FLUVIAL PROCESSES IN GEOMORPHOLOGY

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Preface

THIS BOOK deals primarily with landform development under processes associated with running water. The bias of the book is dictated by our experience and interest and also by our belief that there is a great need at the present time for a review of geomorphic processes.

We have emphasized those things which are best known to us (and about which we feel most is known). Many subjects we have included are by no means treated completely, for they are discussed only from one viewpoint. Others that are treated lightly, such as the evolution of slopes, are ones for which little comprehensive quantitative data are available.

Rather than present a mere rehash of published material which we could not adequately discuss, we decided to omit entirely subjects we have not studied ourselves in the field or laboratory. Some summary monographs are available for wind, shore, and glacial processes, and we have not attempted to cover those subjects here. Combining process and stratigraphy for wind, shore, and glacial morphology would only have enlarged this book to unmanageable bulk; and, as Penck argued many years ago, a case can be made for the thesis that river and hillslope processes provide the central theme of geomorphology.

Our emphasis on process is not intended to minimize the importance of the historical aspects of geomorphology. Unfortunately, because of the limited understanding of geomorphic processes and their associated landforms, we ourselves are unable at present to make a truly satisfactory translation from the dynamics of process to historical interpretation. Better future understanding of the relation of process and form will hopefully contribute to, not detract from, historical geomorphology.

Despite its omissions, we hope that our treatment of geomorphology in this book will provide a logical framework for the subject as a whole, within which students and other readers can integrate material appropriate to their own interests or local physiographic environments.

We have sorely missed our compadre and co-author, John Preston Miller, during the last two years when this book was actively being constructed. Those portions which he prepared were perforce revised during that time. We hope that his principal ideas have been retained and that we have not allowed either divergent viewpoints or errors to creep into his work. Though we can put a book together without him, we can not view the high mountains nor can we pitch a camp in just the same spirit as when he was along.

We are indebted to colleagues and friends too numerous to name who helped in a variety of ways—in technical review of portions of the manuscript, in furnishing data and information, in preparation of copy and illustrations, and in our field work. But some should be noted specifically.

First, May E. Thiesen, although this is not the first manuscript which she has prepared for us. It is a pleasure to be able here to acknowledge her thoughtful and untiring help in all aspects of manuscript preparation, without which this book would not have been brought to completion.

We are particularly indebted to A. O. Woodford and James Gilluly for their overall review, and to Ralph A. Bagnold, Ivan K. Barnes, John T. Hack, Meyer Rubin, and Estella B. Leopold, for their suggestions on portions of the work.

To the other river boys, William W. Emmett and Robert M. Myrick, our thanks not only for help in the field and in preparing the manuscript, but for their company at many delightful campfires beside many distant rivers.

And finally, we wish to mention two men who long have been close friends, admired colleagues, and friendly advisors, Walter B. Langbein and Thomas Maddock, Jr., whose influence on this work has been perhaps deeper and more significant than that of any others.

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Part I

THE EVOLVING LANDSCAPE

Chapter 1 The Changing Scene

When a man makes a pilgrimage to the fields and woods of his boyhood, he does not expect to find the hills and mountains dissolved, or the valleys moved. If other men have not torn up the land to build factories and towns, he expects his children to see the hills and swales as his forefathers saw them. And he is almost right. Probably neither he nor the children will ever notice that in fifty years the surface of the ground has been lowered perhaps a fraction of an inch. Why should they? But they might not be surprised to find that the old mill pond behind the dam is now more mud than water.

Under the action of the force of gravity the land surface is sculptured by water, wind, and ice. This sculpturing produces the landforms with which geomorphology is concerned. Some of these forms owe their origins purely to denudational processes; other forms may be depositional; still others owe their existence to combinations of both processes.

A picture of the dynamics of the earth's surface is by no means complete, however, if only gradation or leveling is considered. Clearly, if there were no counteracting forces we should expect that the land surface, given sufficient time, would be continuously reduced. Eventually, little or no relief would remain. Geologic history demonstrates, however, that the degradational forces acting on the earth's surface are opposed by constructional forces. These internal, or endogenous, forces cause the land to rise, and as they do so it is subjected to attack by the external, or exogenous, agents. Geomorphology is primarily concerned with the exogenous processes as they mold the surface of the earth, but the internal forces cannot be disregarded when one considers fundamental concepts of the origin and development of landforms.

Ideally, the basic principles underlying the development of landforms can be considered in simple terms. A given land area is composed of a particular set of rocks, which have particular chemical and mineralogic compositions and specific physical properties. Because these rocks were formed at different temperatures and pressures within the earth, when they are exposed at the surface they are no longer in equilibrium with their environment and thus begin to decompose. Where a gradient is created by gravity, the moving water, earth, air, and ice help in the attack upon the rock and remove the products of weathering. In the process, landforms of various aspects are created. In a given environment the physical and chemical constitution of the rocks determines the way in which they will break down and, in turn, the size and quantity of debris made available to the denudational agencies.

Each denudational agent, depending upon its density, gradient, and mass at a particular place, is capable of applying a given stress on the materials available. A certain amount of work may be performed by the application of this stress, and the results of this work are the landforms that we see developed in various parts of the world. In a given climatic and vegetational environment the shape or form of the landscape will vary, depending upon the character of the rock and the type and available stress of the erosional agents. But as the land surface is reduced—so long as the products of weathering and the applied stress remain constant—the form of the land should remain the same.

If one were able to evaluate properly the properties of the rocks and the present and past capabilities of the denudational agencies, he should have no trouble in developing a rational, even mathematical, equation capable of describing the development history and equilibrium form of any landscape. William Morris Davis said essentially the same thing in 1902 when he observed that any landform is a function of the structure of the rocks (including their composition and structural attitude), the processes acting upon them, and the time over which these processes have been active. Only as we study the interrelations of these three factors are we able to discern which combinations produce which particular landforms and how they do so.

Some landforms, such as volcanoes, which may have been unaffected by denudational processes, may be considered purely constructional forms. As soon, however, as they are modified by external agencies, their form begins to represent the resultant of an interaction between the constructional forces, the rock substrate, and the applied stress.

The application of such an ideal concept to any actual landform at the present time is fraught with problems. The natural world is highly variable and the mechanics of uplift, weathering, and erosion are for the most part poorly understood. As will be seen, climate itself is a complex factor, and in most regions of the world inorganic processes are inseparable from the complex organic processes carried on by plants and animals. Although it is frequently convenient and helpful to construct a simplified synthetic picture of the natural environment, we should not lose sight of the fact that a given landscape must be the result of a complex set of factors which encompass the behavior of materials and processes over varying periods of time.

It is important to note that whether one refers to the effect on landforms of different rock types, or to the effect of different rates of uplift, such differences or changes must manifest themselves in the environment of the landform in simple physical terms. A normal fault whose strike is perpendicular to the direction of flow of a river, with downthrown block in the downstream direction, constitutes to the river a merely local increase in gradient. A similar increase in gradient might be effected by local changes in lithology, an abrupt shortening in channel length, or by an abrupt change in discharge downstream. The same physical principles determine the river's subsequent response in each case. The permanence or impermanence of the change, as well as its possible propagation either upstream or down, will depend upon the type and amount of material available and the distribution and quantity of flow. Any true principle enunciated to explain one of the cases must be applicable to the others as well.

Thus, although the application of the principle to any one example may be fraught with difficulty, an understanding of the principle at least reduces the burden of innumerable "unique" cases. Geomorphologists have always sought such unifying concepts, and for a proper view of the field as a whole one must turn initially to the classical concepts of landform evolution.

The influence of William Morris Davis on geomorphology was without doubt greater and longer-lasting than that of any other individual. His major contribution was a genetic system of landform description. Beginning in 1899, Davis developed the concept that during erosion of a highland the landscape evolves systematically through distinctive stages, to which he gave the names, youth, maturity, and old age. This entire sequence of stages he called an erosion cycle (or geomorphic cycle), and the end product was supposed to be a surface of low relief, or peneplain. He elaborated the effects of interruptions in the cycle and argued that the principal factors controlling the character of landforms are geologic structure, geomorphic processes, and the stage of development. Davis' genetic concept of landform development was a brilliant synthesis, which grew directly out of the work by Powell, Gilbert, and Dutton and also from the controversial ideas on organic evolution which were prevalent at the time.

The concept of the erosion cycle was never accepted in Europe to the same degree as in North America. The most serious challenge came during the 1920's from Walther Penck, who attempted to show a direct causal relation between tectonics and the properties of landforms. Many of his conclusions about the trends and ultimate results of tectonics and erosion processes differed only slightly from those of Davis. Penck, however, emphasized slope development, and his theory of slope development is a major contribution that is still being tested and debated.

The principal alternative to the Davisian conception differs mainly in the view of the effect of time, the third of the three fundamental elements, on landforms. Restating and extending the work of Gilbert, Hack (1960) emphasizes the concept of a dynamic equilibrium in the landscape which is quickly established and which responds to changes that occur during the passage of time. This view postulates that there is at all times an approximate balance between work done and imposed load and that as the landscape is lowered by erosion and solution, or is uplifted, or as processes alter with changing climate, adjustments occur that maintain this approximate balance.

More will be said about these different views in subsequent chapters, as various aspects of the landscape are considered in greater detail.

Paralleling developments in other phases of geology, the past decade has witnessed a remarkable increase in the application of analytical and experimental techniques to geomorphic problems. These investigations have taken two principal directions: (1) efforts to describe landforms more precisely through the use of statistics and other analytical techniques, (2) application of physical and chemical principles to field and laboratory studies of geomorphic processes. Although a few geologists—G. K. Gilbert, and later W. W. Rubey—helped to pave the way for this current trend, developments in other fields of science, especially in engineering and physics, were more directly responsible for it. One outstanding example is the field and experimental work on sand transport by R. A. Bagnold during the 1930's. Another is the contribution of fundamental ideas on the development of stream networks by R. E. Horton. Recently many developments in hydraulics and in the application of soil mechanics have attracted the attention of geomorphologists. At present there is greatly increased interest in the use of more precise tools for studying landforms. The pace of research seems to be quickening and there is reason to hope that a new era of discovery is under way.

Geomorphology in North America has gone through a phase during which extensive description of the landscape in terms of the erosion cycle has been carried out. It was apparently believed that the processes were known or could be inferred, and that form could be assessed by eye.

Similarly, one current earth-history view of geomorphology assumes that enough is now known to interpret landforms and deposits in terms of processes that operated in times past. In the most qualitative way this is probably true. However, we believe that the genetic system breaks down when it is subjected to close scrutiny involving quantitative data. At present deductions are subject to considerable doubt, for the detailed properties of landform have not been studied carefully enough and the fundamental aspects of most geomorphic processes are still poorly understood. So long as this is true, the interpretation of geomorphic history rests on an exceedingly unstable base.

Accordingly, we plan to concentrate on geomorphic processes. The emphasis is primarily upon river and slope processes; river processes will receive greatest attention, since the greatest volume of information available is on rivers. Our objective is to synthesize the material on these subjects in an attempt to assess the current status of knowledge and at the same time to draw attention to its shortcomings.

Process implies mechanics—that is, the explanation of the inner workings of a process through the application of physical and chemical principles. We realize that some readers may be more interested in descriptions of landforms than in the detailed analysis of the processes that formed them. So far as possible, we attempt to relate the processes discussed to specific types of landforms. Unfortunately, the gap between our understanding of specific processes in microcosm and the explanation of major large-scale landforms is still wide. It is interesting to note that geomorphologists seem to have a better understanding of depositional than of erosional forms. This may be because the formation of depositional features such as sand dunes, deltas, and flood plains is more easily seen in the field, or because many erosional features retain less clear evidence of their mode of formation.

Detailed understanding of geomorphic processes is not a substitute for the application of basic geologic and stratigraphic principles. Rather, such understanding should help to narrow the range of possible hypoth-