Rivers and River Terraces

EDITED BY
G. H. DURY

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BOOKS THAT MATTER

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DEDICATED TO

LUNA B. LEOPOLD

AND

WALTER B. LANGBEIN

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Acknowledgements

'Methods and Results of River Terracing', by Hugh Miller © *Proc. Roy. Phys. Soc. Edinburgh*, VII (1883)

'River Terraces in New England', by W. M. Davis © *Bull. Museum Comparative Zoology*, XXXVIII (1902)

'The Longitudinal Profiles of the Upper Towy Drainage System', by O. T. Jones © *Quart. J. Geol. Soc. London*, LXXX (1924)

'Land Sculpture in the Henry Mountains', by G. K. Gilbert, 1887, U.S. Geographical and Geological Survey of the Rocky Mountain Region (now the Geological Survey)

'Erosional Development of Streams: Quantitative Physiography Factors', by R. E. Horton © *Bull. Geol. Soc. Amer.*, LVI (1945)

'Flood Plains', by M. Gordon Wolman and Luna B. Leopold, 1957, U.S. Geol. Survey, Prof. Paper 282-C

'River Channel Patterns', by Luna B. Leopold and M. Gordon Wolman, 1957, U.S. Geol. Survey, Prof. Paper 282-B

'River Meanders and the Theory of Minimum Variance', by Walter B. Langbein and Luna B. Leopold, 1966, U.S. Geol. Survey, Prof. Paper 442-H

'Meandering Valleys and Underfit Streams', by G. H. Dury, U.S. Geol. Survey, Prof. Paper 452-A-B-C

Introduction

ANTHOLOGISTS run the occupational risk of satisfying few readers, if indeed any; but they may perhaps find comfort in the fable of the father, the two sons and the ass. I am of course aware of very many papers, additional to those actually selected, which could justly have been included; and I am equally aware that the chosen list is short. The range of sampling could have been increased, and the list of items extended, had it been possible to deal entirely in terms of brief extracts; but then the nature of the material could have forced the collection into the undesired form of a monograph, a review article or a dissertation. This would have been to defeat the central purpose of assembling original material from a variety of sources, and of presenting it in conveniently abbreviated form but still at significant length.

As first published, the original works run in text and illustrations to a combined equivalent of more than a third of a million words. The permitted space in this book involves an average reduction to less than a quarter of the original wordage. Accordingly, in undertaking the ruthless task of selection I have been led to exclude works written in languages other than English. Conscious as I am of a massive debt to writers in French and German – among them for instance de Martonne, Troll, Macar, and Tricart – I can do no more than place on record my regret at the obvious omissions.

The chosen items all strike me as fundamental, in some sense or other, to the set theme of rivers and river terraces. They are also intended to illustrate some of the direction taken by studies of fluvial morphology generally. Were demonstration necessary, it could surely be proved that the works by Gilbert, Miller, Davis and Jones, first appearing in the interval 1877–1924, have proved highly influential on a number of subsequent writers; indeed, it can safely be claimed that some of their influence still persists in the minds and writings of those who, by direct means or indirect, have absorbed their ideas and their examples. Horton's paper stands in the direct line of descent from Gilbert's quantitative and experimental work,

which is less well known among geomorphologists generally than is the earlier material used here. Furthermore, as scarcely needs to be pointed out, Horton's work is the immediate and direct precursor of numerous recent morphometric studies. The papers of Leopold and Wolman, Wolman and Leopold, and Langbein and Leopold exemplify the direction and results of investigations into streams and stream behaviour during the late 1950s and 1960s, illustrating the progress from enlightened empirical research through straightforward quantification to the use of stochastic methods. In selecting a brief summary of my own findings for inclusion in a series which I have called fundamental, I do not wish to seem lacking in modesty; the item is required for use in the critical evaluation of the papers by Miller and Davis.

Miller's paper constitutes a quite early, and in some ways a quite full, disquisitional inquiry into terraces in their relation to streams. It is widely cited in the literature, although seldom discussed; and one may speculate that it might not have become so widely known as it is, at least by title, had it not been the acknowledged forerunner of Davis's own account of the river terraces of New England. However, Miller's study is well worthy of attention for its own sake; in listing nine possible modes of origin for terraces, it agrees with the multicausational attitude now being adopted by a number of influential theoretical geomorphologists. It is highly commendable for its appeal to numerical data and to systematic and quantitative conclusions reached by other workers; it also deserves praise for its wide coverage of previous literature. The one point of caution to be observed in reading either the original or the condensed version offered here is that Miller is not wholly consistent in his use of the term 'terrace'; the context shows that, at a number of points, he intends to connote the fore-edge alone.

It would scarcely have been possible altogether to omit from this anthology the work of Davis. Beginning with the proposition that the most appropriate source for this author is *Geographical Essays*, I found myself proceeding as it were by elimination. Of the fourteen physiographic essays, no more than four or five can be regarded as central to the present theme; and I have already had occasion elsewhere to examine two of these in some detail. Neither of the pair entitled 'Rivers and Valleys in Pennsylvania' and 'The Rivers of Northern New Jersey' seems especially well adapted to the purpose in hand. The final choice thus falls on 'River Terraces in New England'. Although some portions of this have also been formerly

criticised by me in a particular context, the version given below is designed as a discussion of terrace cutting rather than one of hypothetical changes in volume, and may therefore be made to stand on its own. On the positive side, I consider this essay to exemplify as well as any the Davisian method of treatment and style of writing. Its strengths lie in the rapid and repeated application of a suddenly conceived and illuminating idea to a whole series of field examples. Its weaknesses include its limited scope in comparison to Miller's study, its failure to appeal to measurement, and its paucity of site investigation. Estimates of the height of fore-edges (which, like Miller, Davis is capable of calling 'terraces') remain merely estimates. The survey mentioned as desirable in the full text was never carried out by Davis, and the augering suggested as a check on the presence of concealed bedrock spurs in numerous cusps was not performed until years later, and then by others. Had Davis made the check himself, he would have found his hypothesis of defended terraces less than fully competent to explain the observed forms.

Jones's paper, projected in part as an empirical investigation of profile characteristics in the upper part of a single catchment, belongs in its historical context to the sequence of works which deal with high-level platforms, and in which reliance is placed on large-scale vertical shifts of the strandline. It is probably true to state that Wales, more than any other area, has been used by workers in Britain to sustain the hypothesis of intermittent falls of the strandline from very high stands indeed. Unlike Miller and Davis, and still earlier Hitchcock, whose influence pervades Miller's paper, Jones was not dealing with the dissection of valley fills of glacial origin; instead, he separates the observed effects which he has under study from the erosive influence of local ice. He makes use of empirical field measurements of profile characteristics, and undertakes a mathematical analysis of them, long before field measurement was at all common in geomorphology, and long before the incoming of quantification in its present guise. His paper is ancestral to numerous subsequent works in which terraces are referred to former sea stands, and where attempts are made to reconstruct these stands by the extrapolation of profiles. In the usual manner, this method of attack has of course been superseded by more recent work; it is now well established that extrapolation of profiles can, at best, provide no more than uncertain fixes, while the results of later studies of channel slope and its controls show that slope is determined by factors additional, or alternative, to stream volume. Nevertheless this item remains in advance of its time.

That portion of Gilbert's work which appears below illustrates the well-established geologic tradition of using an empirical paper as the vehicle of theoretical statement. Charged with the investigation of a vast piece of new country, Gilbert took full advantage of the openness of the landscape to observe structure–surface relationships. He realised that stream channels and stream nets cannot be adequately studied without reference to the entire surfaces of the catchments involved, right up to the very crests of the divides. In this regard his work foreshadows that of Horton, and through Horton the productive explorations of the Columbia school of geomorphology and its adherents. Independently of all this, Gilbert's writing merits inclusion as introducing original terms and concepts which have subsequently been absorbed into the general corpus of geomorphic thinking. To vary the figure, it can be said that some of them still flow in the main current of geomorphic debate; thus in the selected passages below there appears the term 'dynamic equilibrium', which at the time of writing appears good for years of definition, analysis, re-analysis and disputation, whether useful or not.

Some of the readers for whom the present text is meant may not find the selected works of Miller, Jones and Gilbert particularly accessible. Horton's original, while readily available, is uncomfortably long for the purposes of some readers. Accordingly, I trust that the still lengthy but considerably abbreviated version offered below will prove of service. Representing the outcome of studies of the kind initiated by Gilbert, this paper constitutes also the product of years of original thought and inquiry by Horton himself. If any single paper marks the beginning of modern quantitative geomorphology, it is this one. The fact that the rapid advances of the last twenty years have reduced it in part to a work of historical interest is at the same time a tribute to its effectiveness, and a justification of its inclusion. Its implications have probably still to be fully worked out. The one important qualification which needs to be borne in mind in reading it is that, as Strahler has shown, there are advantages in revising Horton's stream-ordering system in the first and second orders, allocating to the second order a stream formed by the union of two fingertip tributaries.

It is with a certain diffidence that I have continued the sequence with the papers by Wolman and Leopold and by Leopold and Wolman, since their conclusions are incorporated in the well-known 1964 textbook *Fluvial Processes in Geomorphology* of Leopold, Wolman and Miller. However, there is room here for a fuller presentation

of the relevant material than is provided in a more general work, and the two items lead directly on to important later research of a somewhat different kind, here represented by the 1966 paper of Langbein and Leopold. As is well demonstrated by the three papers taken together, these workers and their associates have shifted their main attention from empirical studies in the field or the laboratory to the arrival at general conclusions and the development of general theory. This statement is by no means intended as adverse criticism – indeed, precisely the reverse. Furthermore, it is in no way meant to imply that any of the workers in question tend to neglect observation; on the contrary, each piece of investigation begins, just as Gilbert's flume experiments earlier began, as a field or laboratory problem, and, as the selected items fully show, the combination of observation, experiment and analysis is impressive throughout. At the same time it seems reasonable to draw attention to developments in method of attack, wherein these three papers epitomise much of the recent conceptual growth of fluvial morphology.

The paper on flood plains combines quantitative observation of rates of deposition with an application of magnitude–frequency relationships. That on channel patterns deals with channel characteristics and with the complex interaction of the hydraulic variables which control these characteristics and which produce identifiable patterns in plan. Like the first paper, this too is deeply concerned with process, but it enters the realm of general theory when it relates identifiable patterns of channel to identifiable states of quasi-equilibrium. These two papers have brought into fluvial morphology much that is new, and still more that is illuminating. Their empirical content can scarcely fail to stimulate a great deal of further empirical study. However, such study is of full value only when it produces new ideas, or at least when it constitutes check experiments; as Chorley has pointed out, imitative *ad hoc* studies are markedly restricted in worth. The desirable next development is to further the search for general theory, as is done by Langbein and Leopold in the third of the papers under discussion. Although this work begins with the observation of actual meander patterns, this fact merely constitutes the connection of the theoretical exploration with the real world. In obtaining the sine-generated curve as the most suitable form to describe a meandering trace, the two authors employ a random-walk model. In showing that a meandering trace ensures minimum variance among hydraulic parameters, as in stressing steady-state conditions, they are conducting an inquiry into the

operation of stochastic processes. The paper illustrates how far things have come since Horton's day. Quantification in the sense of numerical measurement and data processing of the simpler kind is being outrun by sophisticated calculations of probability and by the construction of new conceptual models. Development in this particular direction is so swift that its nature and pace are perhaps not yet fully appreciated or even comprehended. It can be urged that fluvial morphology in the last twenty years has already effected two internal revolutions and is embarked on a third. It has embraced numerical morphometry; it has assimilated the statistical treatment of a whole range of data on stream channels and of the interrelationships of these data; and it is now producing models with a stochastic base.

In preparing the shortened versions of the several papers chosen, I have needed to exercise a good deal of editorial discretion, quite apart from that involved in making the initial choice of items. As I have remarked, the total length of material has been greatly reduced. Compression of technical material can probably be more readily defended than can compression of writing meant originally as literature. In literature, form and content go inseparably together at a length properly determined by the author, whereas abstracts and summaries are routine in technical writing. Here, content is all, or nearly all, that has been eliminated, for I trust that contrasts of style are reflected in the chapters below.

It would have been possible, although hopelessly clumsy, to effect abbreviation by using the customary rows of dots to mark omissions, and square brackets to enclose words and phrases added for the sake of continuity. Instead, although I have in fact worked mainly by deletion, I have cast the reduced versions in the form of continuous writing. It follows that this book is not suitable for use as a primary source, even though it is meant to deal justly with the statements and views of the original authors. In the same connection the chapter headings have been altered, or at least rearranged, into a form suited to the purpose in hand.

Deletion has been made to fall, wherever possible, on whole sections or whole paragraphs, or at least on whole sentences, rather than on individual words and phrases. Many of the original diagrams and all of the original photographic illustrations have been omitted. The retained diagrams have been renumbered; all have been redrawn or at least relettered, in order to ensure a sensible uniformity of