreement has not been reached, and that some of the conclusions are incorrect. The writer has seen all of the Driftless Area which lies in Iowa and Illinois and much of that which lies in Wisconsin and Minnesota, and it now seems possible to bring together material from which accurate conclusions may be drawn.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge, with appreciation, the assistance of several scores of students in the Universities of Iowa and Chicago, who have used the Driftless Area as a field of instruction under his direction in the ten years during which he was actively engaged in teaching and research work there. Special mention is made of A. J. Williams, Jesse V. Howell, W. D. Shipton, Urban B. Hughes, Leroy Patton and Paul MacClintock, each of whom has prepared a report on the general geology of some assigned portion of the Driftless area, following detailed field work. Most of these reports have constituted Master's or Doctor's theses. Not all have been published. Mr. Williams and Mr. Howell did their work in the Iowa portion of the region, Mr. Shipton in the Sparta quadrangle of Wisconsin, Mr. Hughes in the Richland Center quadrangle of Wisconsin, Mr. Patton chiefly in the southeastern counties of Minnesota, and Mr. MacClintock along the lower Wisconsin river valley. In all the work special attention was given to stratigraphy and structure and to their relations with physiographic forms. The results have been freely drawn upon in the preparation of Part II of this paper.

Thanks are also due to R. D. Salisbury, W. C. Alden and

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[1] Martin, Lawrence, *Wis. Geol. and Nat'l Hist. Surv.*, Bull. 36, pp. 55-70.

Frank Leverett, who spent several days in northeastern Iowa with Mr. Williams and the writer in 1915, going over some of their data and listening with interest to some of their interpretations. For these interpretations, however, the writer assumes full responsibility.

The previous work of Grant and Burchard in the Lancaster and Mineral Point quadrangles, resulting in Folio No. 145 of the U. S. Geological Survey, were particularly useful.

Finally to R. D. Salisbury, M. M. Leighton and Leroy Patton, thanks are offered for thorough criticism of the manuscript of Part II as well as Part I of this paper.

ROCK FORMATIONS

The rock formations of the Driftless Area range from Huronian to Silurian in age. Hard pre-Cambrian quartzite and igneous rocks outcrop in various places in Wisconsin, as at Baraboo, Wausau, Necedah, and Black River Falls and appear to underlie Paleozoic sediments throughout the area. The Paleozoic group consists of Cambrian, Ordovician, and Silurian formations, the names, thicknesses and relative resistance of which are shown in the accompanying table. The Decorah shale is variable in thickness but

TABLE SHOWING THE ROCK FORMATION OF THE DRIFTLESS AREA

System	Formation	Kind of Rock	Thickness in feet	Resistance to erosion
Silurian	Niagaran	Cherty dolomite	200	Resistant
	Alexandrian	Thin-bedded limestone	0-80	Nonresistant
Ordovician	Maquoketa	Shale	100-200	Nonresistant
	Galena	Cherty dolomite	240	Resistant
	Decorah	Shale	0-30	Nonresistant
	Platteville	Limestone	80	Resistant
	St. Peter	Sandstone	20-300	Nonresistant
	Prairie du Chien	Cherty dolomite	0-300	Resistant
Cambrian	St. Croix (Potsdam)	Sandstone, limestone, shale and dolomite	1000	Nonresistant
Pre-Cambrian		Quartzite, dolomite, slate, various igneous rocks	5000+	Resistant

thin in all places, and, lying as it does between two resistant formations, does not affect topography greatly. So far as their effect on topography is concerned the Platteville and Galena formations are a unit. The Alexandrian formation varies in thickness and resistance and affects topography in such a way as to be inseparable from the Niagaran formation in some places, and from the Maquoketa in others. There is an unconformity between the St. Peter and Prairie du Chien formations, which causes both to vary in thickness, but the sum of their thicknesses is nowhere far from 300 feet[1]. The Cambrian formations are all weak but vary slightly in resistance. Devonian and Pennsylvanian formations were perhaps deposited over part or all of the region, but, if so, they have been eroded away. The erosional history of the present surface started with the final withdrawal of the Paleozoic seas and continued through the Mesozoic and Cenozoic eras.

STRUCTURE

Although in most of the Driftless Area the strata dip in a general southwesterly direction, there is a northeast-southwest axis crossing the Mississippi river between La Crosse, Wisconsin, and Winona, Minnesota, and passing north of Sparta, north of which the beds dip northwesterly. In other words, the structure is that of a low anticline with its axis near the north edge of the region, plunging to the southwest, with a long limb to the south and a relatively shorter limb, so far as the Driftless Area is concerned, to the north. Most of the work on which this paper is based has been done south of the crest of the arch and the relationships between topographic forms and structure are consequently best known there. However, Mr. Patton and the writer worked in the axial area and to some extent north of the axis in Minnesota and Wisconsin in 1917.

The average direction of dip of the formations south of Winona and Sparta, as determined by twenty-eight computations is S. 26° W., and the average amount 14.6 feet per

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[1] Trowbridge, A. C., *Ia. Acad. Sci.*, Vol. XXIV, pp. 177-182.

mile. Four computations in the area north of the arch show an average dip there of N. 35° W. in direction and 6.9 feet per mile in amount.

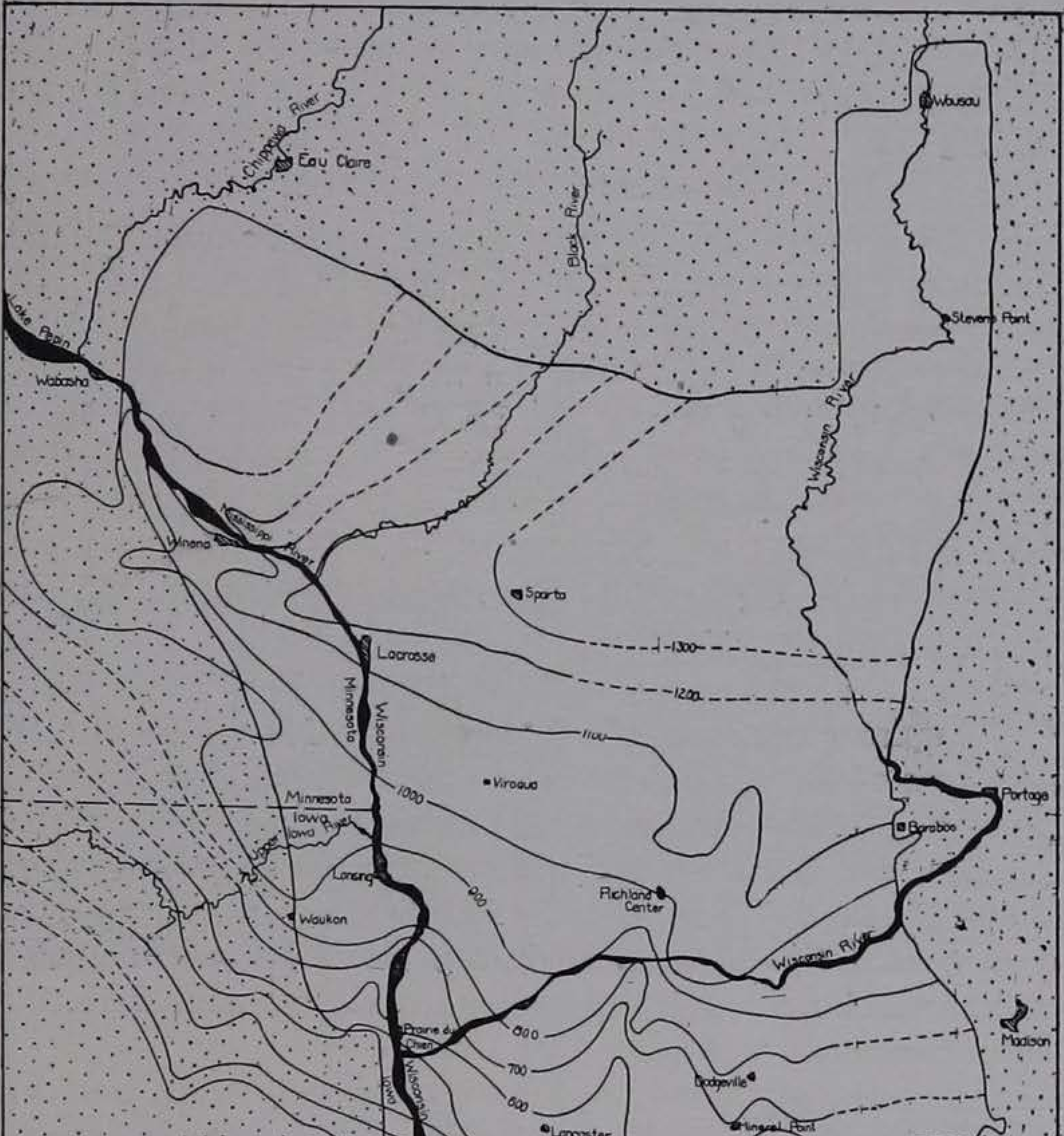

Fig. 11. Sketch map of the Driftless Area and its environs showing structure contours on the contact between Prairie du Chien and Jordan formations. Structural contour interval equals 100 feet. Horizontal scale 1/500,000. Contours are broken where courses are conjectural.

Both the south-dipping and the north-dipping monoclines and to an extent also the nearly horizontal structures of the axial area are interrupted in many places by low anticlines and shallow synclines. The whole composite structure of the Driftless Area might be said to be a low anticlinorium, plunging southwestward. For additional details see Fig. 11.

THE STAGE OF EROSION

In the present cycle of erosion the general surface of the Driftless Area is in late youth or early maturity, although small portions exhibit a later stage of development. The valley of the Mississippi and the valleys of its larger tributaries, such as the Wisconsin, La Crosse, and Upper Iowa rivers, appear to be mature, but if the thick deposits in them were removed the valleys would have a much more youthful appearance. Most of the valleys in the area are young. There are considerable areas of unreduced flattish land on the highest divides and still greater areas at lower altitudes well above the valley bottoms. It is these unreduced upland surfaces which form the chief physiographic problems of the region and which at the same time give the investigator his best clue to the history of the surface. Along the main drainage lines there are narrow graded valley flats which are valuable for comparison with the upland flats. The topography has a relief of over 600 feet within short distances, and before the valleys were partially filled the relief was over 800 feet.

EVIDENCES OF MORE THAN ONE CYCLE OF EROSION

Of the several lines of evidence for more than one cycle of erosion which have been used in determining the erosional histories of various surfaces and which were discussed in Part I, the Driftless Area shows seven, in different degrees of perfection and significance.

Even-Crested Summit Areas (the Dodgeville Plain)

In most portions of the Driftless Area the highest divides are noticeably flat on their summits. These flat surfaces forming the summit areas are the sites of cities, towns, villages, farms, wagon roads and railroads. In the Baraboo district of Wisconsin there is an area more than two square miles in extent so nearly flat that the drainage on its surface is poor, and no spot is 10 feet higher or lower than the general elevation of 1400 feet. In the southern portion of the Sparta Quadrangle, Wisconsin, there is much flat land at about 1335 feet A. T., more than 500 feet above main drainage lines, on which are located the villages of Newberg Corners, Middle Ridge and Portland (Fig. 12). Here, in an area of 5 miles square there are approximately 7,000 acres of land under cultivation, supporting a prosperous population of 4,500, all on flat-topped divides. From the south edge of the Sparta Quadrangle a "ridge road" follows a continuous divide for more than 50 miles, passing through the towns of Cashton, Rewey, Westby, Viroqua, Seneca and Eastman, and leaves the crest of the ridge only about a mile from the bluff of the Mississippi and two miles from Prairie du Chien. In this distance the crest of the divide has a relief of less than 100 feet, and the width of the nearly even crest varies from a few feet to a half mile

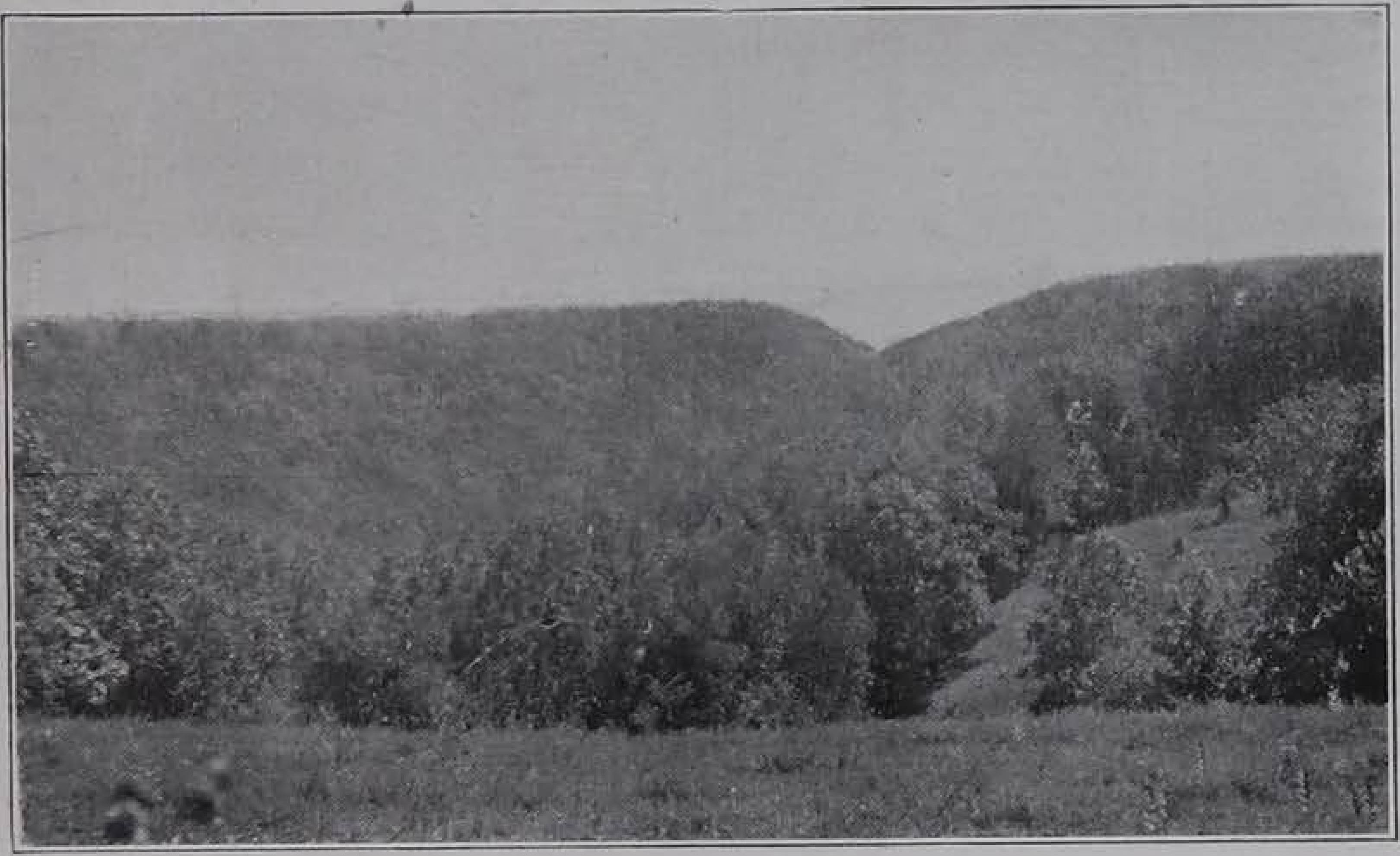

Fig. 12. View of the summit plain in the south portion of the Sparta Quadrangle.

or more. From the main ridge tongues of flat land project out between tributary streams on both sides.

In the southern portion of the Richland Center quadrangle in Wisconsin the summits of many of the divides are nearly flat and noticeably accordant in their levels. These divides are spurs and outliers of a wide, continuous area of gently rolling land known as Military Ridge, extending east and west in the northern part of the Lancaster and Mineral Point quadrangles. Military Ridge is unbroken from Bradtville to Blue Mounds, a distance of over 60 miles. On or near its summit, Bradtville, Patch Grove, Mount Hope, Mount Ida, Fennimore, Preston, Montfort, Cobb, Edmund, Dodgeville and Mount Horeb are located. Connecting these towns are good high roads, whose grades are low and on which bridges are noticeably few in number. From Fennimore to Blue Mounds, the ridge is utilized for the road bed of a branch of the Chicago and Northwestern Railway.

In the north half of the Galena and Elizabeth quadrangles in Illinois, the highest surfaces are the tops of isolated mounds or short dendritic ridges which include only very small patches of flat land, but which have accordant levels at about 1150 feet A. T. In the south part of these two quadrangles there are many long, continuous, dendritic, flat-topped ridges whose summit areas are the sites of homes, farms and ridgeroads. These ridges have an average altitude around 1,000 feet. At about this altitude there are thousands of acres of excellent farm land. In the north part of these quadrangles the summit levels are 450 feet above the beds of the main streams, and in the south part they are 350 feet above drainage.

There are no extensive summit levels in Iowa, although upland plains exist. Between Waukon and Church and extending west from Waukon toward Decorah, east through Elon, and southeast to Rossville, there are dendritic stream divides whose summits are much more nearly flat than the surrounding surface, and are the sites of villages, main roads and farms. The maximum relief of this surface is less than 100 feet (1200-1300). Upland flats are also known at Monona, Luana and Watson in the southeastern part of the Waukon quadrangle, at National, Garnovillo, Upde-Graff, Colesburg, an area east of Graham, Luxemburg and other points in the Elkader quadrangle, and at or near Holy Cross, Sherrill, Rickardsville, Bankston, Balltown, and Tivoli in the Iowa portion of the Lancaster quadrangle. In the extreme southern part of the Driftless Area in the Iowa portion of the Galena quadrangle there are considerable areas of flat land on high divides, which are used for upland farms and roads.

Flat summit areas with accordant levels are not extensive in Minnesota. They are best developed in the western parts of Winona and Houston counties. In Winona county a strikingly flat plain of about 15 square miles in area lies between Utica and St. Charles and to the south from there. It is approximately 1300 feet above sea level. Near Spring Grove, Houston county, at an elevation of approximately 1325 feet, the summit plain is represented by extensive prairie-like uplands, spurs of which ramify from the main area. Similar conditions occur also in the neighborhood of Caledonia.

From the foregoing descriptions, the significant facts concerning the topography of the summit surfaces in the Driftless Area may be summarized as follows: (1) There are many divides whose summits are noticeably even. (2) Some of these areas of upland flat are long and broad. (3) The various areas of upland flat have such slight irregularity in comparison with the rest of the topography that they are favorable sites for farming. (4) If the elevations of isolated summit areas in a given district be compared, they are found to be strikingly accordant, though not identical. (5) Accordant summit levels are known in practically all portions of the Driftless Area. (6) The districts where the summit plains occur are close enough together to warrant correlation from one district to another; from Baraboo, through the Richland Center and Mineral Point quadrangles to Jo Daviess County, Illinois; from Baraboo to Sparta; from Sparta through Viroqua and Prairie du Chien to Iowa; from Dodgeville via Bradtville to National, Iowa;

from Iowa into Winona and Houston counties in Minnesota; from the Minnesota line in Iowa to Dubuque; from the Galena quadrangle in Illinois to the area south of Dubuque in Iowa. (7) If the several summit areas of a district be projected until they meet, a surface is constructed which has a relief of something less than 200 feet. (8) If the constructed summit plains of the several districts of the Driftless Area, as explained in (7) be projected across intervening areas where summit flats are wanting until they meet, an almost reliefless, gently south-sloping plain results which covers practically the whole Driftless Area. Because the surface so reconstructed is well represented at Dodgeville, because there is at Dodgeville a large area of upland flat, and because, from Dodgeville the flat may be traced with certainty in all directions, this uppermost plain, reconstructed by projecting the upland flats until they meet, is hereafter called the *Dodgeville plain.*

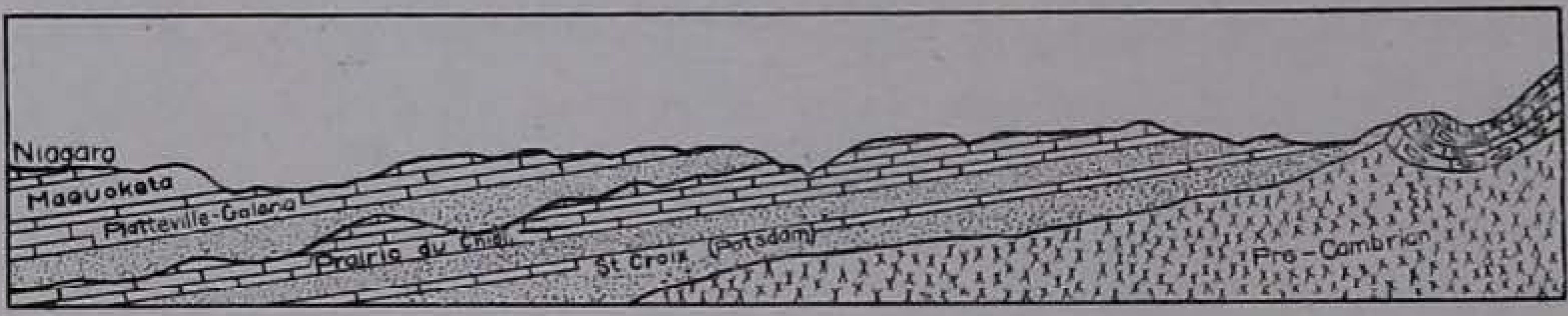

Fig. 13. An idealized north-south section in the Driftless Area, showing the general relation of the Dodgeville plain to the rock formations. The upland surfaces are found in large areas on the resistant Prairie du Chien, Platteville, Galena, and Niagara formations, but are wanting on the relatively nonresistant Cambrian sandstones, St. Peter sandstone and Maquoketa shale.

Topography and rock structures are so intimately and fundamentally related that it is always unsafe to draw important conclusions from analysis of topography before these relations are understood. It is therefore necessary that a careful study be made of the rock formations on which the Dodgeville plain lies, the structure of these formations, and the relative attitudes of plain and formations, before interpretation of the Dodgeville plain is attempted. Failure to give due weight to these relationships seems to be responsible for certain errors of the past.

The Dodgeville plain is underlain by different rock formations at different places. In the Baraboo district of Wisconsin it lies on Huronian quartzite and in the Sparta district on the Prairie du Chien and St. Peter formations. Military Ridge and its spurs are capped by Galena dolomite, as are also the upland divides around Waukon in Iowa. South of Turkey river in Iowa, and south of Lancaster in Wisconsin and Illinois, the plain lies on Niagara dolomite. In southeastern Minnesota it lies for the most part on the Platteville formation but it places cuts across to St. Peter. In a general way the Dodgeville plain bevels the south-dipping formations, lying on progressively younger beds from north to south. Either because of a decrease in the slope of the plain north of the Iowa line, because of a change in the direction of slope, or because the plain has been very slightly warped since its formation, its remnants are not greatly higher in Minnesota than in Iowa, and its stratigraphic position is somewhat but not much lower in Minnesota than farther south. It also bevels the crest of the arch. No remnants of the plain have been observed north of the axis and therefore it cannot be definitely stated that the north-dipping beds are also bevelled by it, although such is probably the case. It is noticeable, however, that only the more resistant formations are found capping the highest divides where these divides are flat-topped and accordant in their

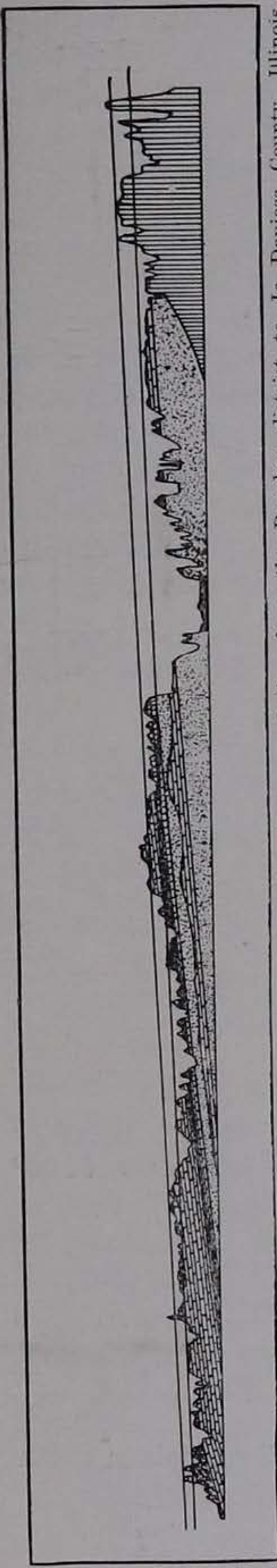

Fig. 14. An accurate topographic profile and structure section taken in a curved line from the Baraboo district to Jo Daviess County, Illinois, crossing the Baraboo, Denzer, Richland Center, Mineral Point, and Elizabeth topographic atlas sheets. The uppermost straight line represents the reconstructed Dodgeville plain. (After U. B. Hughes).

levels. Wide areas of the plain lie on the Prairie du Chien, Galena, Platteville and Niagara formations respectively. The St. Peter sandstone underlies patches of the plain in very small areas only, and the Maquoketa formation is not known to form summit flats at all. In traveling from north to south three distinct belts are crossed, in each of which there are large upland remnants of the Dodgeville plain and between which there is none. (Figs. 13 and 14)

Assuming that the Dodgeville plain is a geometrical plane, it is possible to ascertain its dip and strike if the relative positions and altitudes of three points on the plane forming a triangle are known. If the elevations of a certain stratigraphic horizon under the three points on the plain can be ascertained it is also a simple matter to compute the dip and strike of the strata and get the relative directions and amounts of dip of plain and strata (Fig. 15).

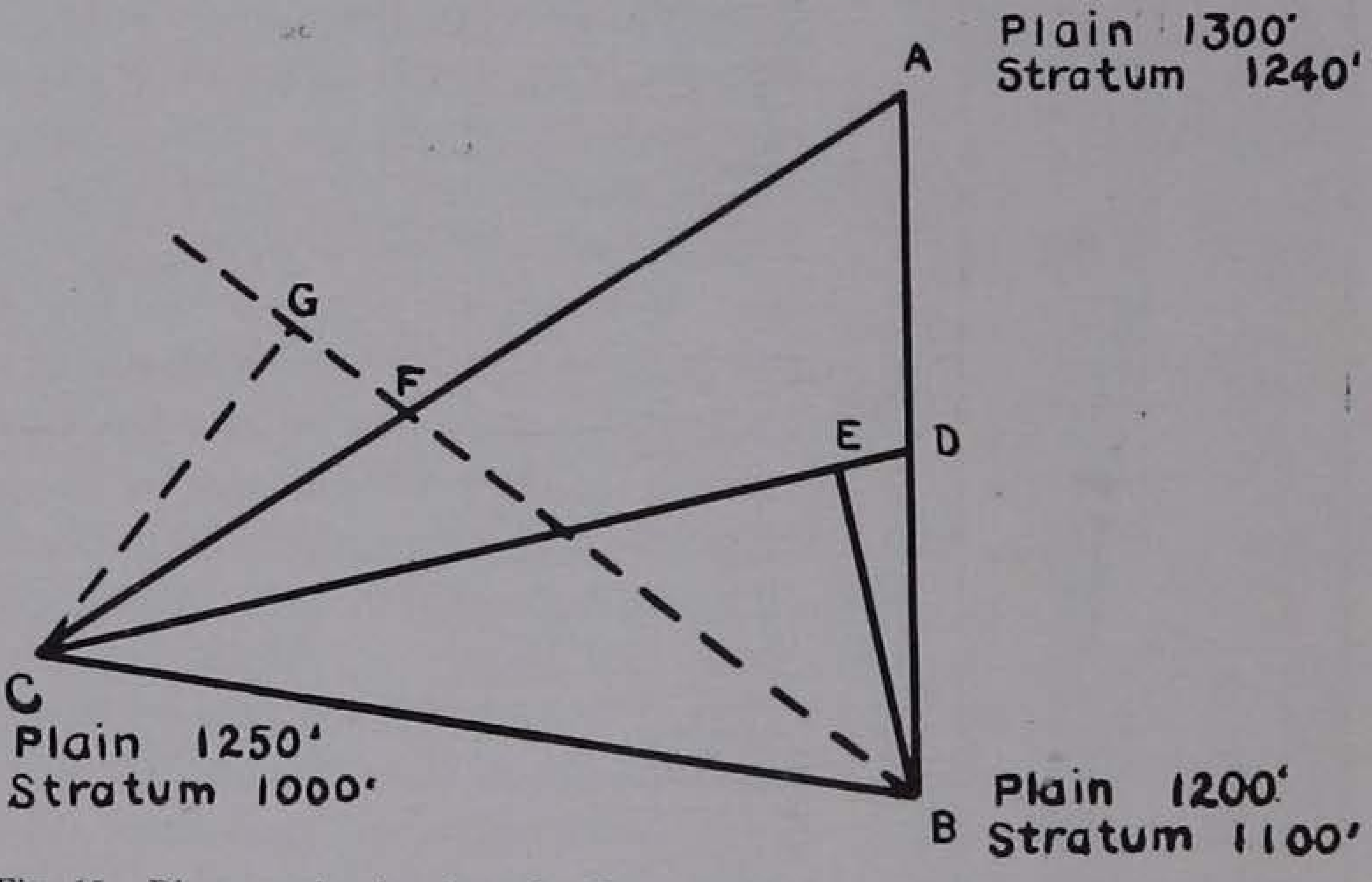

Fig. 15. Diagram showing how the dip and strike of a plain and of a stratum can be determined if the positions and altitudes of three points are known. A, B, and C are three points on the surface plain at 1300, 1200, and 1250 feet respectively. On the line AB there is a point D at which the altitude is the same as at C, 1250′. The line CD is the strike of the plain. The direction of dip is obtained by constructing line EB at right angles to CD through B. Reading the direction of EB the dip is found to be S 14° E. From E to B the surface falls 50′. Scaling EB the amount of dip of the plane is found to be 4.4′ per mile.

Knowing the elevations of a stratigraphic horizon under points A, B, and C to be 1240, 1100, and 1000 feet respectively, locating the 1100′ point on AC at F, BF becomes the strike of the strata, the dip CG is S 37° W, and the amount of dip is 7′ per mile.

The results of 13 such computations, based on points south of the axis of the arch are given in the following table.

TABLE OF RESULTS OF COMPUTATIONS OF DIP AND STRIKE OF DODGEVILLE PLAIN AND ROCK STRATA

General Location	Location of Points	Direction of Dip of Plain	Amount of Dip of Plain	Direction of Dip of Strata	Amount of Dip of Strata
South part of Sparta Quadrangle Wisconsin	A-C Sec. 20 Leon Twp. B-C Sec. 8 Portland Twp. C-NC Sec. 21 Washington Twp.	N 57°W	5.3′	S 59°W	14′
Whole Sparta Quadrangle Wisconsin	A-Castle Rock B-Middleridge C-SC Sec. 18 Jefferson Twp.	N 43°W	2.6′	S 38°W	10.7′
Lancaster, Mineral Point and Richland Center Quadrangles, Wis.	A-Fennimore B-Dodgeville C-7½ mi. S. of Wyoming	N 20°W	9.4′	S 13°W	14.2′
Elizabeth Quadrangle, Illinois	A-Wc Sec 19 Thompson Twp. B-Sw Sec. 31 Woodbine Twp. C-Nc Sec. 33 Stockton Twp.	S 14°W	7.3′	S 28°W	34.4′
Northern Iowa, Waukon Quadrangle	A-Waukon B-Church C-Rossville	S 56°E	10.9′	S 49°E	8.4′
Iowa-Wisconsin	A-Church B-Updegraff C-Mt. Ida	S 76°E	1.2′	S 40°W	17.1′
Wisconsin-Iowa-Illinois	A-Sparta B-Waukon C-Stockton	S 20°E	2.9′	S 22°W	9.1′
Wisconsin-Iowa	A-Sparta B-Waukon C-Dodgeville	S 4°E	1.8′	S 20°W	9.5′
Iowa-Wisconsin-Illinois	A-Waukon B-Mineral Point C-Stockton	S 21°W	9.6′	S 18°W	8.3′
Wisconsin-Iowa-Illinois	A-Sparta B-Bankston C-Stockton	S 51°E	3.5′	S 37°W	12.8′
Iowa-Illinois	A-Waukon B-Updegraff C-Stockton	S 86°E	3.2′	S 32°W	16.4′
Iowa-Wisconsin	A-Waukon B-Dodgeville C-Bankston	S 1°E	1.8′	S 19°W	12.9′
Wisconsin Iowa	A-Denzer B-Waukon C-Updegraff	S 29°W	2.2′	S 12°W	10.8′

These computations bring out certain facts. The plain constructed by connecting areas of summit plains across intervening areas is by no means a geometrical plane, for it dips in different directions and by different amounts in different places. In small districts, widely differing results can be obtained by taking different sets of points as bases for computation. Local irregularities obscure the general slope. If the results of all the available computations are considered, the average slope of the plain is in the direction S 75° E to an amount of 4.7 feet per mile. If the local estimates be eliminated and only those which involve long distances be included, the effect of local irregularities is minimized and the general slope of the plain is found to be S 23° E, 3.3 feet to the mile. The direction and amount of dip of the strata are much more nearly constant and average S 28° W and 14.2 feet per mile recpectively. Nowhere are the plain and the strata parallel. The angle between their respective average directions of dip is 51° and the strata dip more than three times as steeply as the plain slopes. Even in small districts where upland plains are broad and cover a considerable distance in directions at right angles to the strike of the strata, the slope of the plain and the beds are not parallel. The lack of parallelism between the Dodgeville plain and the strata which underlie it is expressed in the fact that progressively younger beds are bevelled by the plain from north to south on the south limb of the arch.

As outlined in Part I such a plain as the Dodgeville plain is open to several possible interpretations: It might be the original marine plain of deposition, a plain of marine erosion, or a structural plain on a single hard stratum. The apparent accordance of levels might be due to the erosion in a single cycle of a surface underlain by gently south-dipping and unequally resistant formations, developing a series of somewhat even-topped cuestas whose summits were never parts of a plain now dissected. Or, the Dodgeville plain might be a true peneplain.

The Dodgeville plain cannot be the sea bottom uncovered by the withdrawal of the Paleozoic sea, for it is known that

Niagara dolomite was deposited in this sea over the whole region, and the plain is directly underlain by Huronian rocks at Baraboo, the Prairie du Chien formation at Sparta, the Galena formation at Church and Waukon and on Military Ridge. From these portions of the surface younger rocks must have been eroded. Also there are monadnocks standing above the level of this surface at several places, for instance, Sauk Point in the Baraboo district, Blue Mounds at the east end of Military Ridge, and Sherrill and Sinsinawa Mounds farther south.

Neither is the Dodgeville plain the result of marine denudation. The erosion remnants above it are not isle-like, nor is it bordered anywhere by shore features. A still more significant fact is that marine deposits, younger than the rock formations across the edges of which the plain is developed, are wholly wanting on the summit surfaces of the region, although other deposits have been preserved there. It is also extremely doubtful if such broad wave-cut terraces have ever been developed anywhere, especially far in the interiors of continents.

The theory that the Dodgeville plain was formed on the surface of a single especially hard formation is untenable for the reasons that the plain lies on different formations at different places, that not all the formations are resistant, and that the plain slopes southward at a considerably lower angle than the angle of dip of the rock formations.

The idea that the Dodgeville plain consists of a series of unrelated structural plains is incoroprated in the theory that the plain is a series of cuesta tops, and this theory is next to be considered.

The Cuesta-Single Cycle Theory

Of the first four possible interpretations outlined above, the idea which has been advanced that the Dodgeville plain, as described on previous pages, does not exist and never did exist, but consists merely of a series of unrelated cuestas, is more probable than any of those thus far considered, and is to be accepted or rejected only after the most careful study of the field conditions. A possible source of confusion should be eliminated at once by the statement that whatever has been the history of the upland surfaces they do constitute cuestas. Martin[1] has defined a cuesta as "an upland with a short, steep descent, or escarpment, on one side, and a long, gentle slope on the other." The three belts containing areas of summit flats answer the definition perfectly, and they are cuestas. The problem remains, however, as to whether their more or less even crests, related as they are to rock structures, could have been developed in a single cycle of erosion. As Martin points out in describing cuestas, "the gentle slope usually corresponds to the inclination or dip of slightly-inclined sedimentary rocks and one resistant layer, as of limestone, may determine the whole dip slope."

Following this definition and description the characteristics of cuestas which have had a history involving only one erosion cycle are illustrated in Fig. 16.

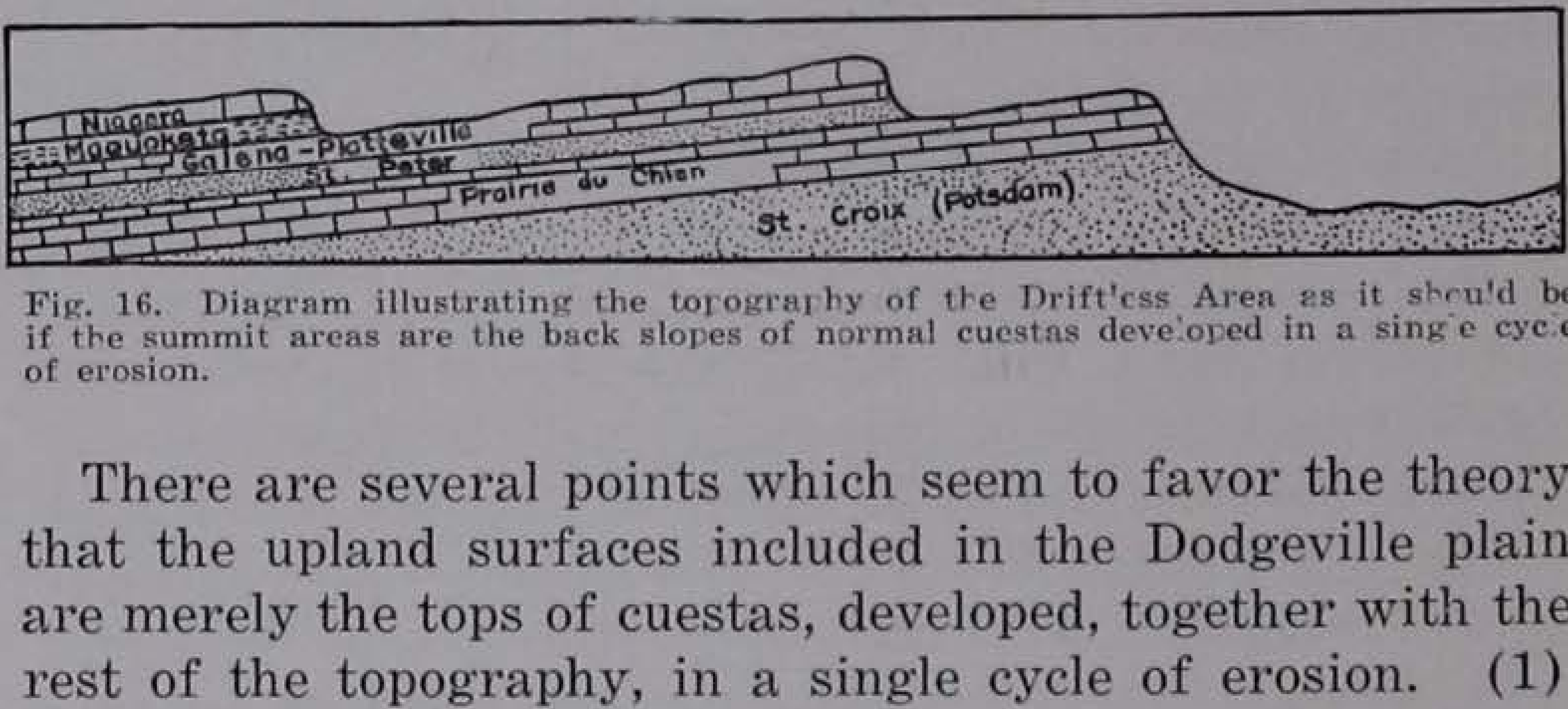

Fig. 16. Diagram illustrating the topography of the Driftless Area as it should be if the summit areas are the back slopes of normal cuestas developed in a single cycle of erosion.

There are several points which seem to favor the theory that the upland surfaces included in the Dodgeville plain are merely the tops of cuestas, developed, together with the rest of the topography, in a single cycle of erosion. (1) The belts in which the upland surfaces are considerable are cuestas. (2) The upland surfaces are practically confined in their distribution to the areas of outcrop of resistant rock formations. (3) There are three resistant formations and there are three conspicuous belts containing upland surfaces south of the anticlinal axis. (4) In individual districts, and in the region as a whole, the upland surfaces have a general southerly slope and the strata dip generally south. However, these arguments are superficial, for their

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[1] Martin, Lawrence, *Wis. Geol. and Nat'l Hist. Survey*, Bull. 36, p. 42.

features can be explained as well on the basis of more than one cycle as on the basis of a single cycle. There are also several points now to be brought out by a more careful study of topography, especially in its relations with structure, which cannot be explained on the cuesta-single cycle theory and are in keeping with the multiple cycle theory.

(1) The south slopes of the upland surfaces are not parallel with the strata as is normal for cuestas. Compare figures 1 and 4. The south slopes of the Dodgeville plain correspond with the dip of the strata neither in direction nor in amount, as shown in the preceding table (p.).

(2) Those portions of the Dodgeville plain which lie on a single rock formation bevel the layers of that formation. Within the bounds of the Sparta quadrangle, the summit of the Prairie du Chien cuesta lies on 35 feet of Prairie du Chien dolomite at Castle Rock, and on constantly increasing thicknesses to the south, until 229 feet of the formation appear below the cuesta top in the southwest corner of the quadrangle. In the Galena and Elizabeth quadrangles in Illinois the surface of the Niagara cuesta cuts from a stratigraphic position 60 feet above the base of the Niagara formation at the north border of the quadrangles to a position 170 feet above the base at the south edge. Likewise the summit of the Galena-Platteville cuesta lies 80 feet above the base of the Platteville limestone near its northern edge in the Richland Center quadrangle and 300 feet above this horizon on one of the south spurs of Military Ridge. This bevelling of different beds in formations by individual cuesta tops is also illustrated between Church and Rossville, and between Updegraff and Monona in Iowa, and at many other localities within the Driftless Area.

(3) In some places at least, two belts of cuesta tops which are roughly parallel with the strike of the strata, are connected by long, continuous, more or less broad summit divides which are roughly parallel with the dip. Such a divide is that connecting the Prairie du Chien cuesta in the south portion of the Sparta quadrangle with the Galena

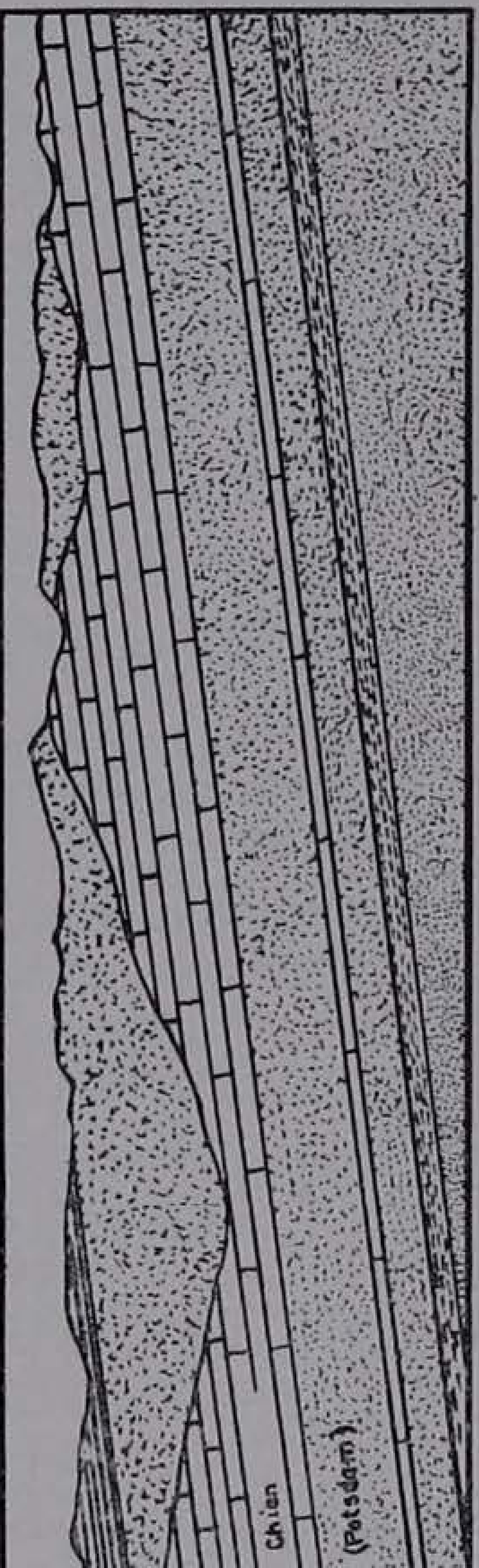

Fig. 17. A cross-section and profile from the Prairie du Chien cuesta near Cashton, Wisconsin, along the crest of the Mississippi-Kickapoo divide, to the Galena cuesta two miles northeast of Prairie du Chien. The horizontal distance is 50 miles. Vertical scale: 1 inch equals 100 feet.

cuesta east of Prairie du Chien. This divide includes much flat land on its summit. Its summit area has a relief of less than 100 feet, and yet it bevels the edges of the Prairie du Chien, St. Peter, Platteville, Decorah, and Galena formations. In its extent of over 50 miles its surface falls from 1300 feet at its north end, to 1200 feet near Prairie du Chien, although a stratigraphic horizon which has an altitude of 1200 feet in the Sparta quadrangle is found at 620 feet at the south terminus of the divide. So independent are the surface and the strata that the change from one formation to another is not expressed in the surface. (Fig. 17) It would be impossible to explain the details of such a ridge on the basis of a single cycle of erosion.

(4) In areas where the summit plains are broad and flat, and such conditions exist in many places in the Driftless Area, it is difficult to conceive a way by which the material from above was removed to make the flats, under the theory that there has been but one cycle of erosion. In the Sparta quadrangle, 200 feet of Niagara dolomite, 100 feet of Maquoketa shale, 320 feet of Galena dolomite and Platte-

ville limestone, 100 feet of St. Peter sandstone, and many feet of Prairie du Chien dolomite have been removed in such a way as to leave thousands of acres of flat land on the divides, 500 feet above present drainage. The three dolomites are cherty and resistant to mechanical wear, although much of the rock is soluble in water. The sandstone and shale are non-resistant physically, but resistant chemically. These same rock formations, in varying amounts, have been removed in making all of the many upland flats of the Driftless Area. On few of these flat surfaces is there any concentration of residual materials such as chert fragments, save those which have been rounded by stream action, although such residual materials are not entirely lacking everywhere. It seems that the removal of the rocks from positions above the flat upland surfaces must have been accomplished by some agent which was capable of removing products of disintegration and of decomposition, even the coarse material. If these surfaces have always been divides, and this must have been the case if there has been no rejuvenation of streams, all of the originally overlying material could not have been removed by streams, for on many of the flats there are now no streams nor stream channels. It is not conceivable that wind degraded the tops of the divides to make flat summits; the region has not been glaciated; waves and currents have been eliminated. It cannot be that solution by ground water has been the method of degradation of these surfaces, for much of the material such as shale, the sandstone, and the chert in the dolomite are practically insoluble. Even if it be conceived that the shale and sandstone constituents were removed by the wind and the soluble portions of all the rocks were dissolved and carried away by ground water, there would be left many feet of residual chert.

(5) It has been made clear that the Dodgeville plain, constructed by joining the various patches of summit plain in each of the three cuestas and the summits of the cuestas across intervening areas, is by no means perfectly flat. But, it is difficult to explain even the rough accordance of summit levels in individual districts and the general slope

of the plain southward, on the assumption that the upland surfaces are merely parts of unrelated cuestas. Estimating that erosion started when the whole region was covered by 1000 feet of strata now gone, and knowing the amount and direction of dip of the strata and the elevation of the various portions of the summit plain, it is possible to estimate what was the original altitude of the surface and to what altitude the upland surface was reduced at any given locality. The dip of the strata is so slight that the altitude of the original surface may be obtained by adding the thickness of the strata removed to the present altitude of the surface, without appreciable error. The results of a series of such computations for a series of localities from north to south and including each of the three cuestas south of the structural axis are tabulated as follows:

TABLE SHOWING THE RELATION OF THE ORIGINAL SURFACE OF THE DRIFTLESS AREA TO THE SURFACE OF THE DODGEVILLE PLAIN

Locality	Original altitude of surface.	Thickness of various formations removed in feet.	Total thickness of rocks removed in feet.	Altitude of present upland surface.
First Series—Sparta-Lancaster Quadrangle				
Castle Rock north part Sparta Quadrangle	2220	200-Niagara 100-Maquoketa 240-Galena 80-Platteville 100-St. Peter 165-Prairie du Chien	885	1335
Near Portland south part Sparta Quadrangle	2130	200-Niagara 100-Maquoketa 240-Galena 80-Platteville 100-St. Peter 40-Prairie du Chien	760	1370
Near Mt. Hope, north part Lancaster Quarangle	1600	200-Niagara 100-Maquoketa 90-Galena	390	1210
Near Richardsville, Iowa, south part Lancaster Quadrangle	1260	130-Niagara	130	1130
Second Series—Richland Center, Mineral Point, Elizabeth Quadrangles				
Near Highland, south part Richland Center Quadrangle	1693	200-Niagara 100-Maquoketa 163-Galena	463	1230

Near Montford, north part Mineral Point Quadrangle	1610	200-Niagara 100-Maquoketa 110-Galena	410	1200
Near Platte Mds. west central part Mineral Point Quadrangle	1440	200-Niagara 50-Maquoketa	250	1190
Four miles south of Shullsburg, south part Mineral Point Quadrangle	1375	170-Niagara	170	1205
Near Erie School, north part Elizabeth Quadrangle	1260	130-Niagara	130	1130
Terrapin Ridge, south part Elizabeth Quadrangle	1135	95-Niagara	95	1040
Third Series—Waukon Elkader Quadrangle in Iowa				
Near Church, north part Waukon Quadrangle	1766	200-Niagara 100-Maquoketa 216-Galena	516	1250
Near Monona, south part Waukon Quadrangle	1555	200-Niagara 100-Maquoketa 45-Galena	345	1210
Near Updegraff, central part Elkader Quadrangle	1200	10-Niagara	10	1190
Fourth Series—Baraboo, Richland Center, Lancaster Quadrangle				
Gibraltar Rock, central part Baraboo Quadrangle	1870	200-Niagara 100-Maquoketa 240-Galena 80-Platteville	620	1250
Six miles south of Hillsdale, southern part Richland Center Quadrangle	1815	200-Niagara 100-Maquoketa 240-Galena 5-Platteville	545	1270
Near Preston, northeast part Lancaster Quadrangle	1610	200-Niagara 100-Maquoketa 140-Galena	440	1170
Three miles east of Bankston, Iowa, southeast part Lancaster Quadrangle	1290	140-Niagara	140	1150

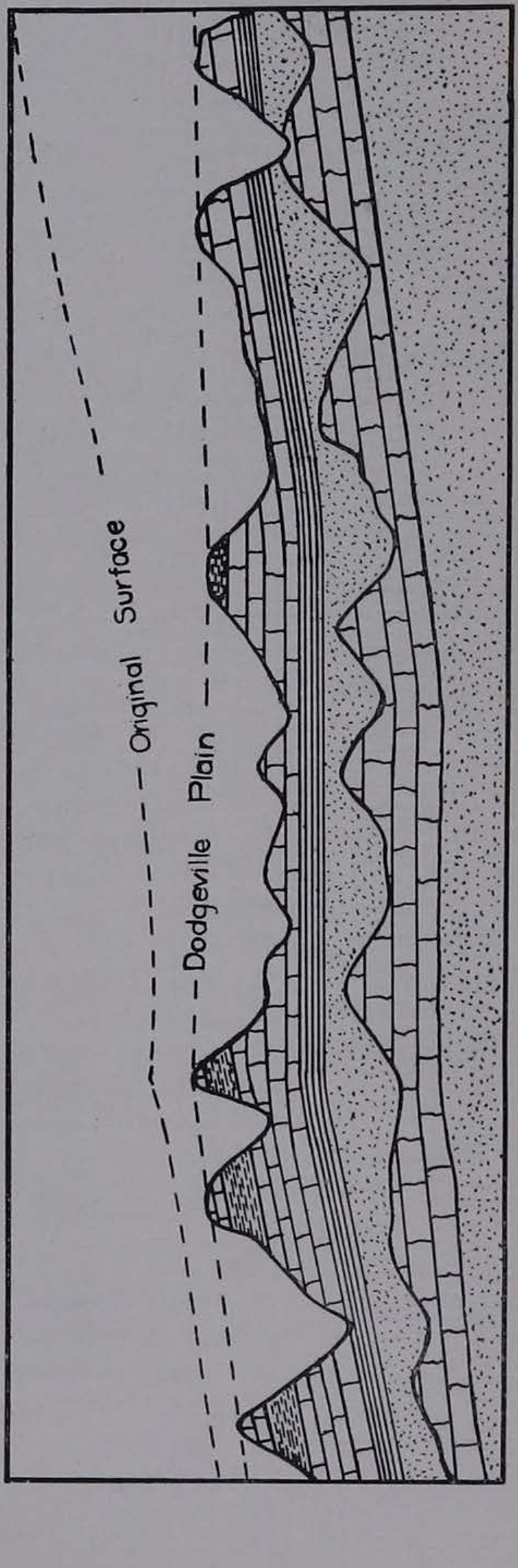

Fig. 18. Diagram to scale illustrating the orderly way in which erosion has progressed in the formation of the accordant summit levels.

These tables show that the original surface was much steeper than the present Dodgeville plain; that the amounts of material removed from the divides decrease by a regular progression to the south; that different proportions of resistant and non-resistant rocks have been removed in different places; and that there is a certain definite order in the relations of original altitudes, amount of rock removed, and present altitudes, irrespective of the relative thickness of resistant and non-resistant formations removed (Fig. 18). It seems improbable that degradation of the tops of divides would take place in so orderly a fashion unless the streams reduced the general surface to grade.

(6) In a region where so much erosion has taken place it would seem that the relative hardness of the resistant formations would express itself in topography if there had been but one cycle. The most resistant of the three should stand the highest, and the least resistant the lowest. But the general southward slope of the Dodgeville plain is uninterrupted by differences in rock hardness, although it is doubtless true that local resistant rocks have influenced local irregularities in its surface. (Compare Fig. 16 with Figs. 13 and 14)

(7) If the upland surfaces in the Driftless Area are entirely structural it would seem likely that the local anticlines and synclines which interrupt the general monoclinal dip would cause undulations in the surface of the Dodgeville plain. In the Galena and Elizabeth quadrangles, where a portion of this plain is well known and where the anticlines and synclines have been carefully mapped, there is no apparent relation between the altitude of the upland surfaces and the folds. The plain bevels the local folds without any expression of the structure in the topography. It is true that there are a few high parts of the upland plain which correspond roughly with anticlines, such as at Waukon, but there are also many high places where there are no anticlines, many high places over synclines, and many low places on anticlines. No general effect of local structure can be observed in the topography of the plain. The higher portions of the upland plain are to be interpreted as resistant portions of the rocks or as original inter-stream areas, not as arched structures.

(8) It is abnormal for the divides of a surface to be lowered greatly before evidences of old age in adjacent valleys appear. During youth of the normal cycle of erosion the main work of the streams is in the development of valleys and the dissection of the original surface. Maturity is ushered in when the upper flat approaches thorough dissection and lasts until lower flats are formed and come to constitute an appreciable portion of the surface. Most of the work of lowering the original divides is accomplished

after the old age of the valleys has been reached. Another principle in the normal erosional cycle is that divides are not degraded much, before permanent divides have been established, that is, before valleys have reached their width and length limits, that is, before the valleys have approached or reached old age. Now the summit divides in the Driftless Area are known to have been degraded by amounts varying from 10 feet to 885 feet (see the fourth column from the left in the above tables), and yet the valleys show few signs of old age, and few of the divides are permanent. If the present surface was formed in a single cycle of erosion, this cycle was not normal.

(9) Assuming that but one cycle has been involved in the erosion of the surface of the Driftless Area, reconstructing the original surface by projecting the Niagara and older formations over portions where they do not now exist, and getting the altitudes of the lowest points reached by streams beneath the present valley fills; it is found that the streams at La Crosse must have reduced their beds from about 2200 feet A. T. to 600 feet in order to reach grade; and the streams in the south portion of the Driftless Area in the vicinity of Dubuque, could have become graded by cutting from approximately 1300 feet to 300 feet. The Mississippi and its tributaries should have reached grade at Dubuque after cutting through 1000 feet of rock of varying hardness long before they brought their beds to grade at La Crosse, where they had to cut through 1600 feet of the same rock, and the topography around Dubuque should now be in a distinctly later stage of development than that in the neighborhood of La Crosse. But the opposite is true. Due to the relative non-resistance of the Cambrian sandstone on which the streams have their courses *at present* in the north part of the area, there is a greater area of lowland there than farther south, and the topography around La Crosse has an appearance of greater age than the surface near Dubuque.

(10) In advance of complete description and interpretation it should be made clear here that there are in many places on the Dodgeville plain considerable areas of gravel

which have undoubtedly been deposited there by streams which could not carry their loads all the way to the sea. These deposits are known near Devil's Lake, Cashton and Seneca in Wisconsin, and near Church, Elon and Waukon in Iowa, as well as at numerous other places within and south of the Driftless Area. This fact is not mentioned by Martin. It seems to the writer to be a fatal objection to the single cycle theory.

The conclusion now has been reached that the Dodgeville plain is not an original plain of marine deposition, nor a plain of marine erosion, nor a simple structural plain. The theory that the plain consists merely of three cuestas whose summits were developed in the present cycle of erosion is untenable.

The Peneplain Theory

It remains to test the fifth possible interpretation. Some of the points in favor of the theory that the plain is an ancient peneplain dissected by erosion in subsequent cycles have been touched upon indirectly in the analysis of the cuesta theory. However, for the sake of definiteness and completeness they are listed below.

(1) The plain includes many upland surfaces so large and so nearly flat that some effective agent of transportation, such as streams, must have operated there in order to remove the large amount of material which originally existed at higher levels. (2) The plain has a slope of about 3 to 5 feet per mile in a general southeasterly direction. Its slope is notably different both in direction and amount from the dip of the strata. (3) The general southerly slope of the plain is obscured locally by irregularities such as old erosional surfaces show. Even locally the slopes of the plain are not parallel with rock structures. (4) The plain bevels the edges of rock formations irrespective of their hardness. (5) In the formation of the plain, thicknesses of rock have been removed, which decrease regularly from north to south, bearing evidence that some sort of a grade was established where the tops of the cuestas now are. (6) The existence of certain continuous north-south ridges

connecting the cuestas, such as the divide from Cashton to Prairie du Chien, described above (Fig. 17), seem to suggest that there was once a plain on non-resistant, as well as resistant material. These connecting ridges are apparently remnants of an upland surface once continuous across inter-cuesta areas. (7) If the Dodgeville plain is an old peneplain there is no necessity for conceiving that the divides have been reduced by hundreds of feet in a cycle of erosion in which the streams have scarcely reached grade. (8) There are distinct erosion remnants standing on the plain, far from present drainage lines. In some cases these remnants consist of material which is more resistant than that outcropping on the adjacent plain. In other cases the rock of the remnant and the rock of the plain are the same. There seems to be no reason why these divides should have been reduced in such a way as to leave remnants above their general flat surfaces, unless the streams reached grade at or near the levels of these surfaces. (9) The presence of stream deposits at many places on the plain not only appears as a fatal objection to the single cycle theory, but it seems practically to demonstrate that the Dodgeville plain is a raised peneplain. (10) Both Cretaceous sediments west of the Driftless Area and Tertiary deposits to the south must have been derived at least partly from erosion in the Driftless Area and both bear evidence that the land of their sources was low and approaching the peneplain stage. (11) The fact that Tertiary deposits of the great Mississippi embayment, extending north toward the Driftless Area, lie in a gently sloping plain which, if projected, would coincide with the Dodgeville plain, is distinctly in favor of the peneplain theory. (12) As will be explained more fully within the next few pages, there are lense-shaped bodies of the softer formations underlying the Dodgeville plain in two or three places, which show that the surface over them was brought to grade. (13) In addition there are within the Driftless Area other strong evidences of more than one cycle of erosion, yet to be described, which in combination with the even-crested summit areas increase the value of these upland flats as evidences and the combination demonstrates that the surface has been eroded in more than one cycle.

Objections which might be advanced to the peneplain theory have been expressed by Martin[1]. Each objection is now to be considered.

(1) Doubt is expressed if the various areas of upland surface making up the plain are large enough, flat enough, close enough together, and sufficiently accordant in their levels to warrant the conclusion that they are the remnants of a once continuous peneplain. As was brought out in Part I, there is no definite degree of flatness which a surface must assume before it can be called a peneplain. Also there are various ways in which such a surface may be made irregular in the second cycle. It is not believed that the Dodgeville plain was degraded to such extremes that the surface was altogether flat. There were doubtless many gently sloping valley walls as well as valley flats. Not all the tributary streams far from the main drainage lines had low gradients. And the facts remain that there are some upland surfaces which are essentially flat; that the upland areas are large enough and numerous enough to furnish thousands of acres of farm land which is notably flat; that the highest recorded slope on the plain is less than 11 feet per mile and the average slope less than 4 feet per mile; and that the Dodgeville plain includes more and larger areas of flat land and is represented by more nearly accordant levels than the Kittatinny peneplain of the Appalachian mountains, the Tertiary peneplain of Idaho or the Miocene peneplain of the Sierra Nevadas.

(2) Martin gives some consideration to the time involved in the erosion of the area and concludes that, although there has been sufficient time since the late Paleozoic for the formation of a peneplain, there has also been time for the destruction of such a plain. The writer does not see that the time involved furnishes points either in favor of or against the peneplain or cuesta theory. So far as the duration of time is concerned, several peneplains could have been formed and destroyed during the Mesozoic and Ceno-

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[1] Martin, Lawrence, Bull. No. 36, *Wis. Geol. and Nat'l Hist. Surv.*, pp. 64-68.

zoic eras. There is, however, no indication in this that some relatively recent peneplain, such an one completed in late Tertiary, could not to-day be represented by remnants.

(3) Believing that sediments must have been derived from the surface of the Driftless Area in the formation of the Dodgeville plain, and not certainly finding such sediments in the Devonian and Carboniferous rock adjacent to the Area, Martin objects to the peneplain theory. Clearly he is laboring under a misconception as to the age of the plain. Whether or not it is an old peneplain, its surface is much younger than the Paleozoic. All of the Paleozoic formations, including the Devonian and Carboniferous are known to be bevelled by the Dodgeville plain south and west of the Driftless Area. Most of those who have previously interpreted it as a peneplain have assigned it to the Cretaceous and the writer will later in the paper present evidence for the late Tertiary age of the plain. Most likely then the sand, silt, and clay derived in the formation of the Dodgeville plain were carried westward into the Cretaceous sea, or most likely southward into the Tertiary embayment. Indeed, both the Cretaceous and Tertiary systems contain materials which must have been derived from erosion in the Driftless and adjacent areas during these periods, and there is evidence that peneplanation was in progress. Thus by reference of the Dodgeville plain to its proper geological period Martin's point of objection to the peneplain theory is converted into an additional argument in favor of that theory.

(4) It is true, as pointed out by Martin, that the Devonian and Carboniferous rocks lie on surfaces of less relief than that of the Driftless Area, and that this does not show that the peneplain of the Driftless Area is projected to lie beneath these sediments. However, it is not to be considered in any way as an objection to the peneplain theory. The plain is clearly much younger than any Paleozoic system. If the Cretaceous or Tertiary sediments could be proven to lie on a projection of the Dodgeville plain, strong evidence would be offered that it is a peneplain. The Cretaceous rocks of Minnesota are bevelled by the plain and

therefore do not lie on its projection. Salisbury[1] has presented evidence that the plain does slope down beneath the Tertiary deposits of the lower Mississippi valley and that those deposits lie on a plain similar to and continuous with the Dodgeville plain in the Driftless Area. This point affords strong evidence in favor of the peneplain theory.

(5) Martin concludes his objections to the peneplain theory by stating that there are no wedge-shaped bodies of non-resistant rock overlying the south-dipping resistant layers, as there should have been when the Dodgeville peneplain was undissected. He agrees, however, that these wedges could have been removed by the rejuvenated streams. Their absence, therefore, is no objection to the peneplain theory, but is in harmony with the cuesta, as well as with the peneplain theory.

As a matter of fact, but apparently unknown to Martin, there are just such wedges of St. Peter sandstone north of the Platteville-Galena cuesta in Wisconsin, and Maquoketa shale north of the Niagara cuesta in Iowa. Fig. 5 affords an illustration of the St. Peter wedges. Other illustrations are found in the south part of the Richland Center quadrangle, where ever-increasing thicknesses of St. Peter cap the north-south divides to the foot of the Platteville cuesta, where the full thickness of the St. Peter is represented. In Iowa the south rim of the valley of Turkey river, south of Osterdock, is underlain by a few feet of Maquoketa shale which dips south with the Galena dolomite below. Along a road which follows a flat-topped divide southward, the Maquoketa gradually thickens until its full thickness is found at the foot of the Niagara escarpment. Martin says: "They (the wedge-shaped bodies) would furnish excellent evidence of previous baselevelling, but no such remnants are known to exist." Now that such lenses of non-resistant material have been discovered, this point is transferred from the unfavorable to the favorable column for the peneplain theory.

In conclusion it may be said that the summit areas in

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[1] Salisbury, R. D., *Bull. Geol. Soc. Am.*, Vol. 3, pp. 183-186, *Jour. Geol.*, Vol. III, pp. 655-667.

the Driftless Area, after analysis, seem almost certainly to be remnants of a peneplain uplifted since its formation and now almost entirely destroyed by the rejuvenated streams. And yet demonstration of the multiple cycle theory does not rest on this evidence alone. It remains to be seen whether there are other indications of more than one cycle and whether there is a *combination* of evidence which actually proves the case.

Intermediate Plain (the Lancaster plain)

At many places in the Driftless Area there are isolated areas and more or less continuous surfaces, sharply set off from the remnants of the Dodgeville plain, but forming divides several hundred feet above drainage. Though similar in most respects to the summit surfaces, these flat-topped but lower divides occupy a position intermediate between the remnants of the Dodgeville plain and the valley bottoms. If the tops of these intermediate divides were projected across the valleys and across the areas where remnants of the Dodgeville plain exist, a plain similar to the Dodgeville plain would be formed, having a general altitude approximately 200 feet lower than the Dodgeville plain. This is the more conspicuous of the two upland plains, and is the one about which most has been written.

Various names have been applied to this plain by different writers. It is Hershey's[1] plain No. 1. Grant and Burchard[2] named it the Lancaster Plain. The writer[3] called it the Galena Plain in Jo Daviess County, Illinois. In Iowa it has been called the Lower Plain or Plain No. II[4]. Shipton[5] called it the Sparta Plain and Hughes[6] assigned to it the name Limeridge Plain. The surface is as well developed in the neighborhood of Lancaster, Wisconsin, as anywhere, and therefore the name assigned by Grant and Burchard is retained for this plain.

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1. Hershey, O. H., *Am. Geol.*, Vol. 20, pp. 246-268.
2. Grant, U. S. and Burchard, E. F., *Lancaster-Mineral Point Folio, U. S. Geol. Surv.*, p. 2.
3. Trowbridge, A. C., *Jour. Geol.*, Vol. 21, pp. 739-741.
4. Howell, J. V., *Iowa Geol. Surv.*, Vol. 25, pp. 59-60.
5. Shipton, W. D., *Geology of the Sparta Quadrangle*, unpublished thesis in library of University of Iowa, p. 57.
6. Hughes, U. B., *Geology of the Richland Center Quadrangle*, manuscript in preparation.

Portions of the Lancaster Plain are known in the northern part of the Sparta quadrangle at an average altitude of 1100 feet; in the Baraboo district at 1200 feet; in the northern and central portions of the Richland Center quadrangle on divides sloping southward from 1200 to 1100 feet; in the central and southern portions of the Lancaster and Mineral Point quadrangles at levels varying from 1100 to 1000 feet; in the northern and central portions of the Galena and Elizabeth quadrangles, Illinois, sloping southward from 1000 feet to 900 feet; in southeastern Minnesota at altitudes of about 1200 feet; and in northeastern Iowa from the Minnesota line at an altitude of 1100 feet to Dubuque, where it lies at and around 900 feet altitude. The best general view of the surface may be obtained from the Mississippi river between Bellevue, Iowa, and La Crosse. Along this whole extent of river the immediate rim of the Mississippi valley appears to be almost a horizontal line except where broken by tributary valleys. Nowhere does the Dodgeville plain come to the edge of the bluff, although, near Turkey river and Prairie du Chien, remnants of the higher plain are close enough to be visible from the river and appear as monadnocks standing above the plain which forms the rim of the valley.

On the whole, the Lancaster plain is represented by upland surfaces which are more numerous, larger, closer together, and more nearly continuous than the summit areas which constitute the remnants of the Dodgeville plain. In the Sparta quadrangle, the Lancaster plain is represented by a series of narrow divides above which stand conspicuous remnants of the Dodgeville plain such as Castle Rock and Balls Bluff. In the Baraboo district portions of the lower plain include the general flat crest of the North quartzite range at Ableman and at the Lower Narrows, broad, poorly drained divides between north flowing and south flowing, streams on the south range, and flat benches on the south range, such as the one at 1200 feet 2 miles northeast of Denzer. Just north of the Wisconsin river the plain is best shown on the crests of north-south divides, such as the divides between Pine, Bear, Narrows, and Honey Creeks, on which are located the main roads of the district, hundreds of prosperous farms, and the villages of Limeridge, Sandusky, and Loreto. Wide areas of the plain are found at or near Blake Prairie, Diamond Grove, Rockville, Hurricane, Lancaster, (Fig. 19), Liberty Ridge, Jamestown, and Cornelia in the Lancaster quadrangle, and near Livingston, Rewey, Belmont, Cuba, and Fayette in the Mineral Point quadrangle. In these two quadrangles the surfaces representing the Lancaster plain are long and broad, and are utilized extensively for various sorts of human activity. Most of the surfaces are north-south divides or east-west projections of north-south divides. In the Elizabeth quadrangle in Illinois there are large areas of this intermediate plain, the most conspicuous of which are south of Apple River and northwest of Stockton, (Figs. 20 and 21), where there are surfaces 1x1½ miles

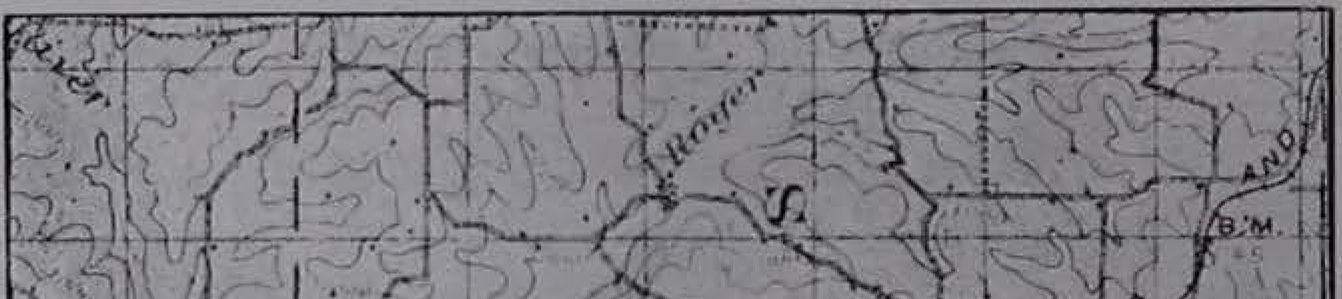

Fig. 19. A portion of the Lancaster topographic map showing the extent and distribution of the Lancaster plain in its type locality.

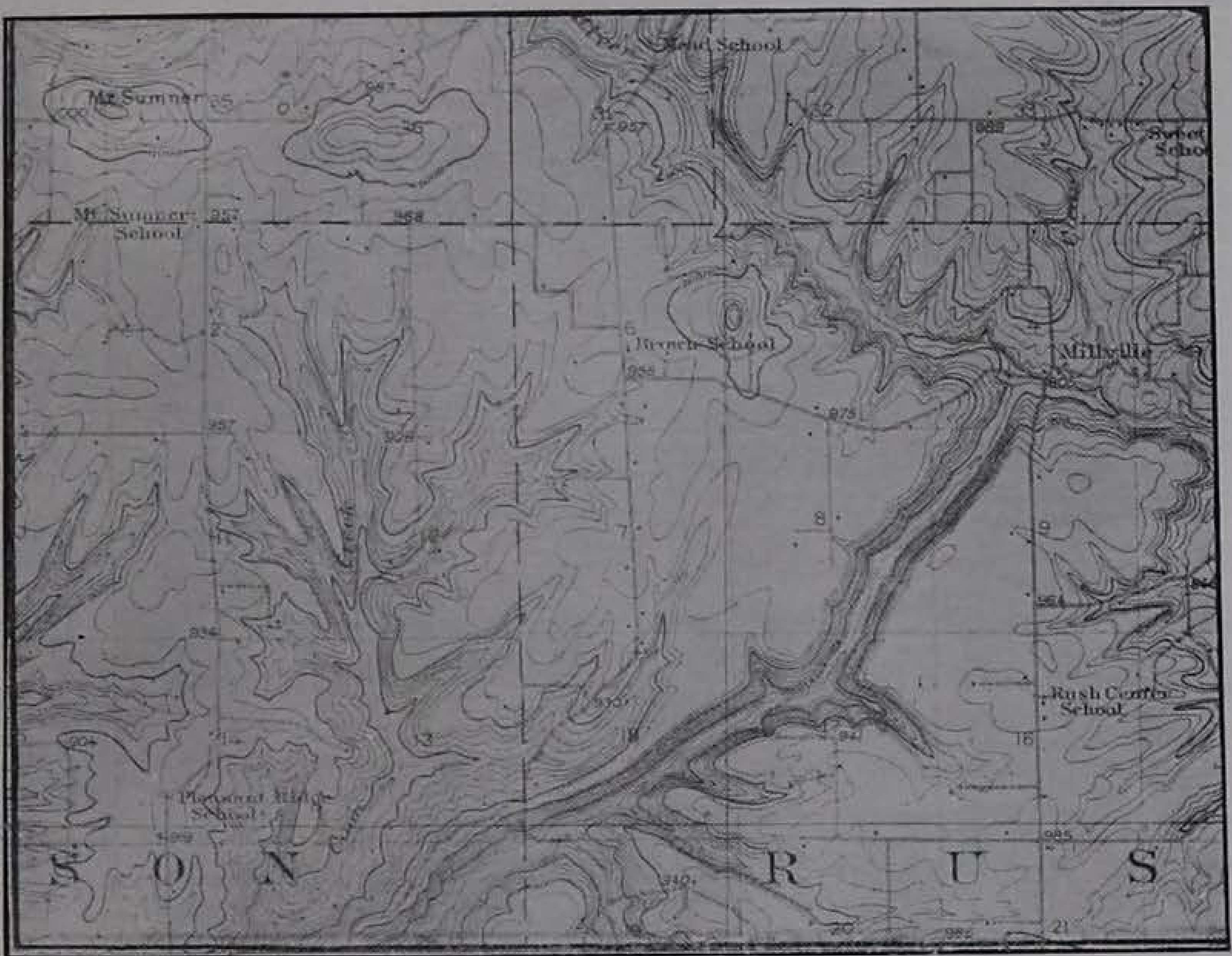

Fig. 20. A portion of the Elizabeth topographic map where the Lancaster plain is exceptionally well represented.

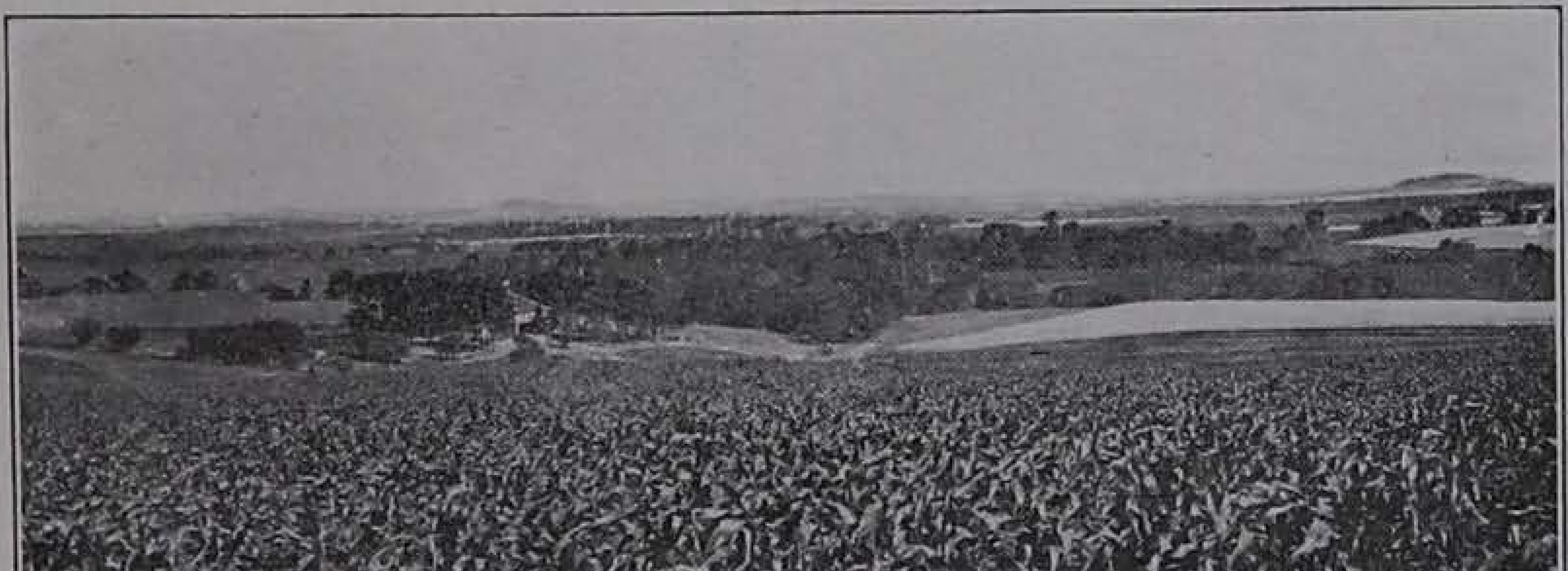

Fig. 21. View of the Lancaster plain in Jo Daviess County, north of Stockton, Illinois. The elevations in the distance are the "mounds" which are monadnocks on the plain. Below the general surface, there are valleys more than 200 feet deep.

in extent. These surfaces have maximum relief of less than 10 feet and are poorly drained. Above them stand conspicuous monadnocks, and below them are abrupt valleys more than 100 feet in depth. The Lancaster plain is represented in the Galena quadrangle by the divides between Sinsinawa and Galena rivers, used as the site of the Hazel Green Pike road, and the divide between Galena River and Smallpox Creek. The tops of these divides consist of flat surfaces or gentle slopes. They average 900 feet above sea, 300 feet above present drainage, and 150 feet below the tops of the mounds which stand conspicuously upon them. In Iowa most of the tops of the divides within eight or ten miles of the Mississippi River are to be correlated with the Lancaster plain; for instance, the divides between Upper Iowa River and the Minnesota line, between Clear Creek and Village Creek, Village Creek and Paint Creek, Paint Creek and Yellow River, Yellow River and Bloody Run, Bloody Run and Sny Magill Creek, the divides north and south of Yellow River, etc. (Figs. 22 and 26). The plain is also represented in the vicinity of Dubuque. The Lancaster plain in the Minnesota portion of the Driftless Area

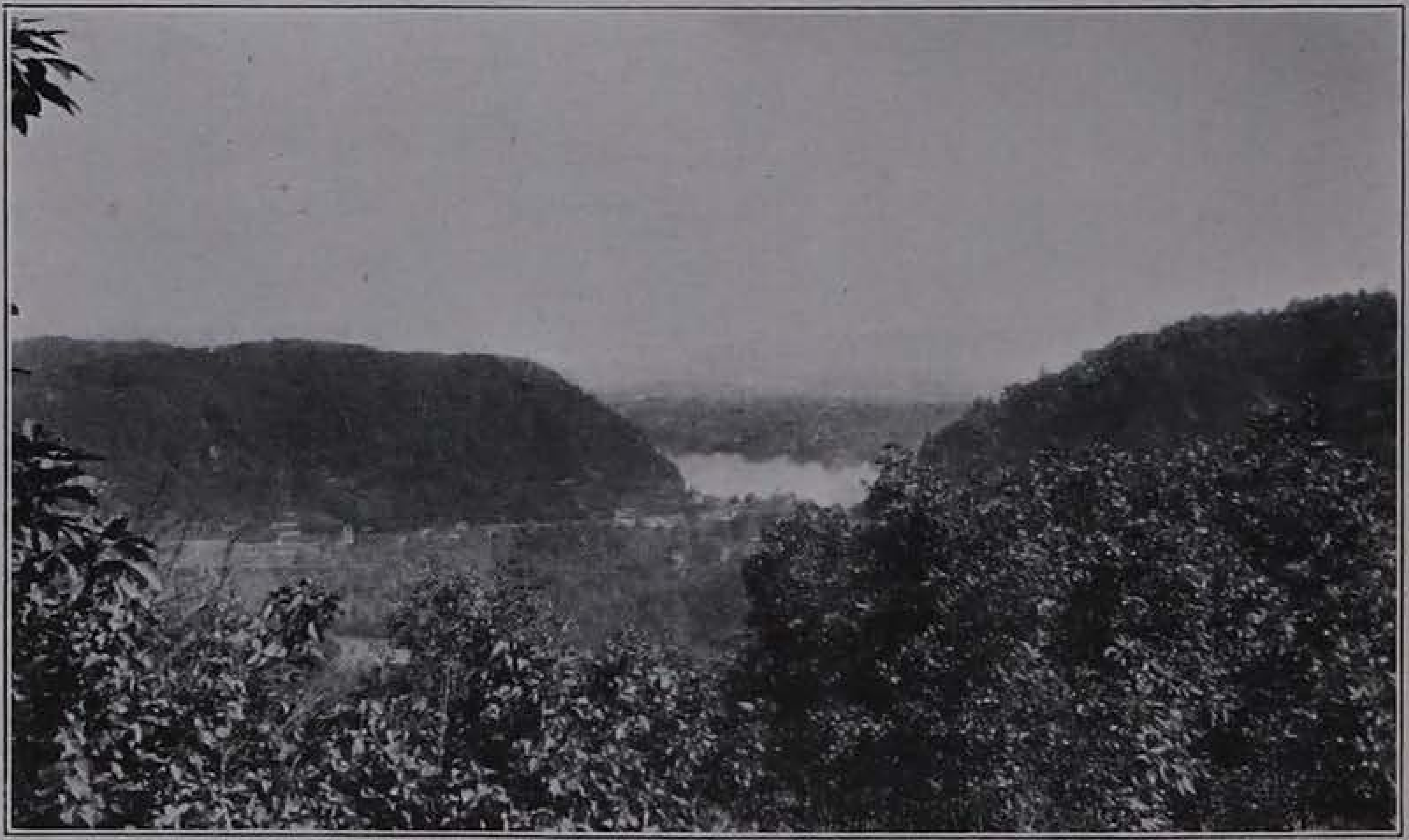

Fig. 22. View of the Lancaster plain and the gorges below it, as seen near Waukon Junction, Iowa.

forms gently rolling intermediate surfaces, so extensive and so nearly flat as to be known locally as "prairies." Areas representing the plain here are known south of Preston and in other portions of Fillmore county, in Houston county south of Root river near Caledonia, in nearly all parts of Winona county and in the southeastern portion of Wabasha county. Though the areas are most extensive away from the Mississippi river, representatives of it are known right to the edge of the river gorge.

As in the case of the Dodgeville plain, the Lancaster plain lies on different rock formations at different places. North of the Prairie du Chien cuesta in Wisconsin it lies on the Cambrian sandstone, in Minnesota on Platteville, St. Peter and Prairie du Chien, south of the Prairie du Chien cuesta on the Prairie du Chien and St. Peter formations, south of the Platteville-Galena cuesta on the Galena and Maquoketa formations. In general, the farther north a portion of the plain is the older the formation, and the lower the part of the formation on which it lies. Progressively younger rocks are bevelled by the plain toward the south.

The Lancaster plain slopes in a general southerly direction at an angle less than the angle of dip of the strata. The details in the relations of the plain and the structure south of the anticlinal axis are shown in the table on page 90.

The computations, the results of which appear in the table, show that there is a marked parallelism of plain and strata in several of the individual districts, such as the Richland Center, Sparta and Mineral Point quadrangles, but that in other districts and where greater distances are involved, this parallelism fails. It is notable that all the local estimates show the intermediate surface sloping in directions west of south, which is the direction of dip of the strata and that those estimates including more widely separated points on the plain show a general slope east of south. Considering only the local districts the plain appears to have an average slope of 10.9 feet per mile in the direction S 17°W and the strata dip S 28°W at an angle of 16.6 feet per mile. Over the larger areas the average direction

TABLE OF RESULTS OF COMPUTATION OF DIP AND STRIKE OF LANCASTER PLAIN AND ROCK STRATA

General Location	Location of Points	Direction of dip of plain	Amount of dip of plain; ft. per mi.	Direction of dip of strata	Amount of dip of strata; ft. per mi.
North part Richland Center Quadrangle	A-Limeridge B-3½ miles south Loreta C-2½ miles N.E. Richland Center	S 25°W	7.6	S 15°W	7.6
North part Sparta Quadrangle	A-1 mile south of Castle Rock B-Center Sec. 3 Burns Twp. C-W. C. Sec. 23 Burns Twp.	S 80°W	12.5	S 59°W	14.
Lancaster Quadrangle	A-Blake Prairie B-Lancaster C-Near Jamestown	S 26°W	8.9	S 29°W	34.
Mineral Point Quadrangle	A-Rewey B-Cuba C-Fayette	S 9°W	7.3	S 9°W	9.1
Galena Quadrangle	A-S. Sec. 24 Vinegar Hill Twp. B-Galena C-N. E. Sec. 23 Galena Twp.	S 46°W	27.2	S 13°W	13.9
Elizabeth Quadrangle	A-Foot of Hudson Mound B-Warren C-C Sec. 9 Rush Twp.	S 8°W	8.	S 20°W	9.8
Waukon Quadrangle in Iowa	A-4½ mi. W. of New Albin B-3 mi. S. E. of Lansing C-3 mi. S. E. of Watson	S 77°E	5.1	S 51°W	27.6
Iowa-Wisconsin	A-Near New Albin B-Near Watson C-Near Bloomington	S 42°E	2.1	S 22°W	15.
Wisconsin-Iowa-Illinois	A-Near Sparta B-Near New Albin C-Near Stockton	N 89°E	3.1	S 7°W	9.4
Wisconsin-Iowa	A-Near Sparta B-Near Bloomington C-Near New Albin	S 82°E	4.	S	9.4
Wisconsin-Iowa	A-Near Denzer B-Near Bloomington C-Near New Albin	S 16°W	2.8	S 11°W	11.
Wisconsin-Iowa-Illinois	A-Near Loreta B-Near Watson C-Near Stockton	S 1°E	3.	S 19°W	11.6

of slope of the plain is S 40°E and the average amount of slope 3 feet per mile, while the corresponding figures for the strata are S 12°W and 11.3 feet. Including the results of all the estimates, both local and general, the plain slopes S 11°E to an amount of 7.6 feet to the mile and the strata dip S. 20°W, 14.4 feet per mile. The plain and the strata fail of parallelism by 31° in direction and 6.8 feet per mile in dip.

In the literature of the subject the Lancaster plain and the Dodgeville plain have in some cases been confused; indeed there has been some doubt expressed that they are really distinct. In his criticisms of the peneplain theory to explain the accordant divides of the Driftless Area, Martin[1] assumes two cases: (1) that there are four upland plains, one for each cuesta, and (2) that there is but one upland plain. He does not consider the problem of two upland plains and appears to believe that all the upland surfaces form a single plain, if indeed they may be said to form plains at all. This confusion doubtless grows out of the fact that there are places where the summit plain only is found and places where only the intermediate plain occurs. In such latter places the Lancaster plain could easily be mistaken for a summit plain. There are also some localities within the Driftless Area in which both plains occur and where they appear to grade into each other.

And yet the summit plain and the intermediate plains are distinct. The evidences are as follows: (1) In most portions of the Driftless Area, as between Waukon and the Mississippi river (Fig. 23), and in the district south of Turkey river in Iowa, in the Galena and Elizabeth quadrangles in Illinois, in the northern and central portions of the Lancaster and Mineral Point quadrangles, in the Richland Center quadrangle, in the Baraboo district and in the Sparta quadrangle in Wisconsin, and in Minnesota both plains are found and in most of these places the lower plain is so sharply set off from the upper one that the two can be distinctly seen in any general view. (2) Even in districts where intermediate levels seem to grade into sum-

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[1] Martin, Lawrence, Bull. No. 36, *Wis. Geol. and Nat'l Hist. Surv.*, pp. 66-67.

mit levels, careful inspection brings out distinct differences in altitude between the two plains. For instance, the Lancaster plain around Lancaster, seems, on casual observation, to grade into the Dodgeville plain on the summit of Military Ridge. Grant and Burchard[1] included Military Ridge and the area around Dodgeville with the Lancaster plain. However, there are many views obtainable in which Military Ridge stands distinctly above the intermediate levels and carefully drawn profiles show the two plains to be distinct[2] (Fig. 24). (3) Where both plains are represented in the same locality, they lie at different stratigraphic horizons, either within the same formation or in different formations, although in practically all cases both lie on resistant rock. (4) If the Lancaster plain be projected from districts where the Dodgeville plain is missing into areas where the Dodgeville plain occurs it is found to lie distinctly below the Dodgeville plain. Similarly the Dodge-

Fig. 23. View east of Waukon, Iowa, showing both the Dodgeville and Lancaster plains. The picture was taken from the Dodgeville plain which shows in the foreground and forms the skyline. The general topography which forms the rims of the valleys in the middle distance is the Lancaster plain.

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[1] Grant, U. S. and Burchard, E. F., *Lancaster-Mineral Point Folio, U. S. Geol. Surv.*, p. 2.

[2] Hughes, U. B., *Proc. Ia. Acad. Sci.*, Vol. 23, p. 131.

ville plain projected from cuesta to cuesta, lies on the average 200 feet higher than the Lancaster plain in the inter-cuesta areas. (See Figs. 14 and 23). (5) Where both plains are found together the change from one to the other takes place either along lines parallel with or oblique to the strike. (6) There are many places along the main south-flowing streams, for instance, along the Mississippi river, where upland surfaces representing the Lancaster plain can be traced continuously from an inter-cuesta area across a cuesta, on the summits of which the Dodgeville plain is represented, to connect definitely with the Lancaster plain in another inter-cuesta area (Fig. 25). There are lines along which the Lancaster plain is unbroken by remnants of the Dodgeville plain for the whole north-south extent of the Driftless Area. (7) If it be assumed that the Lancaster plain in an area south of a Dodgeville cuesta is merely the projection of the Dodgeville plain down the dip of the strata, so that the two plains together form the gentle southerly slopes of normal cuestas (Fig. 16), three points located so as to include both plains, should show a surficial slope parallel with stratigraphic dips. That this assumption is not true is shown by the table on page 95, in which both plains are represented in each computation. Nowhere do the slopes of the surface and the dips of the strata coincide.

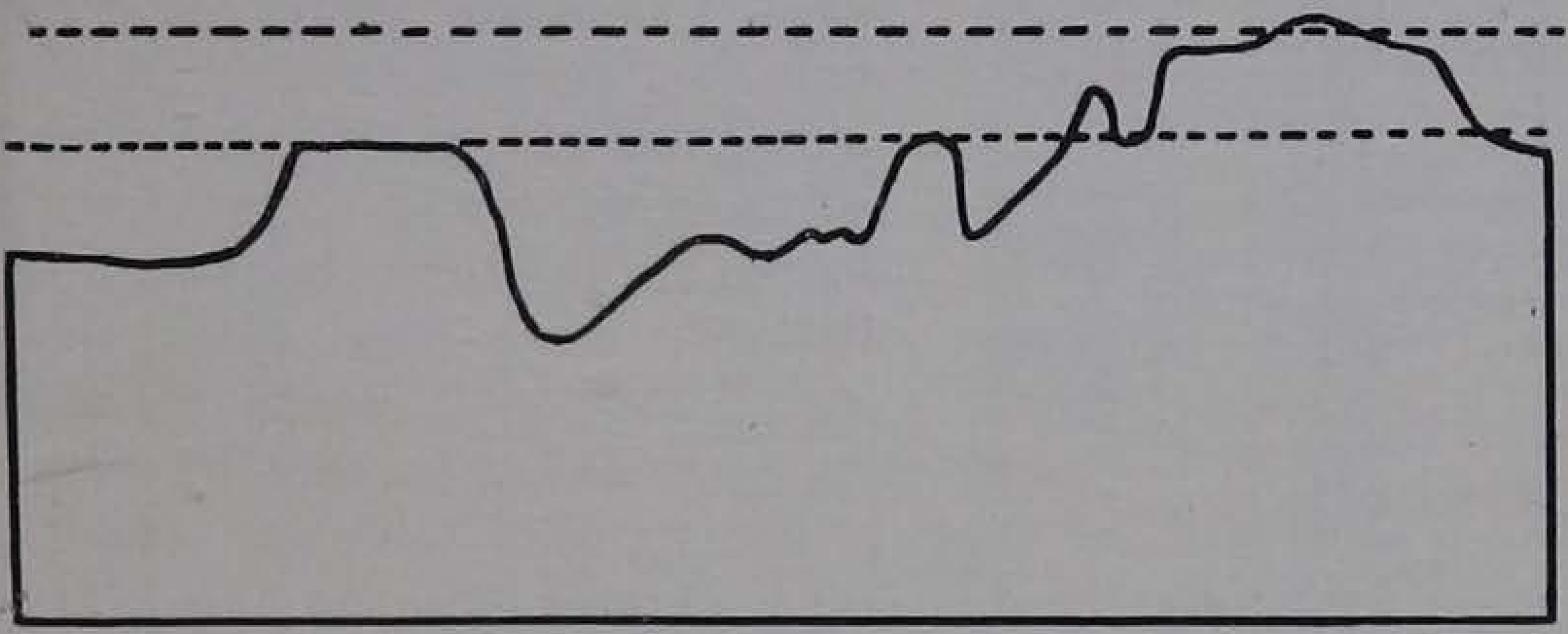

Fig. 24. A profile from Mt. Ida on the Dodgeville Prairie south across a portion of the Lancaster plain. The profile makes it clear that two plains are represented. (After U. B. Hughes).

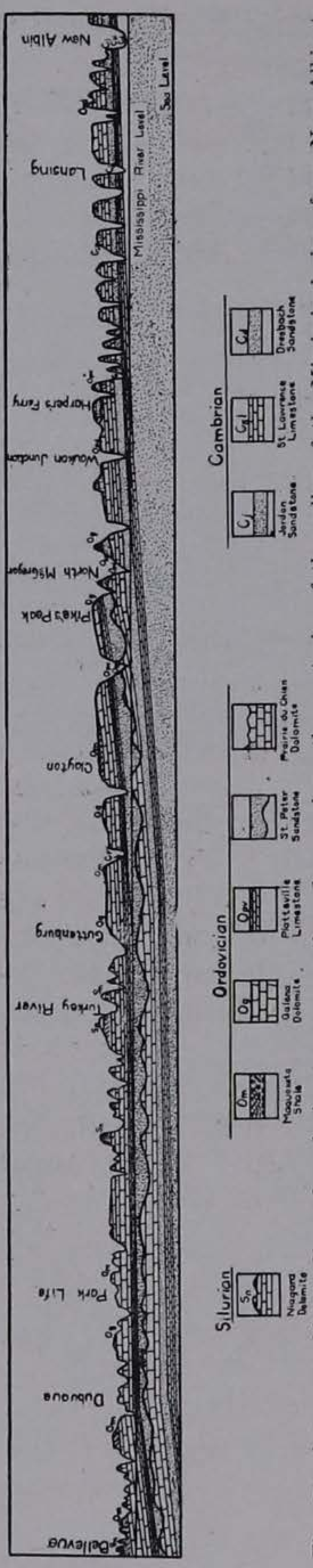

Fig. 25. A topographic profile and geologic structure section, drawn along the west rim of the valley of the Mississippi river from New Albin to Bellevue. The horizontal distance is 150 miles. The vertical scale is exaggerated.

Obviously the Lancaster plain is not an original marine plain of deposition, neither was it formed by marine denudation. Lying as it does here at one stratigraphic horizon and there at another, it cannot be a simple structural plain. Because the Lancaster plain is represented by many broad, flattish, intermediate surfaces close enough together to warrant correlation; because it is distinct from the Dodgeville plain; because it has a general southerly slope; because its slope is not parallel with the underlying strata; because the plain bevels the edges of the strata; because its surface has about the degree of irregularity and slope which a peneplain should have; because it is not confined to cuesta belts but has a wide distribution in the inter-cuesta areas the Lancaster plain seems even more surely to be a true peneplain than is the Dodgeville plain. It cannot be held to be a series of unrelated cuestas. The Lancaster plain, therefore, is believed to be a true peneplain, younger than the Dodgeville plain, uplifted since its formation, and now approaching thorough dissection in the present cycle of erosion. For an additional illustration of the features on which this belief is based, see Fig. 26. It should not be understood that this surface was

COMPUTATIONS SHOWING THE RELATION BETWEEN THE SLOPE OF A PLAIN MADE BY THE COMBINATION OF THE DODGEVILLE AND LANCASTER PLAINS AND THE DIP OF THE STRATA

General Location	Location of Points	Direction of slope of plain in ft. per mi.	Amount of slope of plain	Direction of dip of strata	Amount of dip of strata in ft. per mi.
Lancaster Quadrangle	A-Fennimore (Dodgeville plain) B-Blake Prairie (Lancaster plain) C-Rockville (Lancaster plain)	S 16°W	15.	S 27°W	22.8
Denzer-Sparta-Richland Center Quadrangles	A-Denzer (Dodgeville plain) B-Sparta (Dodgeville plain) C-Loreta (Lancaster plain)	S 41°W	40.	S 28°W	14.
Waukon Quadrangle in Iowa	A-Church (Dodgeville plain) B-3½ mi.S. E. of Lansing (Lancaster plain) C-3 mi. S. E. of Watson (Lancaster plain)	S 76°E	20.6	S 27°W	20.
Iowa-Wisconsin-Illinois	A-Near Graham, Iowa (Dodgeville plain) B-Lancaster, Wisconsin (Lancaster plain) C-Stockton, Illinois (Lancaster plain)	N 78°E	5.2	S 6°W	8.

flat before its uplift and dissection. Many remnants of the higher surfaces stood above it, and even its general lowland topography lacked much of being perfectly flat, as is true of all peneplains.

The Lancaster plain even considered alone, bears strong evidence in favor of the plural cycle theory. And there is corroborative evidence of other sorts which adds still further to the strength of the case thus far developed.

Antecedent Streams

The antecedency of streams and the nature and value of the evidence it bears on the erosional history of a region were discussed in Part I, pp. 21-24. Streams may become antecedent (1) by local warping of the strata and surface of a region after the course of the streams have been established, if the diastrophic warping takes place so slowly that the streams can degrade the up-warped areas as fast as they are uplifted, and thus hold their courses as conditions change, or (2) by the uniform uplift of a surface which has been reduced to grade and on which the streams have reached a final stage of adjustment, flowing by the most direct routes to the sea, provided again the streams hold their courses during and after uplift.

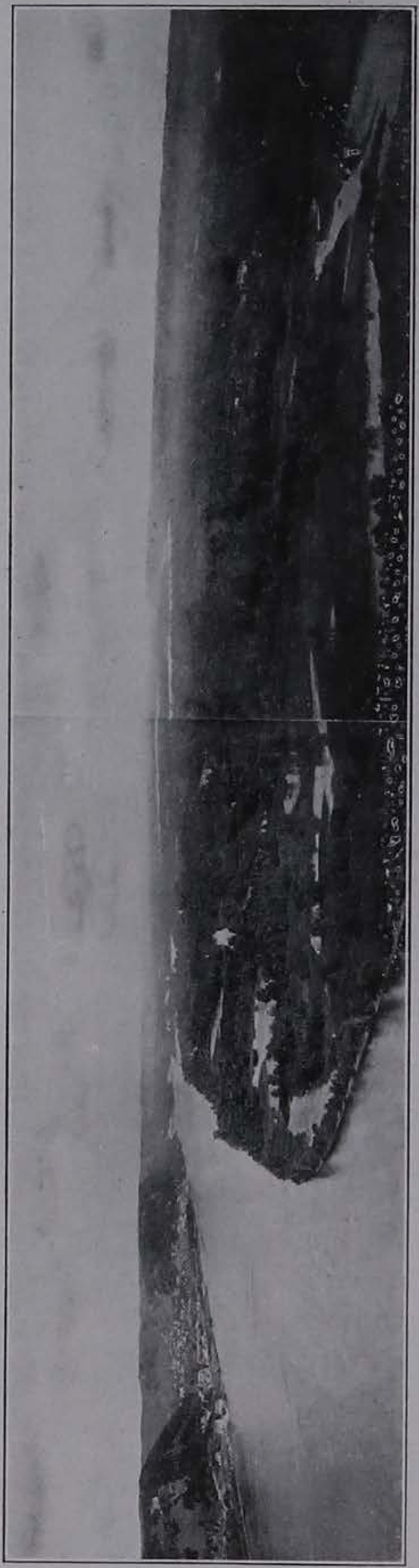

Fig. 26. A panoramic view looking up the Mississippi river toward Lansing, Iowa, and showing the flood plain and both valley walls. Note the even skyline on both sides extending into the distance. This is the Lancaster plain which definitely bevels formations of unequal resistance. (Photographed by Professor W. H. Norton).

By study of the Driftless Area it becomes reasonably certain that the tilting and slight warping which the strata have undergone antedated the establishment of the courses of the present streams, for all the structures are bevelled by the Dodgeville and Lancaster plains. Either the streams of the Driftless Area are in harmony with conditions of slope, resistance, and structure and with the stage of early maturity, or they are antecedent and have courses now which they acquired in some late stage of a previous cycle. If the streams are merely consequent it would seem that the surface of the Driftless Area is in its first erosional cycle. If they are antecedent they furnish valuable evidences of more than one cycle in the erosional history of the region. In case there has been but one cycle of erosion all the streams should be consequent; if there has been more than one cycle the larger streams are likely to be antecedent, having developed their courses in the first cycle and held them into the second, and the many tributary streams should have been developed in the present cycle and be consequent. The problem then involves especially the major streams.

Mississippi River

Study of the present course of the Mississippi river shows certain anomolies in its relations to original topography and structure, which are significant. These anomolies can be made most clear by a study of the various stages of adjustment which major streams should have in the normal erosional cycle under conditions existing in the Driftless Area, and by comparison of the course of the Mississippi river with these various stages, considering the present mature condition of the region.

As has been stated in previous pages, the strata south from La Crosse and Sparta dip in an average direction S 26°W to an average amount of 14.6 feet to the mile. But north of Winona along the Mississippi a dip in the opposite direction is recorded by conformable stratigraphic contacts which decline appreciably from Winona to Minneapolis. The average dip of the strata north of the arch, which seems to run through Galesburgh, Winona, and St. Charles, determined by taking the averages of four computations by means of the three point method is found to be N 35° W 9.3 feet per mile. The highest portion of the original surface, therefore, must have been near Winona and the surface must have sloped down to the north and to the south from the divide. In the knowledge that the formation of this arch antedated the establishment of the present course of the Mississippi river and that the various rock formations do not thin out appreciably in approaching the crest of the arch, it is possible to reconstruct the original surface for a line following the present course of the Mississippi river. This surface is found to lie at 960 feet at Bellevue, 1030 feet at Dubuque, 1520 feet at Prairie du Chien, 1850 feet at Lansing, 2000 feet at La Crosse, 1870 feet at Winona, and 1410 feet at Minneapolis. A section showing this original surface and the attitude of the strata beneath it for the whole length of the Mississippi river from Minneapolis to Bellevue is shown in Fig. 27.

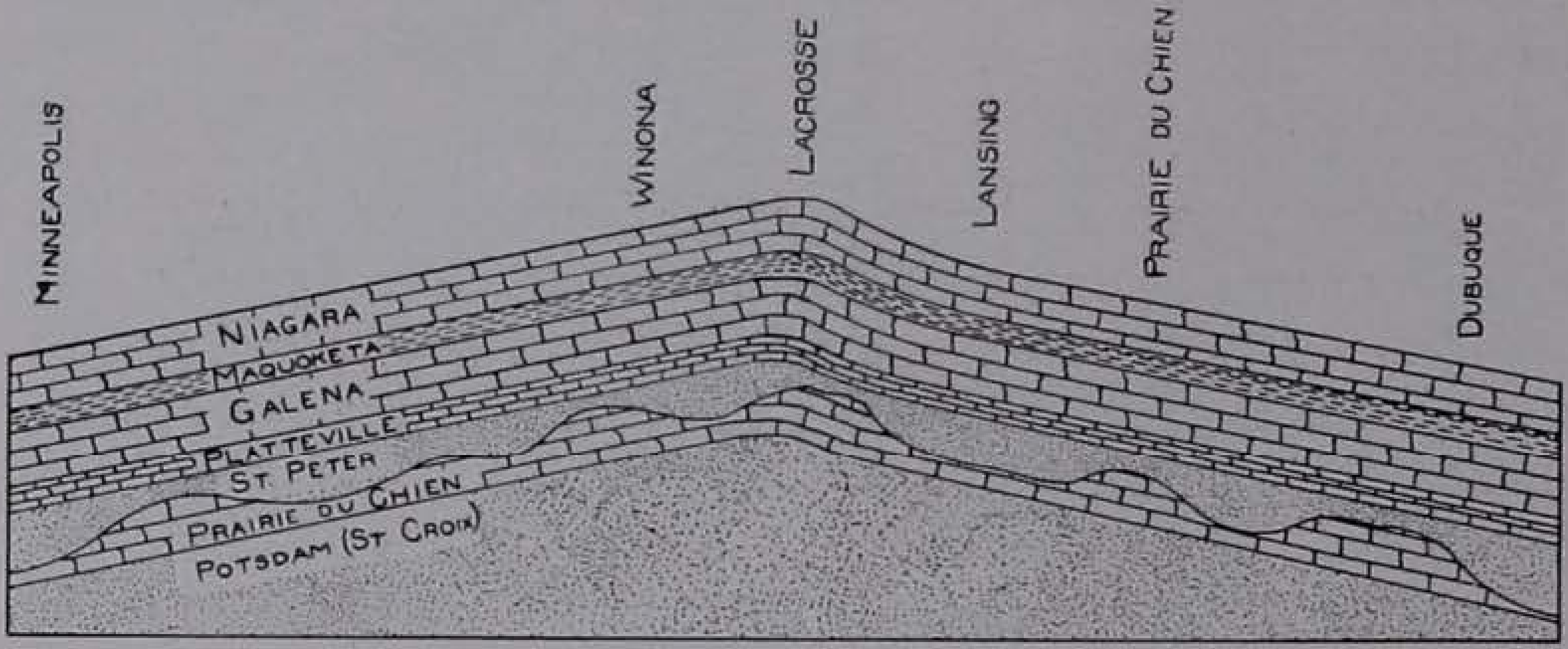

Fig. 27. A section showing the original surface of the Driftless Area and the structure of the strata along a line now followed by the Mississippi river. The total horizontal distance is approximately 250 miles. Vertical scale: 1 inch equals 360 feet.

Such a surface would be eroded by streams which would exhibit different stages of adjustment in different stages of the erosion cycle.

In the first stage of adjustment streams would form, flowing south and north from the crest of the arch. From the main streams, tributaries would develop which would curve headward up the slope of the plain toward the divide from either side. As all the streams in this first stage were flowing on the Niagara dolomite there were only slight differences in resistance, and the courses of the streams would be determined primarily by the topographic slopes which were in turn determined by the structure. The general northerly and southerly slopes from the axis of the arch were not steep, but are believed to have been steep enough to control the general courses of the streams. The details of the courses might be influenced by the minor structures such as anticlines, synclines, accentuations of the monocline, faults, joints, etc., by local irregularities in the surface, or by slight differences in resistance. The conditions during this first stage of adjustment are illustrated in Fig. 28.

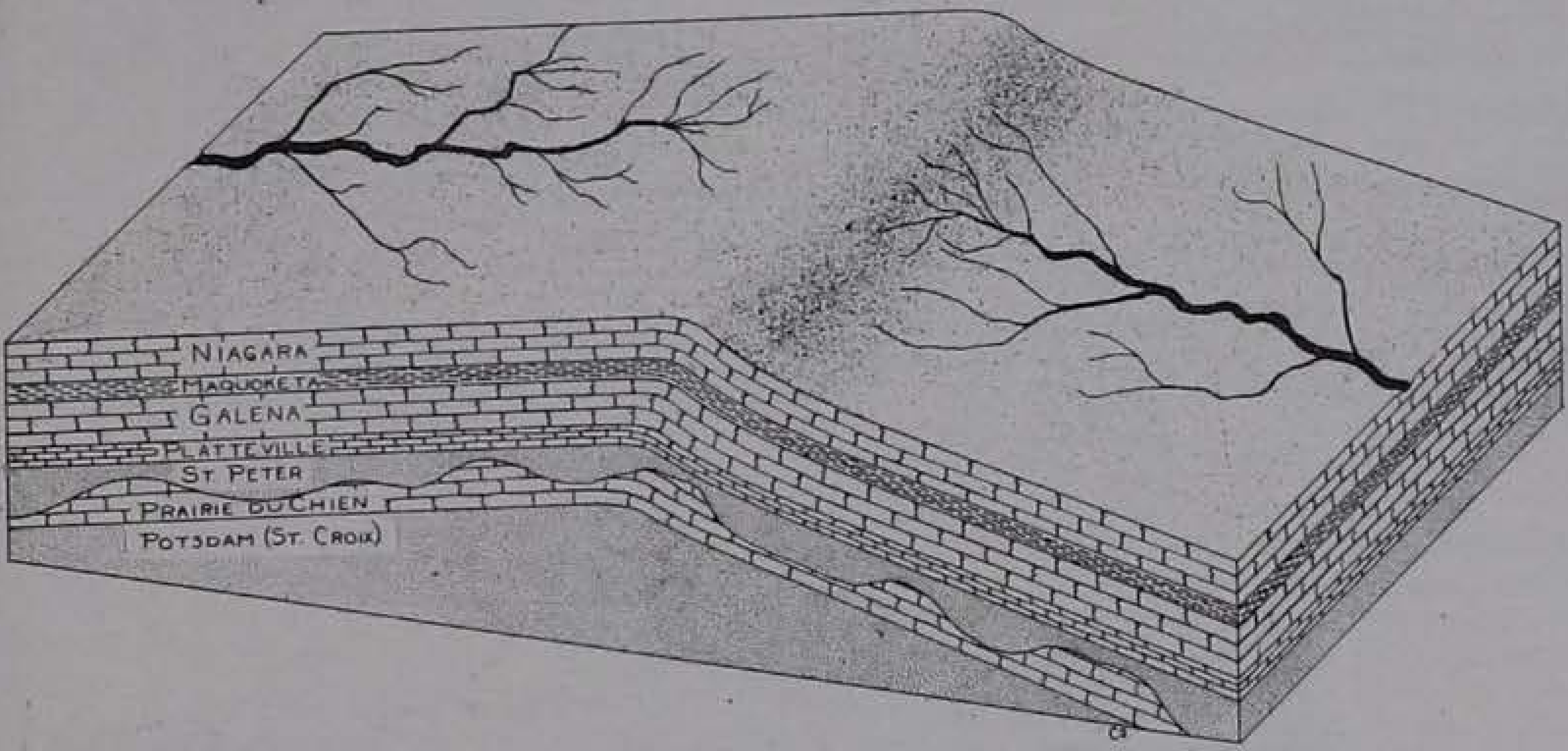

Fig. 28. Block diagram illustrating the drainage conditions in the Driftless Area, as they should have been in the initial stage of stream adjustment.

As the main streams on the two limbs of the arch cut downward they would, somewhere in their courses, penetrate the resistant Niagara dolomite and reach the relatively non-resistant Maquoketa shale. On this soft formation the main streams would develop broad valleys and would send out tributaries (Fig. 29).

When maturity of the erosion cycle was reached and the inter-valley divides had been made narrow, the south-flowing main stream, having greater volume, or a higher gradient, or flowing on less resistant material than the stream on the opposite side of the arch, might work headward through the main divide and steal water by reversion of the main stream flowing in the opposite direction. (Fig. 30). In this case it seems that the pirate stream would work headward down the course already established by the reversed stream, that is, in a line roughly parallel with the dip of the strata and with the original slope of the surface.

Finally when old age has been reached and the main streams have been reduced to grade throughout their courses, *and not before* that stream which has the shortest route to the sea would capture all the drainage and would adopt a course, which for the first time would be independent of structure and original slope and dependent upon the slopes of the graded plain. Some of the tributary streams, of which there would be few, might still be dependent upon structure (Fig. 31).

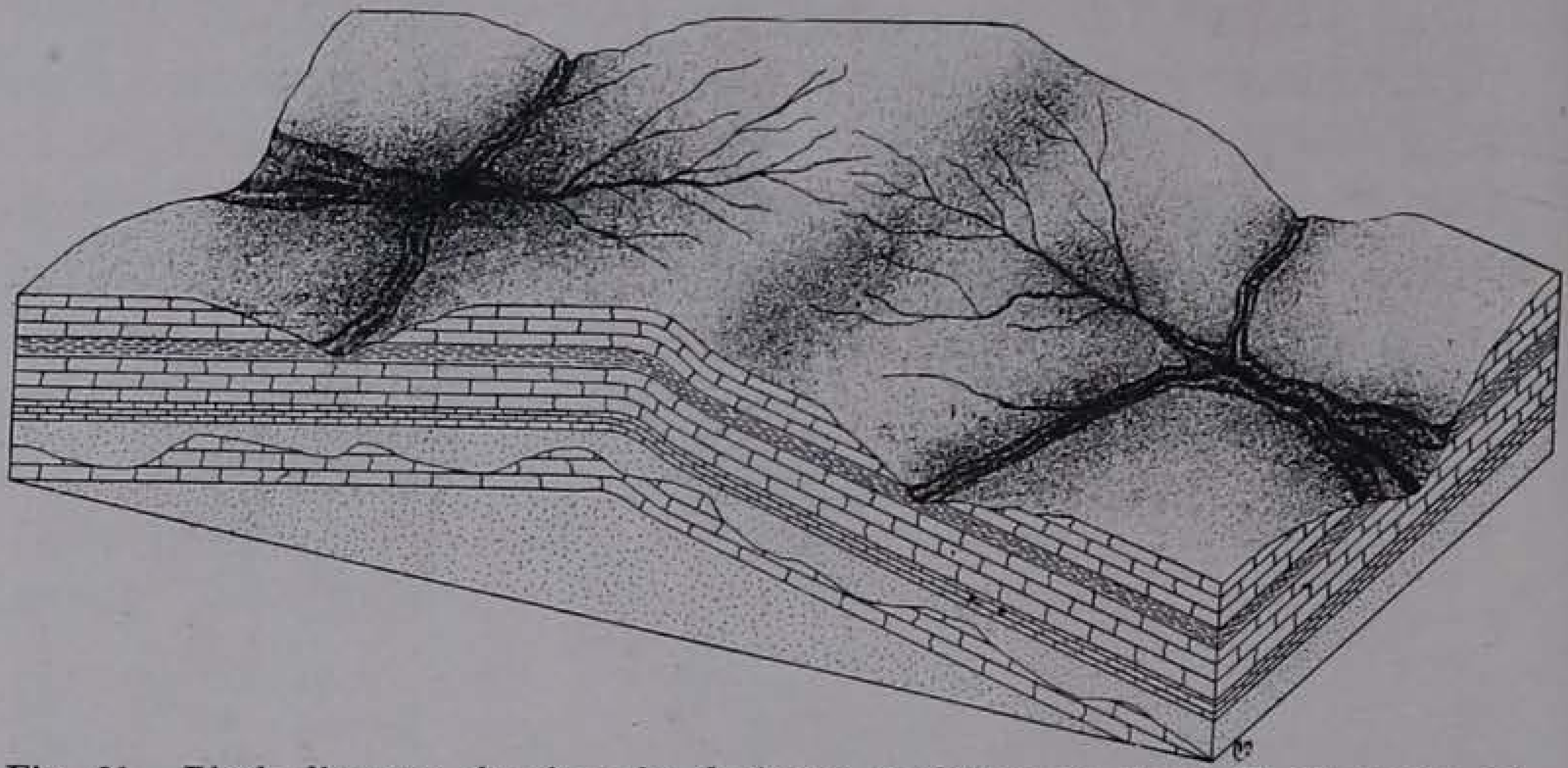

Fig. 29. Block diagram showing the drainage conditions in Stage II of stream adjustment.

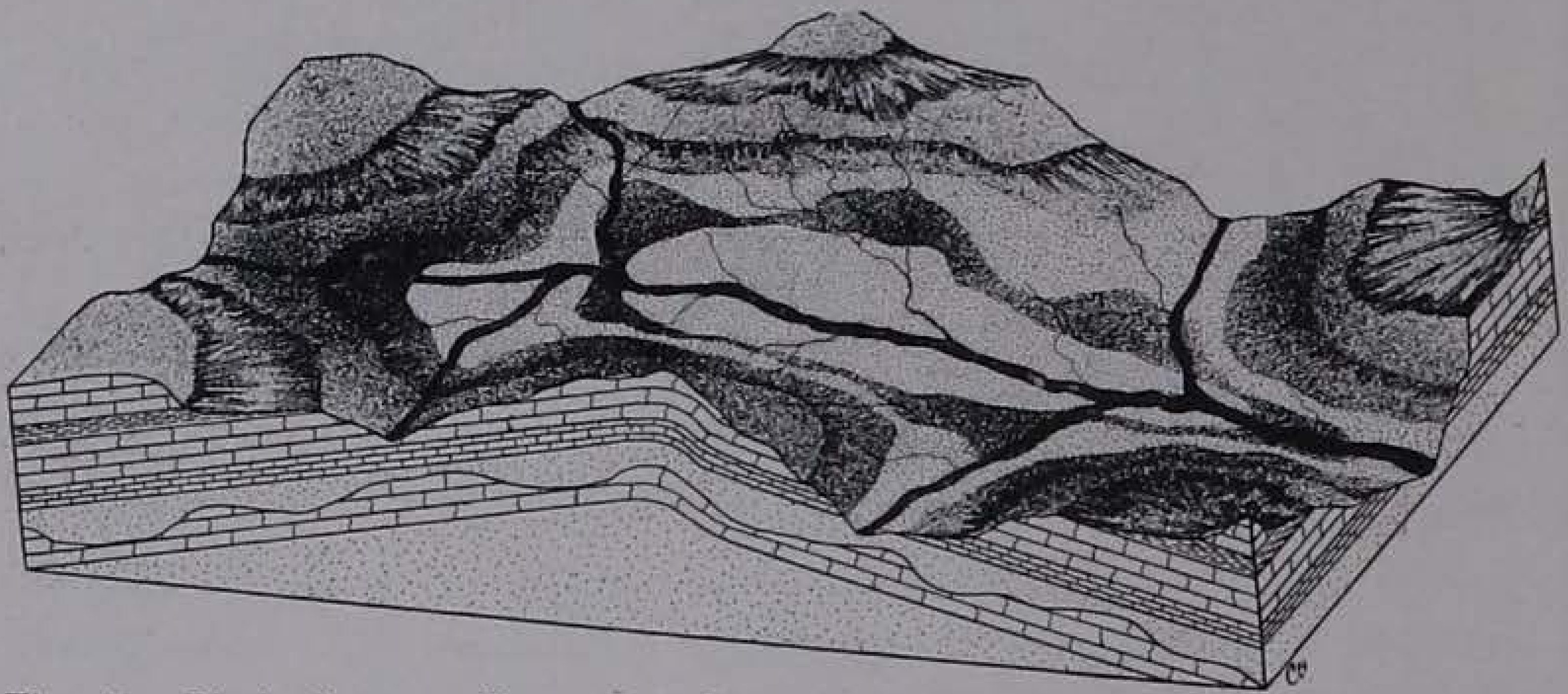

Fig. 30. Block diagram illustrating Stage III of stream adjustment, in case the south-flowing stream has the advantage of the north-flowing one.

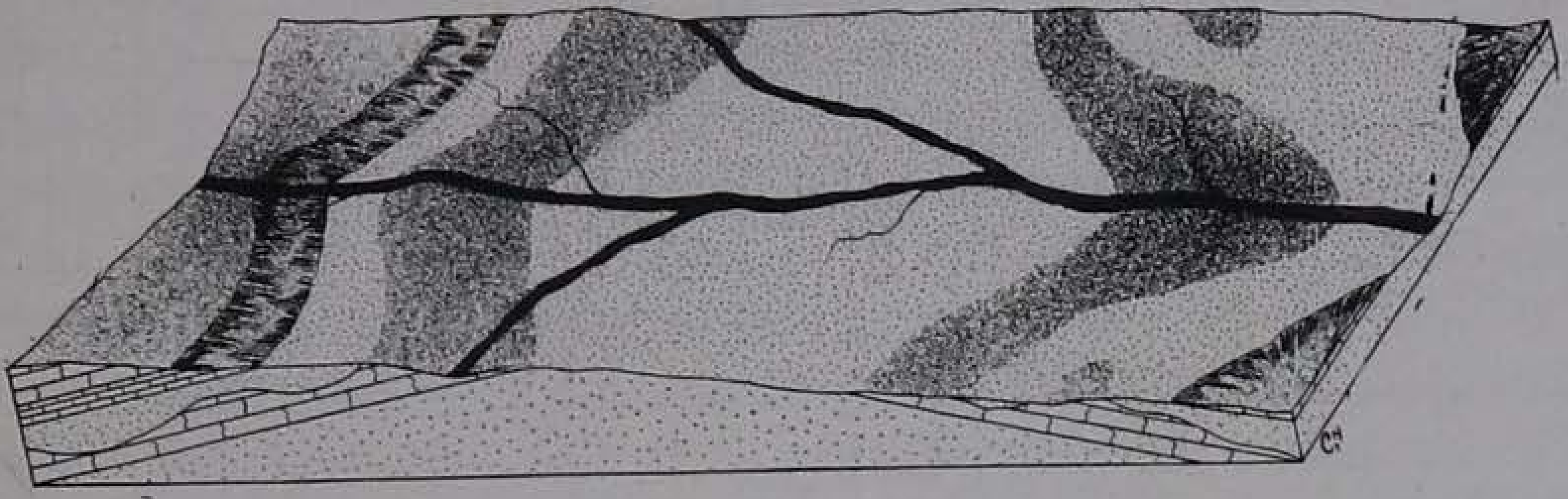

Fig. 31. Block diagram showing the courses of the streams in a final stage of stream adjustment in a first cycle of erosion.

Now the present course of the Mississippi river in early maturity of the present cycle of valley development is almost exactly what would be expected if it were determined by two streams flowing in opposite directions from the crest of the arch, the south-flowing stream having captured the north-flowing one, as outlined above (Fig. 32). North of the axis of the arch, between Minneapolis and La Crosse, the river flows in the general direction, S 51°E, which is an angle of 164° with the average direction of dip of the strata. The river not only does not flow in the direction of the dip but it does not flow parallel with the strike. Its average direction lacks but 16° of being opposite to the dip and to

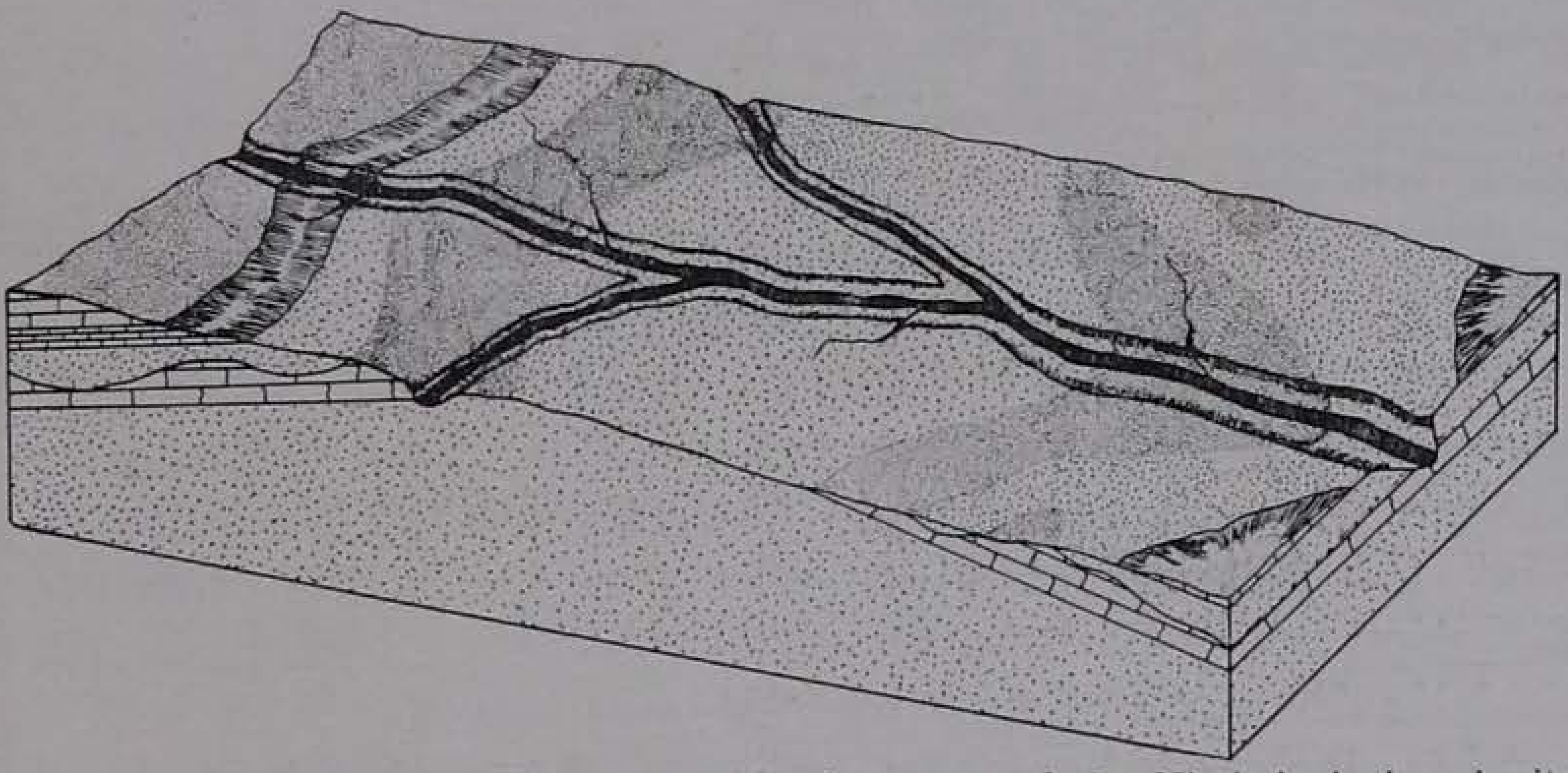

Fig. 32. Block diagram showing roughly the course of the Mississippi river in its relations to structure. The river is antecedent in the same sense that the Susquehanna river in the Appalachians is antecedent.

the slope of the original surface. The original surface had the theoretical altitude of 1410 feet at Minneapolis, 1870 feet at Winona and 2000 feet at La Crosse, and the present river flows from Minneapolis, past Winona, to La Crosse. South of the axis of the arch and the main divide on the original surface, where the strata have an average dip in the direction S 26°W, which also must have been the average direction of slope of the original surface, the river follows a curved course from La Crosse to Bellevue in the general direction S 18°E, forming an angle of 44° with the dip of the strata and the slope of the original surface. On neither side of the arch is there any evidence that the minor curves of the river really are controlled by minor structural features such as anticlines and synclines.

It should also be borne in mind that the Mississippi river, by taking a course more nearly directly south at some point south of St. Paul, would have flowed around the southwest end of the plunging anticline, avoiding the crest of the arch and the high portion of the original surface entirely. Such a course also would have been little if any longer to Dubuque than the course which was actually established.

There is a further indication that the Mississippi river has had such a history as outlined above in the fact that certain of the larger streams north of the axis of the anticline, for instance, Whitewater river, join the master stream with an acute angle down-stream. This suggests that the Mississippi river was flowing in the opposite direction while Whitewater river was being developed, and that its direction of flow was later reversed.

This lack of harmony between rock structures and original slopes on the one hand and the present course of the Mississippi river on the other, cannot be explained on the basis of the ordinary superimposition. Such an interpretation could be correct only in case some post-Paleozoic formation on which the stream could have established its present course, had been deposited over the strata of the district, after they were deformed, so as to let the stream down on the stratigraphic structures and topographies as the covering formation was penetrated. No such covering formation is known to have existed in the Driftless Area; and it seems extremely unlikely that a deposit so thick did exist and has been so thoroughly removed that no remnants of it are left. There are a few patches of stream gravel on the uplands, which some have considered to be Cretaceous and others Tertiary in age, but these deposits are local in their distribution and are believed by no one to have covered the entire Driftless Area. Certainly they did not cover it to such depths as to mask the present structures. Neither is the glacial drift competent to cause such superposition, for there are considerable areas on both sides of the Mississippi which are driftless. Furthermore, the drift must have had a thickness of more than 600 feet at Minneapolis to have carried the river over the crest of the arch at La Crosse.

Because the Mississippi river is generally independent of structure, because it flows for 135 miles in a direction which is up the slope of the original surface, because it cuts across the axis of a fold whose dips are considerable, because the surface of the Driftless Area is in maturity and shows no signs of old age, and because the river has not been superimposed, the Mississippi river is believed to be antecedent and to record more than one cycle in the erosional history of the surface.

The relations between the course of the Mississippi river and the Dodgeville and Lancaster plains north of La Crosse are not definitely ascertainable. On the south limb of the anticline, however, the general course of the river comes within 5° of being parallel in direction with the Dodgeville plain and within 6° of parallelism with the Lancaster plain. It seems likely therefore, that the river established its present course in old age of the cycle of erosion in which the Dodgeville peneplain was formed and held that course without great change during the dissection of the Dodgeville plain and the formation of the Lancaster plain and while the Lancaster plain was being uplifted and eroded.

It is not known that this holds in detail for that part of the river north of La Crosse.

Other Streams

All the smaller tributary streams of the Driftless Area appear to have been formed in the present cycle of erosion, be it the first, second or third cycle which the Area has experienced. It would seem likely, however, that if the Mississippi river existed in a previous cycle, some of its larger tributaries, such as the Wisconsin, La Crosse, Upper Iowa, Turkey, Root and Whitewater rivers might have established their courses at the same time and have held their courses to the present.

Within the Driftless Area, Wisconsin river flows from Prairue du Sac to the Mississippi in a general direction S 73°W, which is at an angle of 47° with the general dip of the strata and what must have been the slope of the original surface. The whole course of the river in this distance is on Potsdam sandstone, but before it had cut quite so deeply it must have flowed from the soft sandstone, across the resistant Prairie du Chien dolomite, instead of remaining on the soft sandstone as it could have done by developing a course more nearly parallel with the strike of the strata. As Wisconsin river is not adjusted to the structure the conclusion seems reasonable that it probably developed a course in harmony with conditions which existed in old age of a previous cycle and held that course during rejuvenation. In the sense in which Willis, Davis, and Hayes and Campbell used the term in connection with certain rivers of the Appalachians, Wisconsin river is, then, probably antecedent and an evidence of more than one cycle of erosion.

The direction of dip of the strata in the neighborhood of La Crosse river near the crest of the arch is not known accurately, and it is not known whether the river, which flows S 56°W is parallel with or oblique to the axis of the anticline. It may, therefore, be antecedent or consequent.

The courses of the streams in Iowa doubtless have been influenced by glacial drift which extends eastward almost or quite to their points of junction with the Mississippi;

and the problem of their antecedency is therefore obscured. Upper Iowa river has a course N 46°E from Decorah to its mouth, which fails of parallelism with the dip by 142°. Indeed the river flows for 35 miles in a direction which must have been up an original slope of 10 or 15 feet per mile. If glaciation had nothing to do with the establishment of this course Upper Iowa river is probably antecedent. Turkey river below Elkader flows in the general direction S 66°E. As this makes an angle of only 2° with the strike of the strata, Turkey river may be considered to be adjusted in harmony with its development within a single cycle. In Minnesota, Root river has a course out of harmony with the structure and the slopes of the theoretic original surface. It flows in a general direction which is up a stratigraphic dip of 4 feet per mile, although by taking a more southerly course it could have flowed around the end of the plunging anticline. Although Whitewater river north of the axis of the arch, as stated on p. 102, flows in a direction which is in harmony with structure and original slope, it joins the Mississippi with an acute angle downstream, suggesting the possibility that its course was established according to original slope and maintained after reversal of the master stream. Thus, while there is little suggestion of antecedency for the Whitewater river itself, its course taken in connection with the course of its main, adds strength to the belief that the establishment of the present course of the upper Mississippi involved a case of piracy of a magnitude which could hardly have taken place all within the present cycle of erosion.

In Illinois, Sinsinawa Creek, Galena River, Smallpox Creek, Apple River and Plum River are so nearly parallel with the dip that their histories probably do not date back of the present erosional cycle.

Intrenched Meanders

If the erosional history of the Driftless Area has involved more than one cycle of erosion it seems that some of the streams at least should have developed meanders in old age of a cycle and intrenched their meanders in the later cycle following uplift. The difficulty in distinguishing intrenched meanders from curves made in other ways not involving more than one cycle of erosion is brought out in Part I, as are also other limitations and possibilities in the application of intrenched meanders to interpretations of the erosional histories of regions.

The two major streams of the Driftless Area, the Mississippi and Wisconsin rivers, show no intrenched meanders, in spite of the fact that they seem to have had a history which would have developed such features. Both streams have flood plains several times the widths of the rivers and the details of their present courses are what would be expected under these conditions; but their curves are not intrenched. Except for their details, the general courses of these rivers are quite remarkably straight. If the streams were at grade on the Dodgeville plain and developed meanders there they must have straightened their courses as they cut down toward the Lancaster plain. Either the Lancaster peneplain was not sufficiently flattened for the development of conspicuous meanders or meanders were formed in this second cycle and cut off again after uplift of the Lancaster plain. It is not unreasonable to suppose that such streams would straighten themselves after rejuvenation; indeed, it is not clear that a stream could maintain the meanders developed in one cycle much past maturity of the following cycle. Therefore, the absence of intrenched meanders in these major streams is not thought to argue strongly against the idea that the Driftless Area has suffered more than one cycle of erosion. On the other hand the curves of these streams have nothing to offer in favor of this idea.

Conditions are somewhat different in the cases of smaller streams. Upper Iowa, Yellow, Turkey, and little Maquoketa rivers in Iowa are quite crooked and spurs from the valley walls project into the curves. But a large part of the courses of these streams lie in an area which has been glaciated, and the curves may have been developed on the surface of the drift and superimposed on the bedrock. But on the east side of the Mississippi river in Wisconsin and Illinois, where the area has never been glaciated and where there is no other known cause for exceptionally crooked streams, Trempeleau, Black, Kickapoo, Grant, Platte, Little Platte, Pecatonica, Galena, and Apple rivers all have distinctly crooked courses where the area has never been glaciated and where there is no other known cause for exceptionally crooked streams (Fig. 33). Kummel[1] studied the Galena, Platte, Grant, and Pecatonica rivers, described their meandering courses and their mature valleys, and concluded that they could not have been developed in a single cycle, either by superposition or by inequalities in resistance of rock. He concluded that they are true intrenched meanders significant of more than one cycle of erosion. His argument is convincing but hardly conclusive. There are so many ways in which curves might be developed and so difficult is it to distinguish curves made in differ-

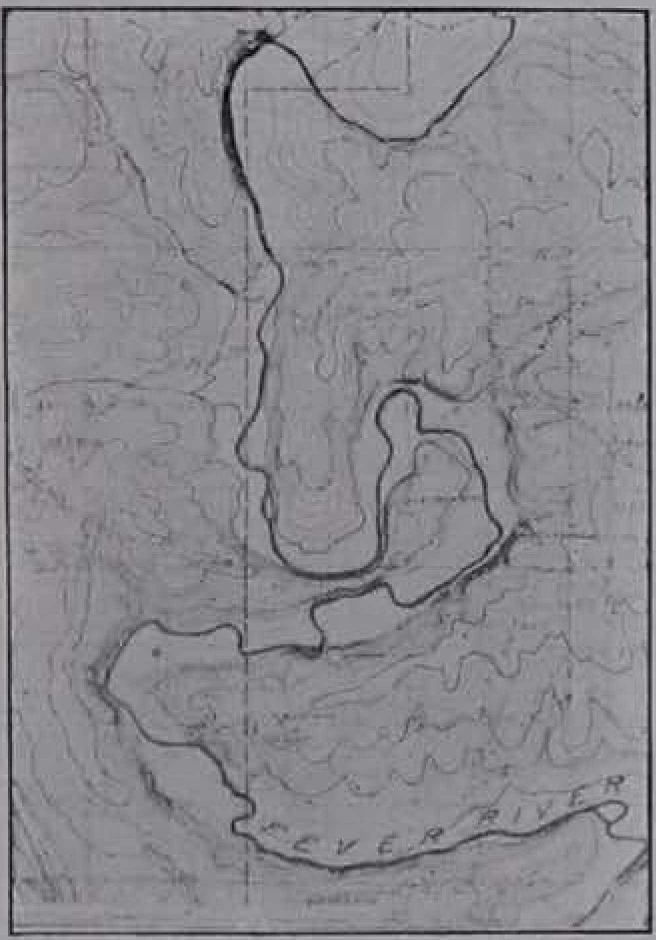

Fig. 33. A map showing a portion of the course of Galena river near Benton, Wisconsin. The curves may constitute intrenched meanders. (After Martin).

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[1] Kummel, H. B., "Some meandering rivers of Wisconsin," *Science*, New Series, Vol. I (1895), pp. 714-716.

ent ways, that the writer believes that these intrenched curving streams, considered alone without reference to relations between mains and tributaries, might have acquired these curves without having experienced more than one cycle. On the other hand it is believed that these intrenched curves bear as much evidence in favor of the plural cycle theory as intrenched meanders ever afford.

Associated Sets of Crooked and Straight Streams

But if the crooked courses of these streams within the Driftless Area have been developed in a single cycle their tributaries must have had the same histories as the mains and should have courses as crooked as the courses of the mains. Neither in the case of the above-mentioned streams in the Driftless Area of Wisconsin and Illinois nor of those in the slightly glaciated portion of Iowa do the mains and the tributaries have comparable natures and degrees of crookedness.

The fact that the tributaries are less crooked than their mains in Iowa is not significant, for it is possible that the main streams developed their course in the drift and that the tributaries were developed under different conditions after superimposition had been accomplished.

In the cases of those streams in areas which were not even slightly glaciated, however, and in which the tributaries are straight and the mains are notably curved, a suggestion is offered that the histories of the main streams and of the tributaries have not all been worked out in a single cycle. It would seem likely that the mains developed meanders when they were at grade in maturity or old age of a previous cycle of valley development and that either the tributaries had not reached grade and therebore did not meander before the first cycle was interrupted, or the tributaries did not exist at the close of the first cycle and have developed their straight courses entirely under conditions of higher gradient in the present cycle.

There is a marked difference in degree of crookedness between tributaries and mains in practically all of the drainage systems intermediate in size between the largest and the smallest, as illustrated in Fig. 34. This fact is of some value as evidence in favor of the idea that more than one cycle was involved in the erosional history of the Driftless Area. This evidence is chiefly corroborative, however, and is not conclusive considered alone.

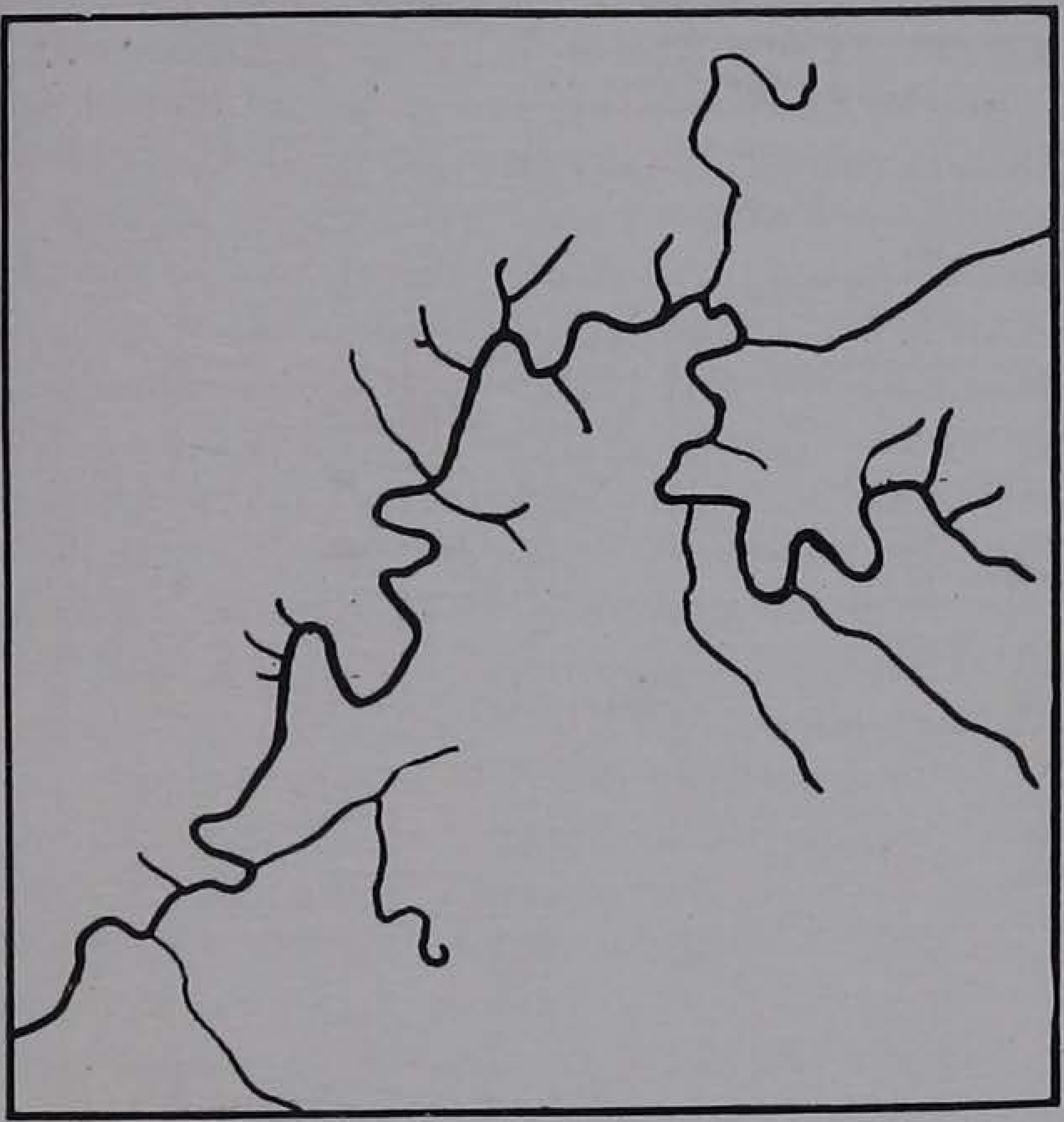

Fig. 34. A plat of part of the course of Grant river and its tributaries. The fact that the tributaries are not nearly so crooked as the main stream suggests that the curves of the river were developed in the last stages of a previous cycle and that the tributaries were mainly or wholly developed in the present cycle.

Stream Terraces

The Driftless Area abounds in stream terraces of various sorts, but none of them is significant as an evidence of more than one cycle of erosion.

At many points throughout the area there are projections or benches along the valley walls, whose tops are more or less flat, whose outer faces are steep, and to which the term terraces might be applied. These features are well known in Jo Daviess County, Illinois[1], in the Sparta district[2] and along the Wisconsin river[3] in Wisconsin, and in many of the valleys of Iowa, notably in the valley of Village Creek. These terraces are formed by resistant layers of rock at various stratigraphic horizons, as for instance, certain resistant sandstone layers in the Potsdam formation, the Mendota limestone member, the cherty member of the Galena formation, and the calcareous beds in the upper Maquoketa. They are purely structural, occur at different levels, cannot be correlated with either the Dodgeville or the Lancaster plain, and cannot be used as evidence of more than one cycle of erosion in the Driftless Area.

In several of the main tributaries of the Wisconsin river, notably in the valley of the Kickapoo river and the valley of Pine creek, there are distinct and almost continuous terraces which slope gently downstream. They consist of non-resistant rock, and bevel the layers of the Potsdam sandstone. The valleys have a double appearance, there being a narrow, rock-bound valley within a much wider, older one. These terraces are also due indirectly to structure. The Wisconsin river flows west and south with a gradient considerably less than the slope of the strata in that direction, so that its bed is on progressively younger strata towards its mouth. Although it has now penetrated the resistant Prairie du Chien formation where it joins the Mississippi, there was a time when its lower course was in this resistant formation and its upper course and its tributaries were on the Cambrian sandstone. Under these conditions the degradation was so much slower on the Prairie du Chien formation than was possible upstream on the sandstone that a temporary grade was established and maintained on the sandstone. There the main and tributary streams developed broad, open valleys with flat bottoms. When the resistant dolomite at the mouth of the river was finally cut through the sandstone beneath it was excavated rapidly and the streams above the resistant rock were allowed to intrench

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1. Trowbridge. A. C. and Shaw, E. W., Bull. No. 26, *Ill. Geol. Surv.*, pp. 144-5.
2. Martin, Lawrence, *Bull. Geol. Soc. Am.*, Vol. 28, pp. 148-149.
3. MacClintock, Paul, *The Wisconsin River between Prairie du Sac and Prairie du Chien*, manuscript so far unpublished.

themselves. The renewed activity was felt last in the tributary valleys and the terraces have therefore been eroded least there, so that they are now most conspicuous in valleys tributary to the main streams rather than in the main valley itself. There are coarse stream-laid gravels on some of these terraces, as for instance in the valley of Pine Creek southwest of Richland Center, and in the valley of Honey Creek near Plain. It is clear that these terraces also are not significant in connection with the erosional history of the general surface of the Driftless Area.

Flat-topped terraces, consisting of alluvial and lacustrine materials are found abundantly in nearly all the larger tributary valleys to the Mississippi and Wisconsin rivers. The origin of these terraces has been worked out[1] and found to be due to a partial filling of the Mississippi and Wisconsin river valleys by fluvio-glacial material at the time of the Wisconsin ice invasion, the consequent ponding of the tributaries, and the re-excavation of the fill in the mains and the tributaries after the retreat of the Wisconsin glacier. The origin of these terraces too has little to do with the general erosional history of the Driftless Area as a whole.

Although there are many terraces in the Driftless Area, it is concluded that none of them bears evidence of more than one cycle of erosion in the region.

Upland Fluvial Deposits (high level gravels)

One of the best evidences that there have been more than one cycle of erosion in the Driftless Area is found in the fact that stream deposits exist on some of the summit surfaces of the Area. These deposits have been known for a long time and have usually been referred to as "high-level gravels."[2] As the term implies, these deposits occupy the highest portion of the topography and consist almost entirely of gravel.

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[1] Trowbridge, A. C. and Shaw, E. W., Bull. No. 26, *Ill. Geol. Surv.*, pp. 145-152.

[2] Strong, Moses, *Geol. Wis.*, Vol. IV, 1875-79, p. 88.
Winchell, N. H., *Geol. and Nat'l Hist. Surv. Minn.*. Vol. I, 1884, pp. 305-310; 353-356.
Chamberlin, T. C. and Salisbury, R. D., *Sixth Ann. Rept. U. S. Geol. Surv.*, 1884-85, p. 273.
Salisbury, R. D., *Bull. Geol. Soc. Am.*, Vol. 3, 1892, pp. 183-186; *Jour. Geol.*, Vol. III, 1895, pp. 655-667.

So far they have been found at Seneca, Wisconsin, on the flat summit of the south quartzite range near Devil's Lake, Wisconsin, on the summit plain in the south portion of the Sparta quadrangle north of Cashton in Wisconsin, in the Tomah quadrangle, Wisconsin, at Iron Hill near Waukon, near Church, and near Elon in Iowa, and in various portions of the Driftless Area in Minnesota. In all these places the gravel is thick enough to form a measurable deposit and at Senaca and Waukon the thickness is as great as 35 feet. The deposit occupies summit positions in the topography, which position represents the Dodgeville plain in each case. In addition to these localities where the gravel is in place, there are many places in Iowa and Illinois and probably in Wisconsin and Minnesota, where scattered pebbles which have been derived from the deposit are found at all levels. However, there is no place known where the gravel lies in its original position at levels below the Dodgeville plain. At Devil's Lake they are associated with potholes in the summit surface. It is not believed that these patches of gravel are remnants of a formation which once covered the entire Driftless Area, but that the gravels were deposited only along stream courses.

There can be no doubt that these gravels are of fluvial origin. The pebbles range in size from a small fraction of one inch to three or four inches in diameter. The smaller ones are rounded and highly polished and seem to have been carried far, or at least to have undergone transportation for a long time. The large ones are more irregular and some of them seem hardly to have been transported at all. At Seneca, Waukon and Elon, the gravel deposits are distributed in crescent shaped areas resembling the curves of streams.

The writer has broken hundreds of the pebbles and has yet to find one composed of anything but silica. Most of them are chert, but some are white quartz, some are almost black, and some have the color and appearance of jasper and chalcedony. They are known to include nothing which could not have been derived from the pre-Cambrian and Paleozoic formations which originally covered the Driftless

Area. At Waukon, Elon, Seneca, and at some points in Minnesota, the gravel is firmly cemented with iron, so that a conglomerate exceedingly resistant to erosion is formed.

Some of the pebbles contain fossils which are of Ordovician and Niagaran age. Some of the pebbles and fossils collected from the Sparta quadrangle are shown in Fig. 35.

The conclusion seems unavoidable that streams were once nearly at grade on the Dodgeville plain; that they deposited extensively in their beds, and that deposition ceased as the dissection of the summit plain was inaugurated by uplift. The coarse texture of the fluvial deposit, their apparently local origin, and their association at Devil's Lake with potholes all suggest that they were not deposited by the largest and oldest streams of the time, but rather by secondary streams whose gradients were still appreciable and whose sources were not far distant, and yet by streams which have long since ceased to exist. Presumably the larger streams deposited also, but the material probably consisted of sand and silt rather than of gravel, and these non-resistant deposits have been entirely removed or mingled with the upland soils so thoroughly as to be indistinguishable. The gravel was probably deposited on those portions of the Dodgeville plain which were somewhat above the lower valley bottoms, and by subsequent erosion they have come to stand as the very highest points because of their superior resistance.

Whatever may have been their detailed origin and distribution these fluvial gravels, occurring at widely separated points on the Dodgeville plain, hundreds of feet above present drainage, go far to prove that the surface of the Driftless Area has not been formed by erosion in a single cycle. Certainly there is no provision in the cuesta single cycle theory for the occurrence of these deposits on the Dodgeville plain.

Conclusion

As was brought out in Part I, the most satisfactory proof of more than one cycle of erosion is to be found in certain *combinations* of evidences. A combination amounting to

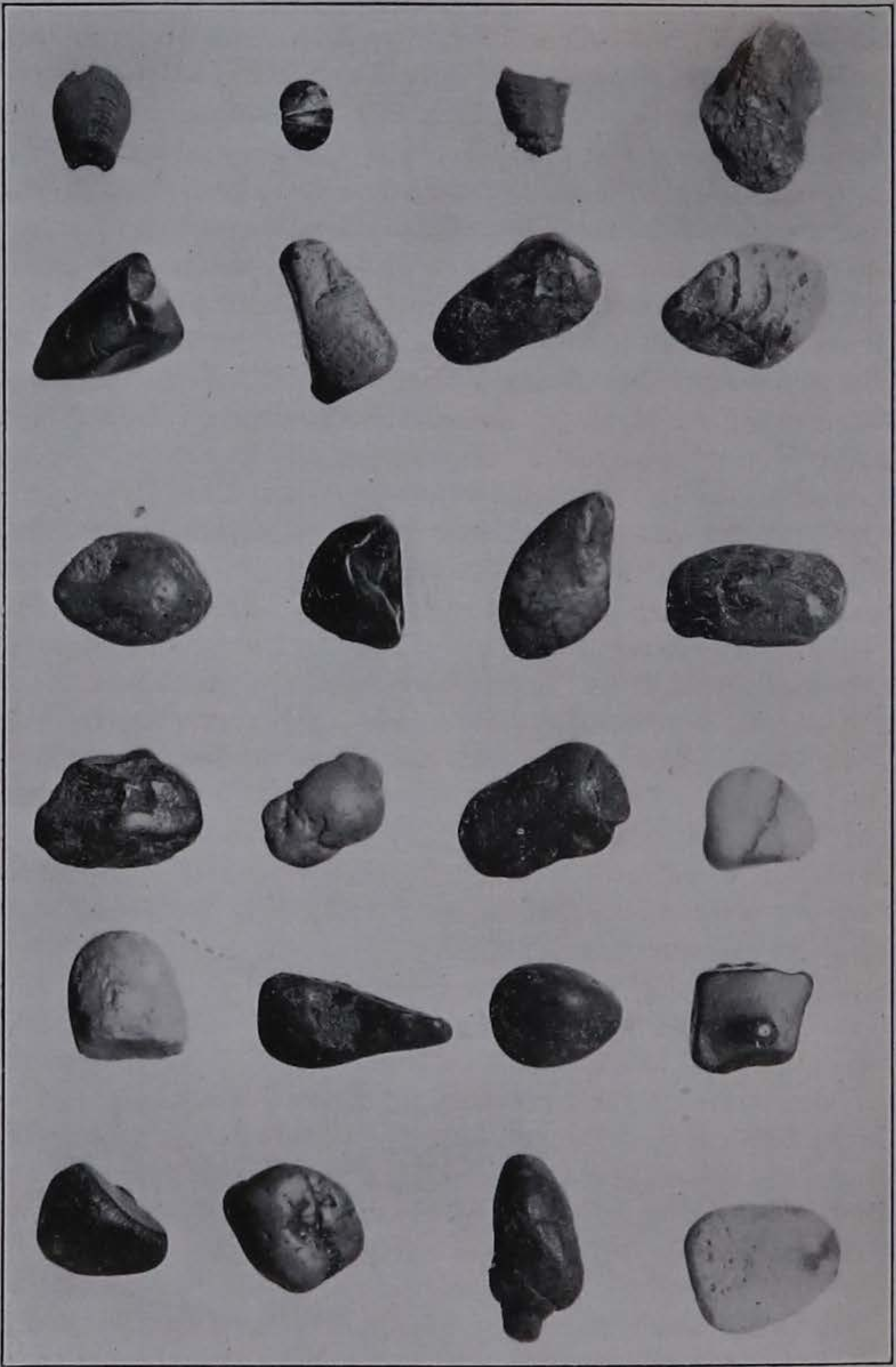

Fig. 35. Pebbles and fossils from the summit fluvial deposits in the south portion of the Sparta Quadrangle. (After Shipton).

proof exists in the Driftless Area. It is impossible that a surface could have been developed in a single cycle of erosion, which has (1) even-crested summit areas which, after analysis, represent a peneplain, (2) an intermediate plain which can be interpreted only as a partial peneplain, (3) antecedent streams which could have developed their present courses only in old age of an erosion cycle, (4) intrenched meanders for which no other explanation than that they record more than one cycle have been worked out, (5) associated sets of crooked and straight streams which are valuable corroborative evidence of plural cycles, and (6) undoubted fluvial deposits widely distributed on flat surfaces far above present drainage.

THE NUMBER OF EROSIONAL CYCLES

The next question which confronts the interpreter of the erosional history of the Driftless Area has to do with the number of cycles of erosion which have been involved in the formation of the surface. The question can be answered when it has been determined how many distinct *sets* of evidences of more than one cycle are included among the five evidences outlined above.

In the first place, there is no way to ascertain how many cycles, if any, intervened between the time of withdrawal of the last Paleozoic sea and the cycle in which the Dodgeville plain was formed. There may have been time for several cycles of erosion between these dates. But of any such cycles all evidence was obliterated in the making of the Dodgeville plain. If it be assumed that the cycle which was inaugurated by the final withdrawal of the sea was the same cycle as that in old age of which the Dodgeville plain resulted, there would be no way to prove the assumption to be incorrect.

Considering the evidences of more than one cycle of erosion it is clear that the Dodgeville plain and the Lancaster plain could not have been formed in the same cycle. From foregoing discussions it is clear that the antecedent streams and upland fluvial deposits go with the Dodgeville plain, and the intrenched meanders and associated sets of crooked and straight streams with the Lancaster plain. Even-crested summit areas, antecedent streams and fluvial deposits on divides constitute evidence of one ancient cycle, and an intermediate plain which is a partial peneplain, intrenched meanders and associated sets of crooked and straight streams afford evidence of another one. Below the intermediate plain the streams in their deeply excavated valleys show that a third cycle is involved.

It is believed that the surface of the Driftless Area has been eroded in at least three cycles, the first known one being represented to-day by the Dodgeville plain, the second one by the Lancaster plain, and the third one by the present valleys below the Lancaster plain. These cycles are called the Dodgeville cycle, the Lancaster cycle and the present cycle respectively.

THE HISTORY OF DIASTROPHISM

The first recorded diastrophic event involved in the erosional history of the Driftless Area caused the warping of the strata to form the anticline with its axis crossing the Mississippi river at or near La Crosse, and with its south and north dipping limbs, together with the gentle and local anticlines and synclines on the limbs of the larger fold. This movement may or may not have accompanied or caused the final withdrawal of the Paleozoic seas. It was an uplift of the surface with warping.

After the initial movement and the establishment of the land surface, after the streams had reached grade and developed the Dodgeville plain, an uplift occurred which interrupted the Dodgeville cycle and inaugurated the Lancaster cycle. Although the Dodgeville plain is not perfectly parallel with the Lancaster plain nor with the present flood plain of the Mississippi river, this uplift was not accompanied by marked warping or tilting. The local irregularities of the Dodgeville and Lancaster plains are clearly due to erosion rather than to diastrophism and are neglected in the following estimates. The relative directions and amounts of slope of the Dodgeville plain, the Lancaster plain, and the graded plain of the Mississippi river, south of La Crosse, are shown in the accompanying table.

TABLE SHOWING THE RELATIVE DIRECTIONS AND AMOUNTS OF SLOPE OF THE DODGEVILLE PLAIN, THE LANCASTER PLAIN, AND THE MISSISSIPPI FLOOD PLAIN

Plain	Average direction of slope	Average amount of slope
Dodgeville Plain	S 23° E	3.3 feet per mile
Lancaster Plain	S 40° E	3 feet per mile
Mississippi Flood Plain	S 18° E	4 inches per mile

The difference in direction of slope of the Dodgeville and Lancaster surfaces is not great, considering the possibilities of error in estimating averages, and could be due to differences in direction of drainage during the respective cycles. Consequently, they cannot be said to record warping or tilting of the Dodgeville surface during uplift. The amounts of slope of the Dodgeville and Lancaster plains are almost identical, which seems to prove that there was no notable tilting of the Dodgeville surface before the formation of the Lancaster plain. The second diastrophic movement recorded in the features of the surface was then one of nearly uniform uplift.

The amount of this uplift can be ascertained at least roughly by the average difference in altitude between the Dodgeville plain and the Lancaster plain. On the average these two plains are 235 feet apart vertically in the Baraboo district, 265 feet in the Sparta quadrangle, 148 feet in the Richland Center quadrangle, 175 feet in the Lancaster and Mineral Point quadrangles, 218 feet in Jo Daviess County, Illinois, 117 feet in the Waukon quadrangle, 190 feet in the Elkader quadrangle, 125 feet in southeastern Minnesota. As the average of these figures is 184 feet, the second recorded diastrophic movement was an uplift of about that amount.

The Lancaster cycle was interrupted by a third uplift which was the greatest of all the movements which affected the Driftless Area. Streams which had developed graded flats on the Lancaster plain during the Lancaster cycle were able in the following cycle to cut to the levels of the bottoms of the rock valleys below the later fluvio-glacial fills. The average depth of the valleys cut during this cycle is approximately the amount of the uplift which closed the Lancaster cycle. The following table gives details of the depths of valleys cut during this cycle.

TABLE SHOWING DEPTHS OF VALLEYS WHICH MEASURE THE AMOUNT OF THE UPLIFT WHICH INTERRUPTED THE LANCASTER CYCLE

Valley	Altitude of Lancaster plain (feet)	Altitude of rock bottom of valley (feet)	Depths of Valley below the Lancaster plain and amount of uplift (feet)
La Crosse River near Sparta	1100	600	500
Devils Lake Gap	1200	570	630
Galena River near its mouth	860	490	370
Upper Iowa River near its mouth	1150	530	620
Mississippi River at La Crosse	1100	470	630
Mississippi River at Prairie du Chien	1100	473	627
Mississippi River at Dubuque	880	279	601

Considering the fact that not all the wells, the records of which were used for the altitudes of the bedrock beneath the surfaces of the fills, are in the middles of the valleys and the probability that not all the streams had reached grade when the filling began, the depths of these valleys are quite remarkably uniform. This average depth, approximately 600 feet, seems to be a fair estimate of the amount of uplift. If the streams were not at grade when degradation ceased and aggradation began the amount of uplift may be considered to have been more than this. Of the two uplifts which have occurred since the land surface of the Driftless Area was established the second one was three times as great as the first.

From the table showing the relations between the two upland plains and the bottoms of the present Mississippi Valley, (p. 117), the inference might be drawn that the uplift which interrupted the Lancaster cycle was accompanied by tilting, for the Lancaster plain and the present Mississippi flood plain are not parallel. However, the nature of this uplift is to be obtained by comparison of the Lancaster plain not with the present flood plain, but with the rock bottom of the valley beneath the present river level. The streams rejuvenated by the uplift of the Lancaster plain continued to cut downward until the rock bottoms of the present valley were reached. The present flood plains of the streams were established later, under different conditions. Although it is impossible to determine the exact slope of the surface represented by the buried bock bottoms of the valleys, it is shown in the last table that the depths of the valleys cut during the post-Lancaster cycle and consequently the amount of uplift which inaugurated that cycle are notably uniform. This suggests that the peneplain which would have been developed if this cycle had gone to a late stage would have been roughly parallel with the Lancaster plain. This being the case the uplift of the Lancaster plain is more likely to have been uniform than accompanied by tilting.

The rather low altitudes of the parallel Dodgeville and Lancaster plains in Minnesota suggests the possibility that the movement which interrupted the Lancaster cycle was accompanied by warping in that state. On the other hand, a slightly decreased slope in old age of each of the two cycles or a slight change in the direction of slope of the two plains would explain the slight discrepancy equally well.

There seems to be no escape from the conclusion that there has been still another period of diastrophism in the Driftless Area, this time a subsidence rather than an elevation of the surface. The evidence of subsidence is found in the fact that the Mississippi river and its main tributaries are now at grade at levels on the average 180 feet above levels to which they were formerly able to reduce their beds. It is not believed that this fact is to be explained on the supposition that the present grade is merely temporary and controlled by some obstruction such as the rock ledge at Rock Island or the rapids at Keokuk. These obstructions are far from sufficient to explain the difference in grade levels now and as they were, for the Mississippi river today has a gradient of less than 6 inches per mile from La Crosse to the Gulf, including the rapids. It is believed, therefore, that the last diastrophic movement in the history of the Driftless Area was a subsidence of about 150 to 200 feet and that it took place sometime before, during, or just after the partial filling of the valleys by fluvio-glacial debris.

If it be assumed that this subsidence was accompanied by tilting, so that the south portion of the Driftless Area subsided more than the north portion, the apparent parallelism of the Dodgeville plain, the Lancaster plain, and the rock-bottomed valleys, and the more gentle slope of the present Mississippi flood plain would be explained. This assumption is rendered unnecessary, however, if it be considered that the present Mississippi has a sufficiently greater volume and lighter load than all previously existing streams, to allow it to develop and maintain a gradient one-tenth as steep as any preceding gradient.

The conclusion is reached, therefore, that at least four different diastrophic movements affected the Driftless Area, namely, (1) uplift with warping and tilting which initiated the land surface; (2) a nearly uniform uplift of about 180 feet interrupting the Dodgeville cycle; (3) a nearly uniform uplift of 600 feet or more which started the excavation of the deep valleys; and (4) a subsidence, perhaps accompanied by tilting, which raised the level of grade to that of the present Mississippi river.

THE DATES OF EVENTS

The whole history presented in this paper is limited in time between the Niagaran epoch on the one side and the Wisconsin epoch on the other. The sequence of events has already been worked out. The accuracy with which the dates of these events can be stated depends upon the accuracy with which the ages of the upland plains can be determined. There has been disagreement concerning the ages of these plains and perhaps the final conclusion will have to await further work, but strong evidence now at hand leads to the conclusions here presented.

The Age of the Dodgeville Plain

There is no known way to determine the age of the Dodgeville plain by a study confined to the Driftless Area. The most promising method lies in the attempt to determine the age of the high level gravels which are contemporaneous with the plain. In 1882 Winchell[1] discovered silts and sands and clays of undoubted Chetaceous age in southeastern Minnesota, and in the same district he found a gravel deposit later found to be similar in some respects to the hige-level gravel of the Driftless Area. Because the gravels were associated with the Cretaceous deposits Winchell tentatively assigned a Cretaceous age to them. In 1895, after study of the Tertiary gravels of the Gulf Coast and of Arkansas and southern Illinois, and after seeing the gravel deposits of the Driftless Area at Seneca and Devil's Lake, Salisbury[2] concluded that the gravels were not older than Cretaceous nor younger than Lafayette, and was inclined to believe that they are late Tertiary in age. For unstated reasons most recent writers have followed Winchell and tentatively assigned a Cretaceous age to the high-level gravels and the plain on which they lie. Perhaps the reason is that marine Cretaceous rocks in western Iowa and Minnesota lie on a base of slight relief and bevel the same southwest dipping formations as occur in the Driftless Area.

After having spent part of a field season in southeastern Minnesota, assisted by Professor Leroy Patton, the writer is strongly inclined to favor the Tertiary age of the plain, for the following reasons: (1) The gravels of the Driftless Area are dissimilar from the rocks which carry Cretaceous fossils in Minnesota and from certain deposits of stratified gravels in Minnesota believed to be related to or derived from the Cretaceous rocks. Near New Ulm, Brown County, there is an exposure of stratified high-level gravels interbedded with sand and clay. The surface rock at this place is regarded as Cretaceous. The stratified deposit itself may be Cretaceous but might easily have been locally derived

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[1] Winchell, N. H., *Geol. and Nat'l Hist. Surv. Minn.*, Vol. I, pp. 309-310; 353-356.
[2] Salisbury, R. D., *Jour. Geol., Vol. III*, pp. 655-667.

from the Cretaceous. The latter seems quite probable for the reason that the Cretaceous deposits in this district contain pieces of gravel similar to the high-level gravel and also chalky particles which appear in the stratified deposits. The latter particles, however, could not have stood much transportation and are of themselves a strong argument for the local derivation of the high-level gravels. Other material derived from the Cretaceous in the earlier stages of the dissection of the Cretaceous surface might have become widespread as stream gravels on the old surface of the peneplain. (2) It should be noted that although Winchell may have been correct in his conjecture that certain gravels described by him were locally derived from Cretaceous deposits, it does not follow as a corollary that the *time* of derivation was Cretaceous and that therefore any surface upon which these gravels lie is Cretaceous. In Winchell's report[1] he distinctly states his belief that the gravels which he here describes were placed in position "by drift forces." Whether he meant that they were Cretaceous deposits reworked during the Pleistocene period by a glacier is not clear. Certainly they are not glacial, but undoubtedly they were derived from the Cretaceous deposits revealed by post-Cretaceous streams. Winchell seems to have believed that at least some of the gravel deposits in Minnesota were of post-Cretaceous age. The writer believes that the high-level gravels of the Driftless Area, nowhere associated with sands, silts, or clays, are post-Cretaceous, though perhaps derived partly from Cretaceous formations containing gravel layers or levels. (3) Winchell's conclusions were with regard to local and isolated cases only and had no reference to gravel deposits of similar nature found in localities not suggesting a local derivation. (4) The Dodgeville plain constituting a stratigraphic base for the gravel has never been traced and found to underlie Cretaceous rocks but on the contrary its altitude in Minnesota is such as to cause it to bevel the Cretaceous. (5) The gravels extend far beyond any known Cretaceous and occur extensively where there is not the slightest indication of Cretaceous age.

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[1] Winchell, N. H., *Geol. and Nat'l Hist. Surv. Minn.*, Vol. I, p. 309.

(6) The gravels of the Driftless Area are strikingly similar to the Tertiary gravels of the Gulf region. (7) There are numerous patches of similar deposits south of the glaciated area and beneath the drift which seem to connect the gravel formation of the Driftless Area with the Tertiary deposits of the Gulf Coast. (8) The Dodgeville plain on which the gravels lie slopes south toward the Tertiary deposits rather than west toward the Cretaceous. (9) Salisbury's interpretation has been in print for a quarter of a century and all new discoveries seem to corroborate his tentative conclusions. (10) All patches of gravel between the Driftless Area and known Tertiary deposits occupy summit areas in the topography. (11) If the base of the Tertiary deposits were projected north it would coincide roughly with the Dodgeville plain. (12) The base of the Tertiary deposits is in itself a peneplain. (13) The Tertiary gravels are known to lie on a raised peneplain in the southern Appalachians and elsewhere. These facts seem to the writer almost conclusive of the Tertiary age of the Dodgeville plain. Whether the plain is Eocene, Oligocene, Miocene, or Pliocene in age cannot be determined, for the precise age of the Tertiary gravels on the Gulf Coast is in doubt. It is believed, however, to be *late* rather than *early* or middle Tertiary.

The Age of the Lancaster Plain

The Lancaster plain is clearly younger than the Dodgeville plain and is probably therefore late Tertiary or Pleistocene in age. It has been generally understood that the great uplift in the interior of the United States came at the close of the Tertiary, in the epoch known by some as the Ozarkian. Because the greatest movement which affected the Driftless Area uplifted and started the dissection of the Lancaster plain this plain has been most generally referred to the late Tertiary.

The writer is not certain that the Lancaster plain is not Tertiary in age, but he wishes to present some evidences that it was not completed and uplifted before the first ice invasion. The work of the writer during several years, and the work of A. J. Williams[1] has shown that there is old

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[1] Williams, A. J., Manuscript so far unpublished.

drift extending eastward beyond the mapped border of Kansan drift on the west side of the Driftless Area in Iowa, almost and in many places quite to the Mississippi river. There is also at least one area of this upland drift in Illinois[1]. Whereas the Kansan drift within the mapped area lies at all levels of the bedrock topography from the tops of the highest hills to the bottoms of the deepest valleys, this drift beyond the Kansan border, with the exception of a tongue of supposedly Kansan drift near McGregor, is found most abundantly on the Lancaster plain, sparingly on the slopes above the Lancaster plain, and still more sparingly on the Dodgeville plain. Of the several hundred isolated remnants of this drift which are now known, not a single patch is in place in the valleys below the Lancaster plain. If this drift were Kansan and deposited after the deep valleys were cut, it would seem difficult to explain why it would all have been removed from the valleys and valley benches so that the drift now extends farther east on the narrow divides than in the broad, open, terraced valleys. Still more difficult would it be to explain, if the deposition of this drift took place after the valleys were cut, how a glacier thick enough to fill valleys 600 feet and more deep so as to spread over the divides could have advanced, deposited this drift and retreated without so having changed the profiles of the valleys or so having modified the divides or so having marked the rock surfaces as to have left some trace on the surface below the Lancaster plain. When it is recalled that almost wherever known this oldest Pleistocene drift lies on high divides or benches above valleys believed to have been cut after the deposition of the drift, as in New Jersey[2], Montana[3], and the San Juan mountains of Colorado[4], there is nothing new nor radical in the supposition that in the Driftless Area also, it antedated in its deposition the formation of the deep valleys. This upland drift has the appearance of great age but perhaps not of greater age than

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[1] Trowbridge, A. C. and Shaw, E. W., *Bull. Ill. Geol. Surv.*. No. 26, p. 87.
[2] Salisbury, R. D., *Ann. Rept. State Geologist of New Jersey for 1893*, pp. 73-123, especially p. 87.
[3] Alden, W. C. and Stebinger, Eugene, *Bull. Geol. Soc. Am.*, Vol. 24, pp. 529-572.
[4] Atwood, W. W. and Mather, K. F., *Jour. Geol.*, Vol. 20, pp. 385-409.

the Kansan drift, where it is thin. Where either drift is thin, it has been brought to its limits of weathering.

There is then some evidence, which seems to the writer to be strongly indicative, if not conclusive, that this drift, in a district which has been called driftless, is pre-Kansan in age, and that it was deposited while the Lancaster plain was still intact and before the deep valleys were formed. Otherwise, why should there be no patches of the drift in the valleys? And why should the valleys show not the slightest indication of having been glacially worn? The Kansan drift seems clearly enough to have been deposited after the valleys were formed.

The above evidence seems to justify the interpretation, at least as a working hypothesis, that the Lancaster plain was intact at the time of the pre-Kansan ice invasion, but that it was uplifted and partly dissected before the Kansan epoch. Leverett[1] objects to this interpretation and cites the presence of pre-Kansan drift in the bottoms of deep rock-bound valleys in Wisconsin and southeastern Iowa. So far as the writer has been able to investigate the evidence, he finds it inconclusive. The writer's interpretation is strengthened by E. W. Shaw[2], whose recent work in the Ozark district seems to show that the main uplift and the main development of the Mississippi valley there took place during the early Pleistocene, rather than at the close of the Tertiary as was previously supposed.

Accepting the above interpretations of the ages of the Dodgeville and Lancaster plains, at least as probabilities, the probable dates of diastrophic events and erosion cycles are easily determined and are stated in the following summary of events.

SUMMARY OF EVENTS

The first step in the history of the surface of the Driftless Area was the final emergence of the surface from the sea and the formation of an anticline with its axis running through La Crosse and its south limb forming a great

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[1] Personal communications and oral discussions in the field.

[2] Personal communications to the writer.

monoclinorium which extends far beyond the boundaries of the Driftless Area to the south and southwest. This movement left the surface high above the level of grade, with a stream divide on the axis of the fold. This event took place after the Niagaran epoch of the Silurian period and probably after the Pennsylvanian period, but before the Cretaceous. The date may be set roughly at the close of the Paleozoic era.

Following its initiation, the surface was eroded in one or more cycles and was brought to the condition of a plain with a relief of less than 200 feet, the Dodgeville plain. The cycle was not complete, but a stage at least as late as early old age was reached. The divide at La Crosse was probably obliterated before the close of this cycle. The stage in the history of the region was probably brought to an end at some time during or at the close of the Tertiary period.

Probably in late Tertiary time the gravel-strewn Dodgeville plain was uplifted almost uniformly to the amount of approximately 180 feet.

The uplift mentioned in the last paragraph inaugurated a new cycle of erosion known as the Lancaster cycle, which continued probably until the advance of the pre-Kansan glacier in the earliest part of Pleistocene period, by which time a second peneplain, the Lancaster plain, had been formed. Neither was this cycle of erosion complete. However, the surface at this time was much more nearly flat than the present surface. The surface doubtless lacked something of having gone so far in its stage of reduction as was the case during the Dodgeville cycle.

The Lancaster erosion cycle was interrupted most likely at some time soon after the retreat of the pre-Kansan glacier in the early Pleistocene, by a diastrophic uplift without tilting or warping, amounting to 600 feet or more. This movement raised the Lancaster plain to levels high above grade and inaugurated a third cycle of erosion.

The details of the post-Nebraskan, pre-Wisconsin history of the Driftless Area are not known, but the history seems to have been one of erosion interrupted locally and temporarily by the deposition of at least two bodies of glacial drift on the borders of the area. Deep valleys appear to have been cut before the advance of the Kansan glacier and the deposition of a thin body of Kansan drift on the west border. The valleys of Pecatonica and Apple[1] rivers had been cut to depths below their present bottoms by the time of the Illinoian (?) ice invasion from the east.

Some time before or during or immediately after the Wisconsin glacial epoch, when the valley trains were deposited in the Mississippi and Wisconsin valleys, there appears to have occurred a subsidence of the surface amounting to about 180 feet and perhaps accompanied by a tilting of all older graded surfaces slightly to the south. The subsidence rendered it impossible for the Mississippi and its tributaries to cut back to their original levels. If tilting occurred the gentler slope of the present flood plain as compared with all previous gradients is explained.

After the withdrawal of the Wisconsin glacier the Mississippi river and its tributaries began to excavate their valleys by the removal of the fluvio-glacial debris but they reached grade 30 or 40 feet below the original top of the deposit and 180 feet on the average above its bottom. Having reached grade, the streams have all developed valley flats in the soft material deposited by waters during the Wisconsin epoch.

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1. Trowbridge, A. C. and Shaw, E. W., Bull. Ill. Geol. Surv. No. 26, pp. 95-99.